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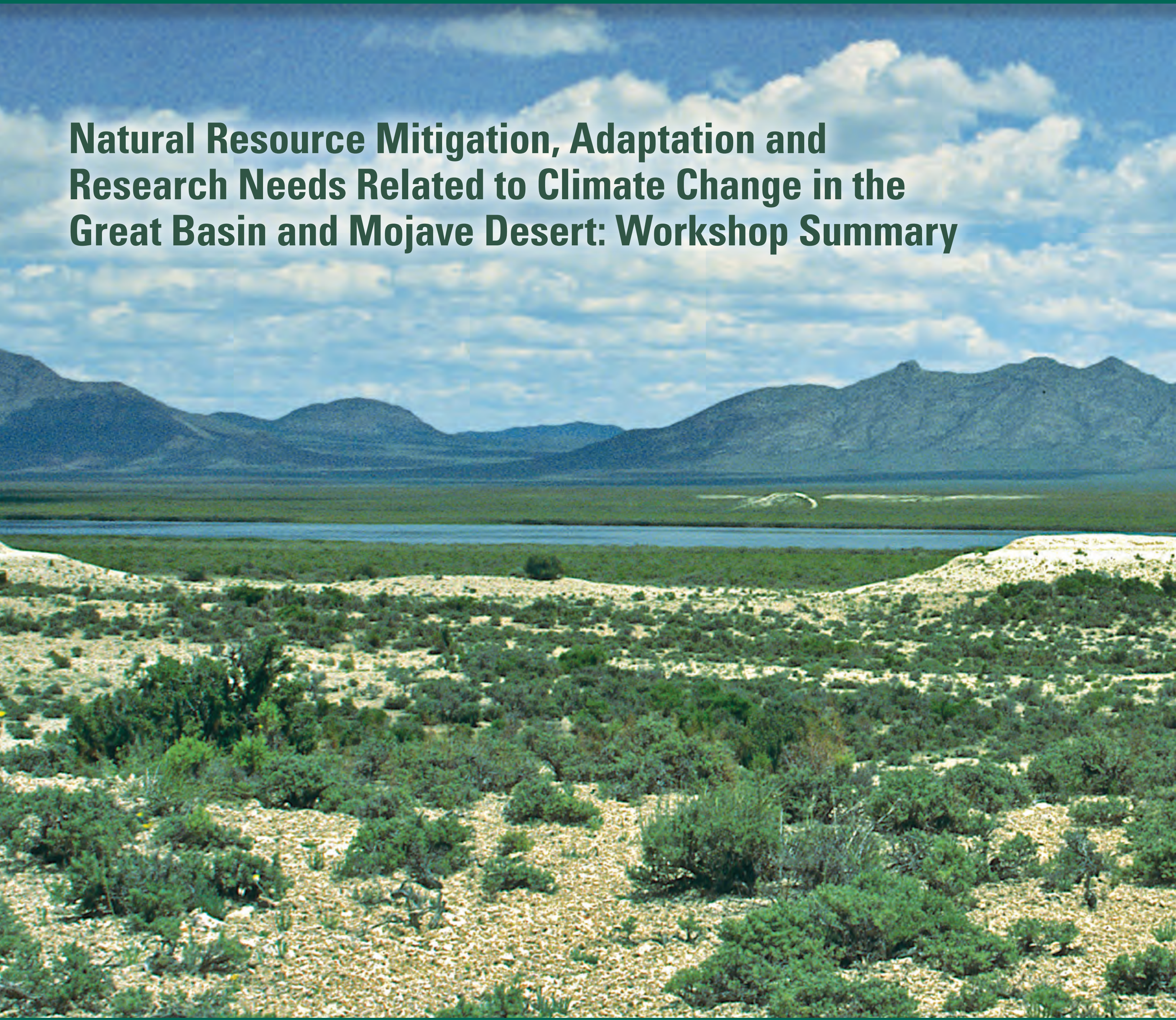
Natural Resource Mitigation, Adaptation and Research Needs Related to Climate Change in the Great Basin and Mojave Desert: Workshop Summary



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Cover: Kirch Wildlife Management Area, White River Valley, Nevada. (Photograph by Steve Caicco, U.S. Fish and Wildlife Service).

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By Debra L. Hughson, National Park Service, David E. Busch, U.S. Geological Survey, Scott Davis, Bureau of Land Management, Sean P. Finn, U.S. Geological Survey, Steve Caicco, U.S. Fish and Wildlife Service, and Paul S.J. Verburg, Desert Research Institute

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Natural Resource Mitigation, Adaptation and Research Needs Related to Climate Change in the Great Basin and Mojave Desert: Workshop Summary

By Debra L. Hughson[1], David E. Busch[2], Scott Davis[3], Sean P. Finn[4], Steve Caicco[5], and Paul S.J. Verburg[6]

Executive Summary

This report synthesizes the knowledge, opinions, and concerns of many Federal and State land managers, scientists, stakeholders, and partners from a workshop, held at the University of Nevada, Las Vegas, on April 20–22, 2010. Land managers, research scientists, and resource specialists identified common concerns regarding the potential effects of climate change on public lands and natural resources in the Great Basin and Mojave Desert and developed recommendations for mitigation, adaptation, and research needs. Water and, conversely, the effects of drought emerged as a common theme in all breakout sessions on terrestrial and aquatic species at risk, managing across boundaries, monitoring, and ecosystem services. Climate change models for the southwestern deserts predict general warming and drying with increasing precipitation variability year to year. Scientists noted that under these changing conditions the past may no longer be a guide to the future in which managers envision increasing conflicts between human water uses and sustaining ecosystems. Increasing environmental stress also is expected as a consequence of shifting ecosystem boundaries and species distributions, expansion of non-native species, and decoupling of biotic mutualisms, leading to increasingly unstable biologic communities. Managers uniformly expressed a desire to work across management and agency boundaries at a landscape scale but conceded that conflicting agency missions and budgetary constraints often impede collaboration. More and better science is needed to cope with the effects of climate change but, perhaps even more important is the application of science to management issues using the methods of adaptive management based on long-term monitoring to assess the merits of management actions. Access to data is essential for science-based land management. Basic inventories, spatial databases, baseline condition assessments, data quality assurance, and data sharing were identified as top information priorities by all participants at this workshop. Optimizing the utility of ecosystem monitoring data will require standardizing monitoring protocols across agencies. Better communication among researchers and managers and cooperation through partnerships to manage resources across boundaries were emphasized as necessary for adapting to changing climatic conditions. However, even these strategies may be insufficient unless policy mandates, agency missions, and funding are coordinated at a high level.

Introduction

This report is a synopsis of the workshop that was held at the University of Nevada – Las Vegas campus on April 20–22, 2010. More than 300 participants attended plenary talks, presented posters, and contributed to discussions in workshop breakout sessions. The workshop focused on how climate change is affecting natural resources in arid lands of the Western United States, in addition to the land, water, and species management and research needs that should be addressed in the coming decade. Workshop goals included:

- Increasing the understanding of climate change processes and their effects on the physical systems and biota of the Great Basin and Mojave Desert.
- Providing the best available scientific information for adapting to change.
- Examining research and management needs.
- Evaluating management constraints and determining potential solutions.
- Developing effective research and management collaborations for addressing climate change into the future.

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Stakeholders in the natural resources management and research communities with interest and expertise in the potential effects of climate change on the arid lands of the Western United States comprised the target audience for the workshop. Participants included natural resource management agency staff and decision makers working at the Federal, State and local levels, university and federal research institute scientists, as well as non-government organization (NGO) and Tribal representatives. The workshop agenda was designed to provide an overview of the climate change drivers affecting the interior West, as well as the ecosystem responses to climate change and associated mitigation and adaptation options available to managers. Another focus was on current research and information needs, with a consideration of different perspectives on potential future research emphases and resource management direction. Data, analyses, models, and conservation planning related to species, habitats, and landscapes were addressed, along with socioeconomic drivers of change in the arid West. Current efforts, including what networks and organizations exist or need to be formed to mitigate and adapt to ecosystem changes driven by a changing climate, were examined during the workshop.

Given the large number of symposia on climate change that have been held, the workshop organizers felt that it was important to develop an agenda with more than just scientists speaking at managers. A key goal was to catalyze dialogue about scientific and management strategies to have positive effects on outcomes in the future. A paired plenary format was used to integrate talks by management leaders with those of leading researchers on strategies, plans, and needs for climate change acclimation and mitigation. Workshop subtopics included climate change mitigation, adaptation, and research needs related to:

- Observed trends and model predictions, including uncertainty and variability in:
    - Precipitation, runoff and their effects on aquatic, wetland, and riparian ecosystems and biota.
    - Soils, vegetation, fire and invasive species interactions in arid land ecosystems.
- Adjusting conservation strategies for protected species and lands in a changing environment; shifting distributions with fixed unit boundaries, maintenance of habitat connectivity, loss of patches (at high elevations and valley bottoms, and in isolated aquatic systems).
- Monitoring to support large-scale, cross-boundary priorities for adaptive management in a variable and uncertain environment.
- Restoration objectives, feasibility, and strategies given environmental change, biogeographic limitations, and uncertainty.
- Data collection networks and information management to support analyses and modeling.
- Overlay of climate change with land use and water management in an ecosystem services context.

The workshop achieved several outcomes and products including:

- Catalyzing information exchange among participants.
- Establishing and using existing interorganizational work groups to explore:
    - Research and scientific assessments, tools, and priorities.
    - Management adaptation and mitigation strategies.
- Refining information needs related to individual organizations' missions and interorganizational collaboratives.
- Development of scientific publications, an Internet presence, and other communication paths using existing organization and collaborative capabilities.

As part of a series of climate change workshops throughout the Nation, the U.S. Fish and Wildlife Service and the U.S. Geological Survey initiated planning for the workshop. The workshop planning team sought the involvement of a broad array of experts and entities to co-sponsor the workshop, and to help provide speakers or other resources. Organizations that helped by leading workshop planning and providing financial and staff support included the Bureau of Land Management, the National Park Service, the Environmental Protection Agency, the Desert Research Institute, and the University of Nevada-Las Vegas. The Great Basin Research and Management Partnership, the Desert Managers Group, the Southern Nevada Agency Partnership, the Western Governors Association, and the U.S. Forest Service contributed to communicating the workshop agenda.

Synthesis

This section synthesizes important points emerging from the keynote and plenary talks and poster presentations with background information summarized from the climate change literature. Breakout sessions on particular workshop themes are presented separately. Publications and symposia on the subject of anthropogenic climate change in recent years have produced a substantial amount of information on the predictions and potential consequences of global warming (for example, Baldwin and others, 2003; Intergovernmental Panel on Climate Change, 2007; Climate Change Science Program, 2009; Furniss and others, 2010). This Great Basin and Mojave Desert Workshop on natural resource needs related to climate change took a somewhat different approach by focusing on amelioration strategies—what land managers can do—and stimulating a dialog between researchers and managers. Many of the plenary presentations paired a scientist, active in a particular area of research, with a current land manager on topics in which both had extensive relevant experience. In this synthesis, we attempt to distill their main discussion points, discuss approaches to current and foreseen problems, and summarize their conclusions for addressing the significant challenges facing land and resource managers. This synthesis is not a review of climate change science, which is available in many other excellent references (for example, Mann and Kump, 2008; Loehman, 2010), nor does it attempt to characterize all threats in Western Desert regions. Threats are instead mentioned in the context of potential amelioration strategies. This synthesis attempts to assemble, integrate, and characterize the adaptations and mitigation aspects of the presentations, including outreach and education with the many stakeholders and partners, to more effectively deal with climate change. The synthesis is organized from general to more specific recommendations and does not follow the order or sequence of topics in the workshop agenda.

Climate Change in the Great Basin and Mojave Desert

A broad scientific consensus has emerged that heat trapped by anthropogenic emissions to the Earth's atmosphere is warming the climate globally at a rate unprecedented in the Holocene epoch (Intergovernmental Panel on Climate Change, 2007). Temperatures have increased between 0.3 and 0.6°C across the Great Basin over the 20th century (Wagner, 2003; Chambers, 2008). Global climate models show a 'hot spot' of climate change (fig. 1) stretching across the Desert Southwest from southern California to western Texas and extending up into southern Nevada, caused largely by changing climate variability (especially in precipitation) from year to year (Diffenbaugh and others, 2008). These same models predict a general drying trend in the Desert Southwest with increasing air temperatures, increasing evapotranspiration, and decreasing precipitation (Seager and others, 2007) leading to decreased runoff and streamflow (Milly and others, 2005). Model projections for the Great Basin and Mojave Desert region indicate a warming trend from 1 to 4°C from early to late 21st century, with drier conditions in the south trending towards wetter conditions in the northern parts of the Great Basin (Redmond, 2010). Minimum air temperatures are expected to increase more rapidly than maximum temperatures (Kharin and others, 2007) leading to a decrease in frequency of freezing days and warmer winters. A shortened duration of snow cover is expected at high elevations associated with earlier spring snowmelt. Already, most monitoring sites in the Great Basin show a decreasing average April 1 snowpack since 1950 (Baldwin and others, 2003) with the onset of snowmelt runoff 10–15 days earlier than 50 years ago (Ryan and others, 2008). Temperature related shifts in plant and animal species and changes in phenology are likely to lead to upslope movements of communities, expansion of desert scrub at the expense of montane conifer forests, and latitudinal migration of Southwestern Deserts.

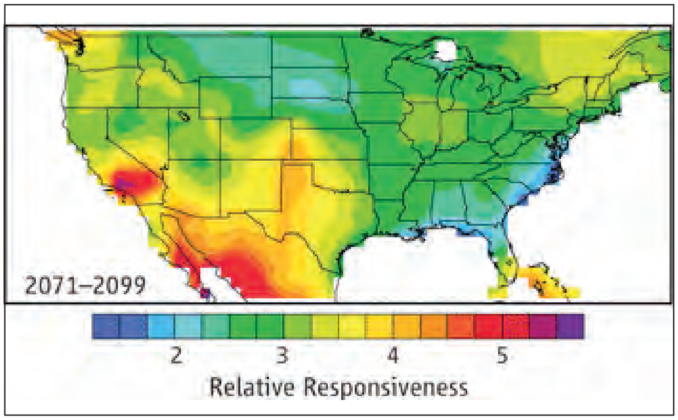

Figure 1. An evaluation of responsiveness to climate change using 15 climate change models from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (from Diffenbaugh and others, 2008). The relative strength of the "hot spot" in the Desert Southwest resulted not from long-term trends in temperature and precipitation but from changing variability from year to year, especially in precipitation.

Warming temperatures and changing precipitation regimes will interact with anthropogenic nitrogen deposition, land disturbance, and invasive species leading to a transition from desert scrub to invasive annual grassland in some places. Work done on the Nevada Test Site in southern Nevada (Smith and others, 2000; Smith, 2010) has shown that elevated atmospheric carbon dioxide will favor invasive annual grass species over native annuals in wet years (fig. 2), resulting in an increased proportion of fire-adapted grassland in the region. Larger and more frequent fires are associated with high winter rainfall, increased primary productivity of non-native annual grasses, and low summer rainfall. Higher temperatures associated with heat waves, relaxed frost conditions and drought will result in pathogen range expansions and Piñon-Juniper mortality, possibly shifting the grass-fire cycle upslope. Increased precipitation variability means that both wet winters, such as the winter of 2004–05, and severe drought, as experienced in 2002–03, could increase in frequency.

A general drying trend coupled with a variable precipitation regime is likely to severely alter the hydrologic cycle and stress human water delivery systems. In addition to lower snowpack and earlier spring melt, both extreme flood events and extreme drought are likely. Decreased runoff and increased evaporation on the Colorado River system (fig. 3) imply that current regional water demands will not be met in the future (Christensen and Lettenmaier, 2006; McCabe and Wolock, 2007; Barnett and Pierce, 2008), which will lead to increased conflicts between supplying water for agriculture and municipal uses and sustaining aquatic and riparian ecosystems. Decreases in Colorado River flow from 7 to 20 percent due to climate change induced variations in temperature and precipitation (Nash and Gleick, 1993) may be exacerbated by anthropogenic dust sources (Painter and others, 2010), causing an additional loss of 5 percent of annual average flow. Low streamflows with degraded water quality combined with high water temperatures and low dissolved-oxygen content will negatively impact fish populations and other aquatic species. Reduced recharge will limit groundwater pumping options for maintaining water supplies, although it may take centuries to propagate through aquifers (Webb, 2010). Low flows combined with increasing urban populations will require that water managers prepare for reductions in water supplies. Managers are beginning to focus on vulnerabilities and building increased resiliency to adapt to climatic extremes (Willardson, 2010).

Figure 2. Increased annual productivity of *Bromus* spp. in wet years as a result of elevated atmospheric carbon dioxide (550 ppm) at the Free-Air Carbon Dioxide Enrichment facility on the Nevada Test Site north of Las Vegas, Nevada. The stimulatory effects of elevated atmospheric carbon dioxide appear negated during intense drought (Smith, 2010).

Figure 3. "Bathtub ring" at Lake Mead that indicates when the reservoir is near full capacity at 1,225.85 feet. The reservoir was 1,095.69 feet at the time of this photograph in May 11, 2011, which is approximately 43 percent of capacity. (Photograph by National Park Service).

Increased climatic variability will lead to increased environmental stress, shifting of ecosystem boundaries and species distributions, opportunities for invasive species expansion, potential decoupling of biotic mutualisms, and impacts resulting from modified hydrologic conditions. Because freshwater resources are at particular risk, attention must be devoted to protecting water quality and quantity. Managers and scientists need to work together to improve capacity for predicting extreme events and their ecosystem impacts. Better models for forecasting at regional and local scales for applied scientific decision support are needed along with improved data collection, integration, and distribution. But above all, management must be undertaken collaboratively at the ecosystem level, across political boundaries and organizational cultures, in order to sustain ecosystem function and services at a landscape scale while maintaining flexibility to respond to the added stressor of climate change.

Partnerships and Managing Across Boundaries

Perhaps the most consistent theme that arose during this workshop was the need to manage ecosystems across political boundaries. Policy mandates, agency missions, planning processes, and financial structures often create obstacles to management of natural resources for conservation and sustainability. Nonetheless, a number of partnerships and organizations (See "Collaborations and Partnerships") have grown to work cooperatively and their successes can be a model for improved collaboration.

Collaborations and Partnerships

Great Basin Research and Management Partnership

The Great Basin Research and Management Partnership (GBRMP) promotes comprehensive and complementary research and management collaborations to sustain ecosystems, resources, and communities across the Great Basin. Seventeen State, Federal, and university partners signed a Memorandum of Understanding to support GBRMP's goals and new members are welcome. The Partnership facilitates collaboration among researchers and managers to reverse current ecosystem losses and to sustain long-term productivity, resource values, and services of natural and managed ecosystems. GBRMP provides an integrated organizational framework to promote collaboration and provide leadership, commitment, and guidance for effectiveness. GBRMP does not replace existing regional collaborations and partnerships, but builds upon their strengths by increasing coordination and communication among them. GBRMP provides a mechanism for assembling diverse research and management groups working in the Great Basin to:

1. Obtain consensus in identifying and prioritizing regional issues;
2. Expand and help focus existing collaborative efforts;
3. Facilitate new teams to address emerging issues; and
4. Provide critical information-sharing for existing collaborations and new teams.

GBRMP provides various tools and services including the following searchable databases:

- Participants and Experts;
- Science Locator;
- Consortia;
- Great Basin Bibliography; and
- a Great Basin Metadata Server.

GBRMP also facilitates establishment of self-organizing Working Groups. Currently, active Working Groups are focused on Bromus invasion ecology, science delivery to field managers, ecological monitoring, and information management. Each of these Working Groups considers climate change factors in their work processes. GBRMP is poised to support a Working Group specifically focused on climate change impacts in the Great Basin.

GBRMP is committed to providing current resources to Working Groups and the larger community of natural resource professionals in the Great Basin to help them do their jobs more effectively. In that sense, GBRMP offers services with no desire to exert control of any partner's agenda. GBRMP relies on the interplay of agency and university leadership, field-level scientists, managers, and support personnel, and targeted interest groups to identify and address priority needs for addressing climate change impacts. By responding quickly through established communication networks, building robust tools, and removing traditional institutional barriers, GBRMP strives to enable and encourage future research and management on climate change in the Great Basin.

California Desert Managers Group

The vision of the California Desert Managers Group (DMG) is to work collaboratively to conserve and enhance the California Desert for current and future generations. Part of the DMG mission is to coordinate and integrate efforts in the California Desert to:

- Conserve and restore desert resources;
- Provide high quality recreation, public education, and visitor services; and
- Provide for safety of desert users.

The diverse agency missions in the 25 million acre California Desert will be continued only if the area's rich biodiversity is maintained. Climate change will necessitate continued agency collaboration to manage resilient, adaptable ecosystems. The DMG brings together the agencies that manage the California Desert land and resources. This unique forum provides the opportunity to plan collaborative management actions and achieve landscape scale results that would not otherwise be realized. The DMG also provides a forum to identify and prioritize conservation research needs and provide technology transfer so land and resource managers can better utilize state of the art research in their daily decisions. The DMG is developing a new strategic plan that incorporates an ability to respond to new information regarding global and local change. This strategy involves collaborating with other landscape scale partnerships in the Mojave Desert to form the framework for a Landscape Conservation Cooperative. DMG also plans to develop a science strategy that would complement the Southern Nevada Agency Partnership science strategy.

Western Governors Association

The focus of the Western Governors Association (WGA) is cooperation and collaboration. The WGA's general mission is to develop policy for the Governors of the Western States, recommend the best way for policy to be implemented, and facilitate dialogue and understanding among Western States that have diverse goals, demographics, and challenges. WGA is an organization for the Western States, all of which have crucial and important concerns about how to deal with climate change. Western States currently play an invaluable role in the dialogue of adaptation and will continue this dialog into the future.

In 2009, WGA approved a policy resolution that formed its Climate Advisory Adaptation Work Group. The governors directed the Group to:

1. Determine appropriate uses of climate adaptation modeling in informing natural resource and economic infrastructure planning and policies, and
2. Identify and fill existing gaps in climate adaptation efforts within WGA.

The Climate Advisory Adaptation Work Group's released its Scoping Report in June 2010 describing the WGA's approach to smart practices for climate adaptation, climate science to support adaptation, and Federal legislation. The report includes recommended actions that Western States can take to incorporate adaptation practices into resource management and decision making while considering issues of uncertainty. The report also outlines currently available science and factors that Western States should consider when supporting and promoting legislation at the federal level. The Scoping Report concludes with more than 47 references and resources directing the reader toward additional information and tools to understand and adapt practices to climate change.

Southern Nevada Agency Partnership

The Southern Nevada Agency Partnership (SNAP) includes the Bureau of Land Management, National Park Service, Fish and Wildlife Service, and Forest Service. Through SNAP, these agencies work with each other, the local community, and other partners for the benefit of Southern Nevada's federally managed lands, which total more than 7 million acres and encompass 11 distinct and fragile ecosystems. Southern Nevada public lands also are rich in irreplaceable cultural and historical resources. Since 1999, SNAP agencies have been developing interagency programs and projects to enhance services to the public, improving stewardship of the public lands, and increasing the efficiency and effectiveness of their management activities. SNAP's Science and Research Strategy defines four major strategic focus areas:

1. Restoration;
2. Protection;
3. Public Education, Recreation, and Use; and
4. Science and Research.

The core purpose of the SNAP Science and Research Strategy is to integrate and coordinate scientific research programs in Southern Nevada, and improve the efficiency and effectiveness of these programs. Information resulting from the Strategy implementation will be disseminated to local, regional, and national groups, and to the public, as appropriate. SNAP will utilize, when appropriate, existing agency funding, special legislative funding and partnerships to address climate change questions within the context of each agency's mission. Every day the Federal Government must make complex land-management decisions on the basis of assumptions and incomplete information. In order to improve land-management decisions in response to climate and other agents of change, SNAP has developed an adaptive management process designed to update priority science questions on an annual basis, including regular synthesis of new knowledge, reaching out to share findings with outside science providers and encouraging their participation, and assuring quality research and monitoring activities ultimately to develop authoritative data sources.

As the public has become aware over the last few years, climate change may alter ecosystems constituents and functions at a landscape scale. SNAP agencies anticipate that these ecosystem changes may be observed across a number of SNAP research areas (fire, invasive species, watersheds and landscapes, and biodiversity). Other research areas focusing on human activities (prehistoric, historical, current, and future land uses) can provide information on historical climate changes in context of human responses, and inform land- management agencies of strategies to adapt management in response to climate changes. The SNAP Science and Research Strategy specifically addresses science questions regarding climate change under its Goal 1: restore, sustain, and enhance Southern Nevada's ecosystems and Sub-goal 1.3: restore and sustain proper function to Southern Nevada's watersheds and landscapes.

Additional Partnerships

- The National Phenology Network employs citizen scientists in the study of seasonal cycles of plants and animals, including the timing of vegetation sprouting, flowering, and fruiting and animal reproduction, migration, and hibernation.
- The Intermountain West Joint Venture facilitates bird conservation across 495 million acres of the Intermountain West through a partnership of Federal agencies, State agencies, non-profit conservation organizations, and profit organizations representing agriculture and industry.
- Conservation of native desert fish in cooperation with State and Tribal fish and wildlife agencies, Federal resource agencies, research and private organizations is the mission of the Desert Fish Habitat Partnership.
- The Western Regional Partnership provides a framework for senior-policy level Federal, State, and Tribal leadership to identify common goals and emerging issues in the States of Arizona, California, Nevada, New Mexico, and Utah, and to develop solutions that protect natural resources, while promoting sustainability, homeland security, and military readiness.

The Department of Interior (DOI) is initiating a series of Landscape Conservation Cooperatives (LCC), comprised of management-science partnerships that will help inform resource management actions to address climate change and other stressors on landscapes. These self-directed cooperatives are formed by land, water, wildlife, and cultural resource managers, and interested public and private organizations to help integrate and communicate information on climate change. The DOI-wide response to climate change includes the LCCs and associated regionally based Climate Science Centers (CSC) along with a high-level approach to data integration and management, initiated by Secretarial Order Number 3289, "Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources." The National Climate Change and Wildlife Center and regional CSCs will provide scientific information, models, and techniques for land, water, wildlife, and cultural resource managers to adapt to climate and ecologically driven responses at regional-to-local scales. Prioritized climate-change-impact projections and decision-support tools will be delivered through the LCCs to meet the adaptive management needs of policy and decision makers. The Great Basin and Desert LCCs are building from the existing partnerships, providing natural resource managers with the opportunity to meet regularly, exchange information about current activities, set goals, and form targeted work groups to focus on specific cross boundary issues. These partnerships are beginning to develop effective mechanisms for prioritizing management across organizations at landscape scales based on an ecological understanding of the Great Basin and Mojave Desert.

The LCCs will be challenged to conduct cross-boundary strategic planning, obtain consensus on priorities, develop adaptation strategies, leverage resources to implement activities and monitor outcomes, and collectively determine the adaptive management adjustments needed to effectively anticipate and manage the impacts of climate change on the Great Basin and Mojave Desert (Kearney, 2010).

Managers with extensive experience in existing partnerships made several recommendations at the workshop for improving collaboration. For instance, many agencies have planning processes that are duplicative and redundant. Management plans can be strategically realigned to address climate change and increase collaboration. New planning documents, such as Habitat Conservation Plans, also can include cooperation under existing authorities, such as the Endangered Species Act and the National Environmental Policy Act. These laws expand the governmental processes to include the public and thus can be used to facilitate increased collaboration not only across State and Federal agencies but also with Tribes and NGOs. Agencies can increase support for interdisciplinary training and reward collaborative activities. Networks of experts can be established including interdisciplinary teams of resource specialists, scientists, and private individuals. Managing for climate change necessitates collaborative research and management that effectively crosses administrative boundaries and increases understanding of connectivity, resilience, and thresholds.

Science-Based Management

Land and natural resource managers have long recognized that high quality research and access to scientific data are central components of sound management practices. The well-known yet under-utilized techniques of adaptive ecosystem management directly use the scientific method in formulating, implementing, and assessing the outcomes of management actions (Williams and others, 2009). The role of science in management is becoming even more important in coping with the adverse impacts of climate change. Managers and the landscapes they manage are facing new threats in which knowledge about the past may no longer serve as the best guide to the future (for example, "Stationarity is dead," Milly and others, 2008), where the consequences of both management action and inaction carry unknown risks. Effective management strategies begin with an understanding of the threats and resources at risk obtained through scientific research and resource assessments. But the utility of these studies and inventories is realized only if the data are easily accessible and usable. Standardization, quality assurance, and distribution of data help to connect research to management. Long-term monitoring is the feedback loop between management actions, results, and adaptations making integration and distribution of monitoring data of great importance.

The importance of communication between researchers and decision makers was emphasized during the workshop. But more than just communication, integrating climate change science with management of the Great Basin and Mojave Desert landscape requires data organization and distribution systems for sharing common databases and decision support tools across agency boundaries to build resilience, adapt to changes, mitigate damages, and restore ecosystems.

Research and Monitoring

This workshop identified research and data needs of managers so that researchers can provide scientific information essential for responding to climate change. The needs expressed by the land managers were consistent. Common themes were

- Standardized basic datasets accessible to all,
- Long-term status and trends monitoring of key ecosystem indicators,
- Better predictive models at the scale of the management issues, and
- Decision support tools, and sharing of data.

Data essential to land managers include common geospatial databases, current status of community composition and species abundance and distribution, ecological condition of ecosystems, information on current research and collaborative activities, and common databases of land treatments and monitoring results that can be used for adaptive management. Adaptive management based on collaboration will require shared information and the development of effective adaptation strategies. Research is needed to test hypotheses and demonstrate effectiveness for:

- Landscape connectivity—the degree to which the landscape facilitates or impedes movement among resource patches.
- Resilience—the capacity to maintain characteristic processes in the face of climate change or other perturbations.
- Ecological thresholds—the point at which a system does not return to the original state through natural processes but instead transitions to an alternate state.

We have only a rudimentary understanding of the effects of climate change based on climate envelope modeling (for example, Lawler and others, 2009) for a few species. Obtaining this basic ecological understanding is essential for developing effective adaptation strategies. For example, management actions will depend on ecological resilience and whether ecological thresholds have been crossed. Thus, monitoring of key ecosystem indicators must be linked to management thresholds, with early warning points preceding ecological thresholds, so that a generalized approach for alerting managers and assessing possible management responses (including no action) can be implemented. A structured approach to risk analysis and decision making requires regional assessments and conceptual models of interactions between primary ecosystem drivers, conservation targets, and threats coupled with predictive modeling, sets of feasible responses, and management strategies.

Landscape-scale climate change impact assessments require species inventories and distributions, habitat models, and habitat vulnerability assessments generated across standardized spatial coverages and administrative boundaries. This starts by having inventories, spatial coverages, databases, and monitoring protocols not only standardized but also shared among agencies. Predictive models must be validated against historical data and appropriately scaled to meet management needs. Regionally and locally scaled predictive modeling capacity is needed to evaluate interactions between biophysical indicators and landscape-level processes and to improve understanding of processes controlling impacts of climate change on species dynamics and disturbance regimes. Greater collaboration between research, management, and policy specialists will be essential in constructing decision support systems that focus on vulnerabilities and building increased resiliency to climatic extremes.

The prospect of climatic change may render invalid the assumption in water and ecosystem management that natural systems have known and stable patterns of variability (Betancourt, in press). This assumption is embodied to varying degrees in the concepts of hydrologic stationarity (for example, Milly and others, 2008) and historical range of ecological variation (see Betancourt, 2010a). Responding to climate change requires rethinking traditional concepts and developing alternatives that will work better for managing resources and ecosystems under nonstationary climatic, hydrologic, and ecologic conditions. It will be necessary to develop new probabilistic models of relevant environmental variables and, combined with risk analyses, use them in a structured decision making framework to optimize adaptive management. New methods must be developed for estimating model parameters that combine historical climate and paleoclimate proxy data with projections of multiple climate models, driven by multiple climate-forcing scenarios, where the probability distributions of stochastic model parameters evolve temporally. Continuity of observations and monitoring data is perhaps the most critical need in dealing with non-stationarity conditions and variables. Continued support is required to maintain existing networks for snow surveys, stream discharge gaging, remote sensing of evapotranspiration, monitoring groundwater, and water usage while increased support is needed to expand standardized ecosystem monitoring to the landscape scale.

As large-scale ecological disturbances regimes shift with climate change and plant invasions, there will be an increasing need to manage the course of vegetation succession as climate variability will differentially affect opportunities for various species. Long-term success of post-fire vegetative restoration in the desert ecosystem could require novel seed mixes of phenotypes, genotypes, and species adapted to future, not past, climates. A significant question then is what combination of factors should be used to adapt restoration techniques to a changing and uncertain climate? What incentives, over what time frame, are needed to mobilize native seed production in service of habitat restoration and adaptation to an uncertain and changing climate? Successful restoration strategies require regional studies crossing administrative boundaries on soils, soil organisms, and potential impacts on livestock and wildlife. Land managers will need to re-evaluate forage production utilizing refined and improved restoration expert decision support systems. Assisted migration may become a major subject of research, targeting not just endangered species but also common ones. Restoration and assisted migration would require abundant and judiciously accessioned seed sources.

Data Integration and Distribution

Most speakers at this workshop emphasized the importance of standardizing and improving both the access and the sharing of information and data, including improving connections between the research community and natural resource managers. Along these lines, the DOI is undertaking a data integration and management initiative to provide a foundation for understanding and managing climate change impacts over multiple scales (Armstrong, 2010). The goals of this initiative are to make data collected by DOI agencies comprehensive, integrated, standardized, and accessible to other Federal and State agencies, universities, Tribes, NGOs, and private landowners. Motivated and enthusiastic data owners (that is, scientists, managers, and the public) working together can leverage smart technology and standard practices to make the most critical data work together for broad use among scientists, resource managers, and the public. A unique opportunity exists to integrate data to help us understand changing dynamics over the last century and into the future.

Existing data management and distribution partnerships are described in "Collaborations and Partnerships." The Great Basin Research and Management Partnership is an example of an information sharing effort to unite agencies for more effective collaboration on grazing, water, fire, and land treatments projects. This partnership has helped prioritize management at landscape scales by evaluating existing ecological conditions to assess whether or not to initiate restoration treatments. The Partnership's web database provides many tools (see "Collaborations and Partnerships") that foster effective collaboration. An analogous partnership including the Department of Defense exists for the California part of the Mojave Desert at the Mojave Desert Ecosystem Program. This website is a data portal for land-use coverages and environmental documents including reports and studies from various agencies within the California Desert region intended for public distribution. Collaborative networks planned for the future include the LCCs, the Climate Science Centers, and the National Environmental Observatory Network, which have complementary objectives for integrating data at landscape scales on the impacts of climate change, land-use change, land-cover changes, wildfire, and invasive species.

Amelioration Approaches

The terms "adaptation," "resilience," "mitigation," and "restoration" (see Glossary) were the common themes shared by nearly all presentations and conversations at the workshop regarding how scientists and land managers might respond to the impacts of climate change. Adaptation appeared in several plenary presentations as a synonym for response, suggesting that many in the Mojave Desert and Great Basin believe adaptation is a likely management response to the consequences of a changing climate. But successful adaptation involves optimization, where adjustments in ecosystem components and processes in response to climatic stimuli and their effects moderate harm and exploit beneficial opportunities (Intergovernmental Panel on Climate Change, 2007). In this sense, it is similar to the connotation in which mitigation was used—the moderating of harm—except that mitigation implied direct management action whereas adaptation involved more adjustment of policies and the decision-making process. Note that adaptation has a formal meaning in adaptive management and that mitigation in the context of land management implies alleviating damage to resources, not reduction in greenhouse gas emissions. Resilience, the ability to withstand perturbations or to reorganize so as to retain essentially the same ecosystem function, could be a prerequisite to adaptation. Restoration implies managing to achieve a status that existed prior to disturbance and thus shares an active management paradigm with mitigation. But with climate change, the orientation of restoration is altered because restoration must be to conditions that will exist in the future, not the past.

Resilience and Adaptation.—The Great Basin and Mojave Desert region is likely to experience a mean temperature rise of at least 3°C by mid-century and 5°C by the end of the century (Redmond, 2010). Although projected precipitation patterns are more uncertain, a transition to a drier climate is predicted for the southern part of this region (Milly and others, 2005; Seager and others, 2007) with increasing variability in precipitation from year to year (Diffenbaugh and others, 2008). The importance of precipitation and adaptation to drier conditions was emphasized throughout this workshop.

Its relative scarcity makes water a critical regional driver of ecosystem services, because long-distance flows often support human population centers far from the source watersheds. Because of the risk to freshwater resources, protecting water quality and quantity is a high management priority. Planning for climate change should be undertaken at all levels, from the Federal Government to private and public water utilities. Areas with shared river basin or groundwater resources should (1) consider jointly addressing potential future supply reductions resulting from climate change, (2) examine their existing water laws and institutions, and (3) anticipate an increased need to adapt to the forecasted effects of climate change on the hydrologic cycle.

An assumption implicit in land management and resource conservation practice has been one of a dynamic equilibrium (Betancourt, 2010a), which implies a stable climate over the long term. The management philosophy has been to reduce, eliminate, or mitigate challenges while trying to maintain or return to this state of dynamic equilibrium. Climate change will necessitate a paradigm shift, forcing land managers to abandon the idea of dynamic equilibrium and embrace dynamic trends that are spatially and temporally variable. Combined with the complexity and synergy from resource management challenges other than climate change, this new regime will be dominated by uncertainty regarding species occurrence. Land managers can prepare for regime shifts by projecting possible future scenarios to address uncertainty and consider multiple scales to identify mechanisms of response. Specific policy responses must be identified and include objective criteria for choosing among options. Specific tasks include developing a vision of targets in a warming world, assessing the range of possible future scenarios, identifying effects of scenarios on conservation targets, developing robust scale-specific management strategies, planning for the scenarios at multiple scales, and implementing plans and monitoring in an adaptive (cyclic) framework (Scott, 2010). Basic inventories must be completed because the effects of climate change cannot be assessed without comparative baselines. Conservation targets must be identified because, without targets, adaptive improvements to management cannot be evaluated. Conservation targets may be derived from goals for species, guilds, habitats, and refuges or conservation areas. Targets must be quantified in terms of representation, redundancy, spatial distribution, connectivity, and size. A strategic plan must be developed for prioritizing conservation targets and identifying scales of implementation.

At the national scale, climate change adaptation will involve setting the national vision and identifying targets, strategies, and funding. At the regional scale, collaboration and coordination must be emphasized including establishing performance standards for management and rewarding adaptation. At the scale of the local unit, non-climate change related stressors must be minimized and priorities adjusted to incorporate climate change into unit planning. In order to adequately address long-term ecosystem function in a warming climate, increasing the length of planning and budgeting horizons for operational and research funding would be beneficial. In order to address the status and trends of conservation targets, it is necessary to develop and implement monitoring programs. Adaptive management combined with a monitoring program can be used to inform the planning process, especially regarding required frequency and intensity of monitoring and the additive or compensatory nature of seasonal effects.

Managers can work to maintain and enhance ecosystem resilience by reducing or eliminating non-climate related challenges and stressors. Species can be provided the opportunity to respond to climate change by increasing connectivity among existing habitats. The existing conservation footprint could be increased to connect representative and redundant, functional conservation targets. Species compositions will likely change at the scale of individual land-management units but this change does not invariably imply that the purpose of the land-management units is compromised. Rather the purpose of specific refuges and conservation areas can be re-evaluated to meet emerging needs stemming from global change.

Managers can prepare for ecological regime shifts by developing the capacity to modify management actions, implementing adaptive management and monitoring programs, shifting conservation targets to new areas or agencies as change occurs, and by managing transitions to new states. Communication and education are always needed to reintegrate conservation into the American mindset, to build support for climate adaptation, and to conserve habitat. Relocation of species (assisted migration) should be considered only as a last resort (Scott, 2010). Managers must act now and not wait for perfect climate change models. Lost opportunities can lead to irreversible ecosystem alteration and species extinction. Mistakes will be made but innovative risk taking should be rewarded.

Mitigation and Restoration.—Land managers working toward restoring natural systems that have been lost or degraded must first reduce or alleviate existing stressors and threats. Climate change related mitigation and restoration treatments should be applied using an adaptive management framework such as that described in the DOI Department Manual 522 DM 1. The adaptive approach involves including all stakeholders, identifying measureable objectives, exploring alternative ways to achieve them, modeling the outcomes of alternatives, implementing a subset of alternatives, monitoring effectiveness to understand the results of management actions, and then using these results to update and adjust management actions (Williams and others, 2009). This approach can and should be scaled to fit the needs and resources surrounding specific management issues.

Invasive annual plants and wildfire regimes were cited frequently at the workshop as an example of a management concern that could be addressed through mitigation and restoration using adaptive management. Wildfire, invasive species, and climate change are critically linked. In the arid Western United States, drought- and fire-resistant forms of invasive grasses (for example, *Bromus* spp., fig. 4) are replacing native shrubs and grasses throughout much of the landscape recently impacted by fire and drought. This spread of invasive annual grasses establishes conditions for an accelerated fire regime consisting of more frequent, larger, and more intense fires that favor the invasive species at the expense of native plant species (fig. 5). Recommended management activities that could be implemented immediately include mapping of annual plant invasions, identification of vulnerable soils, documenting ecological effects of ongoing invasions while avoiding soil disturbance and protecting biological soil crusts, controlling wildfires, and active restoration of native plant species in disturbed areas (Pyke, 2010).

Research needs specific to the invasive fire cycle include understanding factors controlling invasion and investigating the potential for soil additives to enhance restoration. Mapping historical fire patterns may lead to better understanding of their causes and their relationships to the proliferation of invasive plant species. There may be ways of enhancing existing soils to improve the success of post-burn restoration efforts. Research has developed models for predicting areas at risk to invasion, improving our ability to predict future distributions of invasive species and to understand related ecological impacts (Bradley, 2010). A crucial aspect of adaptive management, however, is effectiveness monitoring. Expanding the extent of monitoring for areas treated with active restoration and soil additives, along with untreated controls, is needed to evaluate the results and modify management actions.

Figure 4. Red brome (*Bromus rubens*), an invasive annual grass linked to increasing frequencies of fire in the Mojave Desert, southern Nevada. (Photograph by Bureau of Land Management, June 2005).

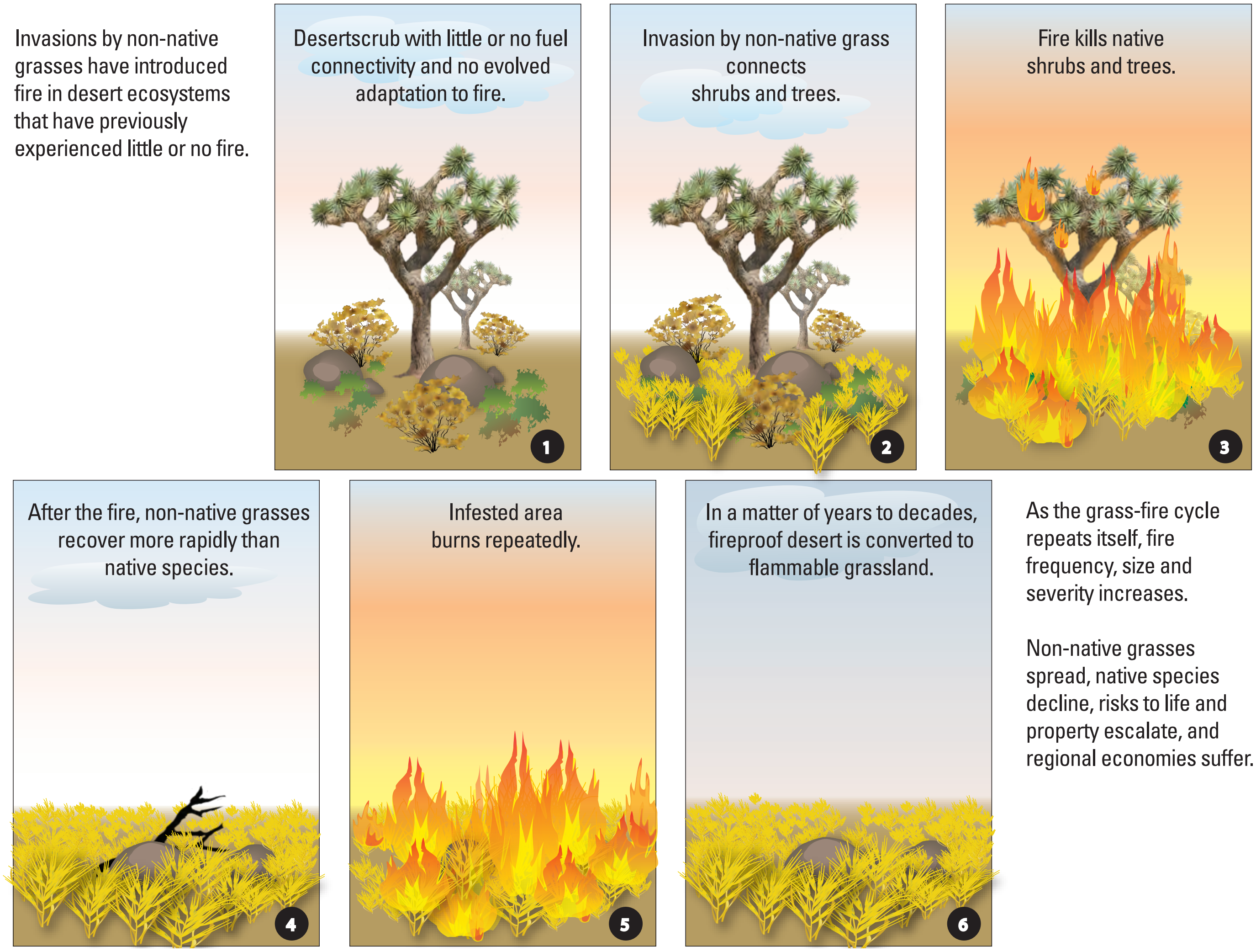

Figure 5. Invasive annual grasses can produce a vegetation type change from desert perennials to invasive annual grassland (Courtesy of Julio Betancourt and Jeanne DiLeo, USGS; Betancourt, 2010b).

Breakout Session Themes

The first day and a half of the workshop was devoted to plenary sessions, where the challenges posed by a changing climate to species, ecosystems, and humans were presented in a science and management context. Breakout sessions on the third day were intended to bring managers, with knowledge of activities, authorities, legal requirements, policies, standard operating procedures, and collective expertise gained from decades of on-the-ground experience in land management together with researchers in a discussion of the current status and limitations of our understanding of climate change and the potential threat it poses to the natural world. Representatives of NGOs and other interested members of the public also participated in the breakout sessions. Each breakout session was charged with engaging an open dialogue on the following three basic questions.

Question 1: What do you perceive to be the major challenges that you face over the coming decade in adapting your practices to the changing climate?

Question 2: What research is needed to inform adaptive management for climate change over the coming decade?

Question 3: How can we best integrate existing and new (for example, Landscape Conservation Cooperatives, ecoregional assessment, Climate Science Centers) approaches to address these needs?

Breakout sessions focused on the topics of Managing Across Boundaries, Ecosystem Services in a Changing Climate, Monitoring for Climate Induced Change, and Species and Habitat Assessment for the Great Basin and Mojave Desert. The session summaries that follow are distilled from detailed session recording. They are intended to help develop and implement an adaptation and mitigation strategy that is flexible enough to integrate our emerging understanding of the science of climate change with natural resource management. Sections representing these three questions are identified in each breakout summary as Major Challenges, Research Needs, and Integration.

Managing Across Boundaries

Great Basin and Mojave Desert ecosystems are patchily distributed on the landscape by natural effects of topography, geology, and hydrology and by anthropogenic conditions imposed by various land uses. Management regimes superimposed on this ecologic setting also have the effect of dividing up the landscape into subunit-defining boundaries, both tangible and administrative. In contrast, pervasive broad-extent ecosystem drivers like climate change can affect systems with little regard to those boundaries. Natural resource managers are charged with considering the effects of changing climate along with more localized ecosystem drivers when managing focal systems. Adjacent land parcels commonly are managed under different agency mandates and land-use plans, which may inhibit cross-boundary management as species ranges and even entire ecosystems migrate and shift around the landscape as expected in response to changing climates. To address this, the workshop convened a breakout session on "Managing Across Boundaries" to identify and frame the problem, isolate impediments to successfully dealing with the problem, and generate solutions to effectively manage the Great Basin and Mojave Desert landscapes in a broad context.

Workshop attendees were primed for this discussion by materials presented in the plenary session by Thomas Armstrong, J. Michael Scott, Dennis Schramm, and Jeanne Chambers among others who spoke on this topic. Several important points were made including the critical need to expand our conservation footprint given predicted climate trends. Speakers expressed the need for unprecedented levels of communication and cooperation because the issues that need to be addressed dictate collaboration across boundaries. The breakout session was attended by about 50 individuals, about one-half of whom worked in the Mojave Desert and one-half in the Great Basin. Attendance was heavily weighted by federal agency employees (about 80 percent; about 80 percent of which were Department of the Interior personnel); the remaining attendees were associated with universities (12 percent), Native American Tribes (4 percent), State management agencies (2 percent), and NGOs (2 percent). Participants were charged to bring their perspective to bear on the three questions stated in the "Breakout Session Themes." Participants were divided into small groups for focused discussion and then rejoined for synthetic critique and consensus. The following is a summary of the groups' recommendations.

Major Challenges

The major challenges that were identified can loosely be grouped into five topical areas concerning problems with policy, planning, funding, communication, and education, training, and tools with some overlap among topics.

Policy.—A large, somewhat overriding challenge to effective management across boundaries involved temporal-perspective conflicts felt by managers faced with changing political administrations. Land managers write and are guided by land-use plans with a 20+ year life span but face the potential of policy changes occurring on a much shorter (that is, 2–4 year) time span. Executive and legislative leadership changes can lead to profound policy shifts, which have the potential to derail well-thought out planning. Workshop participants expressed a desire to maintain consistencies regardless of policy fluctuation, especially when considering a politically charged topic like climate change. A good example of this is the potential for agencies to go ‘off message’ when the time frames of established regulatory processes do not mesh with decision needs. Specifically, managers were vexed by pressures to fast-track renewable energy permits—currently a politically attractive land use—despite established, although slower, permitting processes.

Concerns were expressed about conflicting agency mandates and the difficulty of enacting landscape-scale management when neighboring parcels and managers are legally withheld from collaborative management. For example, a consistent approach to restoring a given habitat-type bisected by an administrative boundary may not be possible under current mandates. Agency mandates would benefit from a fresh strategic planning effort at Department (or higher) levels of government. The improved strategy should address inter-agency agreement and fund-sharing expediency; temporal alignment of funding cycles and project development; approaches to National Environmental Policy Act (NEPA) requirements and processes; and precise definitions and collaborative prioritization of “multiple-use.” Participants also agreed similar issues exist when addressing Federal versus State resource priorities. One potential solution is to build in flexibilities in policy interpretations. Another is to have Federal, State, and local agencies fully embrace effective regional partnerships, such as the Landscape Conservation Cooperatives (LCCs) Desert Managers Group and the Great Basin Research and Management Partnership. Participants recognized a danger in providing too much flexibility at the local scale, yet adamantly expressed a need for a relaxation of overly restrictive policy that stymies effective management.

One other policy concern expressly addressed information technology (IT) security restrictions. The group agreed that most solutions mentioned in this document would only be possible with a restructuring of the way natural resource organizations manage electronic data and tools so as to minimize obstructions to data access.

Planning.—Similar to policy recommendations, suggested improvements to planning processes across boundaries are loosely aggregated by issues of spatial and temporal scale. Participants see an urgent need to cast a wider net with planning that would be based on ecosystem-level space and time frames. Comments in this context generally were proactive, suggesting that these challenges may be more easily overcome than policy-based hurdles. Phrases like ‘break out of the current mold’ and ‘shift paradigms’ were common on this topic. One tangible suggestion is to format land-use planning processes so they are based on criteria that inform decision making, rather than on area-specific designations. This would have the additional advantage of incorporating adaptive management into planning and action. Scenario-based approaches also were suggested as potentially beneficial to managers. In this approach, decisions can be made further into a plan’s life when managers have a better understanding of a given target’s condition and trend. It was suggested that this approach would be more fruitful given that non-stationarity implies that the baselines are changing; therefore, having a suite of potential futures modeled in a plan gives managers the ability to assess resource trajectories and pick from a set of tools (or create new ones) as former uncertainties become better resolved with time.

Partnerships were promoted by the group in a planning sense too. Many suggested resource managers leverage cross-agency resources when planning. The benefits of sharing resources across partnerships as we move to implement LCCs were discussed at length although the need to promote participation in partnerships with incentives and disincentives also was expressed. The challenge raised is that some managers may see collaboration as a sacrifice of autonomy at an agency, district, or personal level. Whereas incentives should help, more intense training may be necessary to promote buy-in. An additional tool suggested is a clearinghouse of case studies describing successes gained through partnerships. These kinds of collaborative tools are already in development (see “Collaborations and Partnerships”). A clearinghouse distributing tested and novel management practices and mitigation measures that managers can use could mean that new paradigms do not have to be developed district-by-district, region-by-region, or collaboration-by-collaboration.

Another major challenge to planning across boundaries is that employees are not expressly incentivized to participate. Collaboration often falls under ‘other duties as assigned’ in a job description. Unless these activities are explicitly defined in planning documents, job descriptions, work schedules, and performance appraisals, practitioners will continue to struggle to find time to participate.

Funding.—Many participants expressed frustration at how project funds are allocated and compartmentalized and about the timing of allocations. An obvious strategy to successfully manage across boundaries is to pool funds from multiple agencies or jurisdictions. However, moving funds across agencies, even those in the same department, can be costly from the project standpoint, making any interagency collaboration more difficult. Along with overhead costs, lengthy and difficult contracting processes slow down fund transfers. Coupled with delayed allocations, worthy cross-boundary management projects may not come to fruition for purely administrative reasons. `Stove pipe funding is not working,’ was one specific comment. The sentiment was complemented by comments that it is very difficult to get funding earmarked for similar objectives through two (or more) agencies in the same time frame. One proposed solution is for legislative units to develop and fund cross-cutting initiatives for collectives of agencies. If multiple agencies identify a valuable multi-jurisdictional management project, each could draw funds from the account and apply the maximum portion of resources on the ground with minimal delays and overhead costs.

Another challenge expressed is limitations on fund carry-over between fiscal cycles. Given the constraints mentioned above, a particular jurisdictional unit potentially could match funds with a collaborator if they could delay spending the funds for a year. However, an inflexible carry-over policy limits that option. A novel solution to these problems proposes bringing in private sector partners. The concept might involve reliable conservation partners brokering funds and facilitating project completion at the broader landscape. Participants suggested setting up a regulated interest-bearing account from which the private sector partner distributes funds as needed.

Communication.—Much of the discussion about challenges and needs for overcoming obstacles to managing across boundaries involved information and data sharing. Communication needs to be improved between researcher and manager, manager and manager, researcher and researcher, and professionals and the general public. Nearly all participants expressed a critical need for centralized, standardized data repositories and information clearinghouses. Many such tools are in place (see "Collaborations and Partnerships") so one solution is better outreach and training. Many novel ideas about how to share data and present results were generated during the session. There was an explicit desire expressed for development of a community of practice on information, outreach, and training. The succinct statement was, `we need scientific leaders to guide information sharing.'

A pervasive group sentiment indicated that there is a close relationship between agency culture and communication tools. Effective tools are needed but agency personnel need to see them function effectively before they consider relaxing the status quo. Similar thoughts were expressed when discussing private lands/landowners and environmental groups. Communication may not solve all conflicts but providing a common platform for communication may ease misperceptions about adverse objectives and mandates.

A technical challenge involves the broad variation in capacity at various organizations and offices. Differences in hardware, software, Internet connections, and data-sharing capacity may derail attempts at cross-boundary collaboration. Land management agency offices—especially remotely located work centers—and research facilities need technical capacity to effectively provide and receive data, and communicate their purpose, goals and accomplishments to local and national publics.

Education, Training, and Tools.—Education challenges come in two forms: educating the public about the importance of climate and other sources of global change on ecosystem goods and services and education of resource professionals about the importance and capacity to think and work across boundaries. The former is obviously important but the latter was more thoroughly discussed. Required education/training opportunities include issue identification and prioritization; general concepts of stationarity, ecological resistance, resilience, and restoration theory; dynamic system processes associated with global change; and the covariate nature of existing threats with climate change. Tools to support this training also are lacking—the need for data management and delivery; decision support; and user-friendly ecological and management-based models were identified.

Research Needs

A remarkable volume of needs were expressed and documented during the breakout session. Specific discussions on research strategies and guidance, subject matter, and integration, models, and communication generated a large suite of ideas.

Strategy and Guidance.—A common theme during the breakout was a need for greater efficiency. For example, attendees referenced the voluminous amount of archived data that are not currently digitized but could be extraordinarily useful as baselines for forward-looking research and monitoring. A priority goal should be to identify, digitize, and deliver decades of research and monitoring data held in agency files. This is a necessary first step for designing monitoring strategies that would complement what we already know about pre-disturbance condition. The exercise also would complement cross-agency data reconciliation, standardization and synthesis, before-after-control-impact study design, and future research needs prioritization. The process would benefit from a thoughtful crosswalk development that synthesizes characteristics of archival data and relates them to digital-era data.

Other suggested research strategy needs include integrating currently disparate inventory and monitoring approaches among federal agencies and programs, incorporating socioeconomic factors into science planning, research that identifies social and political impediments, an optimization assessment of research funding practices, designing research so the results will be inherently persuasive, and structured decision support for evaluating and permitting development projects.

Subject Matter.—Research needs by subject matter spanned a range of issues. Needs expressed include:

- Research to validate cause and effects of climate change.
- Adapt existing information in a climate variability context.
- Improve weather station network and refine weather data resolution.
- Evaluate air quality and drinking water impacts on human health.
- Investigate groundwater/surface-water connections.
- Determine water budgets for renewable energy projects.

- Model corridors and species connectivity.
- Understand ecotones and how they will change in the future.
- Conduct research on grazing and climate change.
- Obtain basic inventories and GIS data.
- Identify areas suitable for development and for protection.
- Conduct social research on demographics and policy impacts.
- Account for human population growth.

Integration

There is a need for integration of planning, research, and monitoring rolled into an adaptive management framework that is spatially and temporally scalable. Work in this arena is being done outside this workshop's focal area. We need to tap into these efforts, adapt them to Great Basin and Mojave Desert systems and threats, and apply them to local solutions. Such an approach, however, requires increased uniformity among agencies and other entities. Models, either improvements on existing ones or newly developed ones, need to be as reliable and accurate as possible to improve the chance of successful prioritization and planning. Finally, all these data and tools need to be delivered in user-friendly formats in order to achieve maximum effect.

Integrative Approaches.—Agency direction over the past decade has consistently moved toward collaboration-driven research and management, which promotes management across boundaries. Much of the discussion at the workshop, including this breakout session, revolved around the integrative potential of newly initiated Landscape Conservation Cooperatives (LCCs) and Climate Science Centers (CSCs). Participants discussed ways that these initiatives might facilitate policy development, science and management strategies, funding options, and communication and training aspects.

Policy Development.—Participants felt that new approaches should help integrate inventory and monitoring programs across and within agencies by improving existing infrastructure. Improving partnerships with industry also was mentioned as a valuable role for programs like the LCCs. Such new approaches could improve disclosure and transparency, which should improve collaboration across boundaries. With this improved exposure, additional partnerships, and greater integration of broad-scope programs, participants expressed optimism that regulatory laws and procedures would more easily be modified to include emerging issues like climate change.

Science and Management Development.—Participants offered potential solutions for nearly all science and management challenges mentioned above within the context of the new approaches at landscape-scale, cross boundary, and inter-agency initiatives. For science development, participants thought an LCC could improve interpretation of existing data and communication of that information more fluidly. Initiatives would facilitate the bridge between research and management that has long been discussed but rarely achieved. They also should help managers work beyond their boundaries, understand existing management actions, and manage for biodiversity and ecosystem services rather than individual species or disturbances.

Funding.—Perhaps the most obvious net benefit of cross-organization initiatives is the emerging opportunity to fund cross-boundary projects. Participants see opportunities for LCCs to serve as virtual collaboration centers where restrictions of the past are replaced with collaborative opportunity in the form of efficient transfer of funds, resources, and personnel. Furthermore, the new initiatives could build on past successes and use existing infrastructure in innovative ways. One example would be to support and use the Great Basin Cooperative Ecosystem Studies Unit as an efficient mechanism to exchange funds collaboratively.

Communications and Training.—The LCCs and similar efforts have the potential to provide the conduit to move information quickly and accurately around a large network, empowering professionals to do their job better and more efficiently while informing the public about conditions, trends, and required management actions on the landscape. Internally, these new approaches promote collaboration without threatening traditional roles and responsibilities. They allow agency, tribal, university, and NGOs to retain their identities while effectively working with a broadened group of partners. Science application can be swift and decisions made with the knowledge of the best available science. Furthermore, all these actions and decisions would be made with a transparency that would garner support from an informed public. The public might not always agree with an action but they will be better informed and might even have opportunities to participate in decision making in ways that were not possible before. This open communication could (and should) be used as an education portal, an extended teaching moment where training materials, interactive models, and feedback loops are available to all participants. In that way, existing and new initiatives will provide the capacity for true integration, collaboration and partnership among all stakeholders, thus improving our ability to manage across boundaries.

Ecosystem Services in a Changing Climate

The concept of ecosystem services was introduced to participants in the plenary session by Ken Bagstad (2010) as the intersection of people and nature in a framework of humans as beneficiaries. Ecosystem Services breakout sessions were attended by 90 people from Federal and State agencies, NGOs, and academics. Each of the two sessions had 10–12 small group discussions focusing on the services provided by air, soils, water, and landscapes.

Ecosystem Services

The term, ecosystem services, refers to a decision support concept for the use and management of natural resources, which recognizes the many critical benefits (for example, clean air and water, food, medicine, health, and safety) that nature provides to people. Other benefits include trees and plants that filter pollution of the air and water, habitats that support diverse natural areas, and lands that provide a buffer to wildfires, floods and storms. Most people acknowledge ecosystem services as part of decisions about how natural resources are managed and used. There is also a strong need to recognize the key role of nature's benefits to address issues of public health and safety in making decisions about how natural resources are used and managed. We need to recognize the value natural areas have in protecting communities as, for example, where wetlands minimize storm damage by capturing flood waters, and recognize the economic value these natural areas have in mitigating damage. Preventing water pollution naturally by protecting and restoring wetlands and rivers is much cheaper and easier than trying to treat contaminated waters. Supporters of ecosystem services always seek to improve and understand concise and accurate ways to calculate the value nature provides to the people, while acknowledging the process as a crucial part of decisions.

Major Challenges

Participants addressed the ecosystem services provided by air, soils, water resources, and landscapes as a concept to assist in the development of practices in relation to climate change and adaptive management. Several challenges were raised including:

- A lack of understanding in how to incorporate an ecosystem services approach into managing public lands;
- Increases in renewable energy and planning needs (possibly hindering adaptive management options);
- Differences among agency policies;
- Differences in scales of information;
- Uncertainties of water supplies; and
- Discontinuity in water laws, conservation, permit issuers, and research.

Many participants in the Ecosystem Services breakout felt that it was difficult to determine the true value or willingness to pay for an ecosystem service. Equally difficult was the willingness to define compensation for the degradation of an ecosystem service or forgo an improvement or restoration of an ecosystem service. Participants questioned how such values are accurately derived, given limitations on time, skills, resources, or data to make proper determinations that minimize disputes and challenges from other parties or stakeholders. Participants stated that policy decisions could benefit from a better understanding and recognition of the contributions of ecosystem services to economic and social welfare, but that there are difficulties in determining how a market-based economy can account for ecosystem services and incorporate them into decision making. Hence, methodological challenges were discussed in terms of assigning monetary value to ecosystem services.

Integrating climate change with ecosystem services requires linking specific services to specific ecological processes, information about the time and geographic scales at which ecological processes occur, identifying the environmental factors that influence ecosystem services, and identifying the ecological assets that support ecosystem services. There also is a need for ecosystem service assessments for air, soil, and water to be integrated into the broader agency missions—including all actions that impact desert landscapes. The value of any ecosystem service must be agreed to and understood by the people living in the area. Even with improved knowledge and data of these ecosystem services, economic valuation will be challenging.

There are significant gaps in knowledge concerning the information from a soil inventory (for example, conducted by the Natural Resources Conservation Service, with a classification based on static subsoil features for consistency in mapping) compared with the many remote sensing techniques that depict dynamic changes in surface land-cover distribution and changes (for example, soil biotic crusts, plant phenology, etc.). This is one of many significant gaps in knowledge concerning values of ecosystem services relating to specific soils data and information in need of clarification. Participants were extremely interested in understanding a concise and accurate way to calculate the values nature provides to people, while acknowledging this process as a crucial part of decision making. Many felt the concept of ecosystem services must be clearly geared equally to the conservation community and the economically motivated business community for it to be trusted. With sufficient data, inventories, and information being difficult to find and synthesize, they cited a strong need for improved access to existing information to increase relevancy and effectiveness at both research and management levels. How existing data can be used in a dynamic world is especially important with monitoring, assisting in prioritizing work, and evaluating what is successful or not.

Communication skills and working through more effective partnerships were recognized as being both crucial and a challenge. There is a need to bridge the many agency barriers as well as landscape boundaries. A general lack of data was noted, leading to difficulty in agreeing on baseline conditions and setting of future objectives in a changing landscape. Ecosystem services may help in defining sustainable human uses and consumption in desert landscapes in the absence of general agreement regarding ecosystem trends. Other challenges (repeated in other sessions) included the need to mitigate climate change by reducing our carbon footprint, the need for information technology necessary to share and data and models, the necessity of an overall communication strategy for outreach and education, and issues related to adequate funding, especially for long-term studies.

Research Needs

Many research needs identified in this breakout session reflected how soils, water, and air will be influenced by climate change, conservation strategies, monitoring, resource uses, and restoration. The lack of inventory data and monitoring protocols was mentioned as was the need to integrate researchers early in the planning stage of studies to better reflect disturbance effects on the soil, water, and air. The need for multi-disciplinary research, effective mitigation methods, and research to addresses landscape connectivity, ecosystem resilience, and ecological thresholds were brought forth. Participants identified a need to conduct a critical review of existing models, particularly global circulation models of climate change at spatial and temporal scales relevant to land managers, including an assessment of their shortcomings. The need for additional research on the effects of energy and water development projects was identified, such as studies on development impacts, cumulative impacts of small and large-scale projects, and research directed toward a better understanding of the effects of groundwater drawdown and overall watershed management approaches. A need also was expressed for socioeconomic research on how people will affect ecosystem services in planning for global change scenarios.

The need for improved monitoring, restoration goals and guidelines, data sharing and communication, outreach, and education were repeated concerns expressed in other breakout sessions. For example, a diverse mixture of plant species often yields cover that more effectively protects soil productivity than a single species, thus providing an ecosystem service function that may help buffer against erosion from wind and water. Research is needed to better understand the consequences of the accelerating loss of species and the actions required to maintain or restore ecosystem services. Most air, water, and soil ecosystem services also are supported by more than one ecological process and therefore empirical ecosystem studies including experiments, observations, and models are needed to improve science-based management. Participants felt that integrated approaches to science-based management require an understanding of complex interactions within and between ecosystems at all scales. Fundamental research is needed for the development of an integrated ecosystems approach, which considers an entire range of ecosystem services and possible trade-offs between them. This will require monitoring of relevant ecosystem functions at appropriate scales to detect trends in ecosystem services and response to management actions. Session participants wanted to include monitoring requirements in land management planning for maintaining or restoring ecological services.

Research needs identified included general issues as well as specific topics related to species, habitat, climate models, conservation strategies, trend monitoring, resource use, and restoration. Among the general issues identified were the lack of basic inventory data and monitoring protocols and the need for improved study designs including both pre- and post-disturbance monitoring, and the need for standardized methods to assign value (monetary and non-monetary) to ecosystem services and to conduct cost-benefit analysis. Other issues raised included the need for multidisciplinary research, effective mitigation methods, and the importance of research that addresses habitat connectivity, ecosystem resilience, and ecological thresholds. More research is needed to assess how climate change will affect air quality and drinking water impacts on human health. Water quantity assessments are needed for renewable energy projects. More research is needed to understand surface-water and groundwater interactions, characterize hydrologic and groundwater basins, and estimate recharge. There is inadequate information on the effects of climate change and human development on soils, wind erosion, and groundwater. Participants felt that interdisciplinary effort is needed to integrate social aspects with natural resource research to improve understanding and to better inform the public. Perhaps most importantly, while much attention is focused on landscapes, habitats, species, and public aesthetics, relatively less effort is expended in identifying public health issues.

Integration

Decisions regarding the management and use of natural resources now more commonly include a consideration of ecosystem services. However, many felt that improvement is needed in the way the topic of ecosystem services is framed and communicated. Although jobs and economic benefits are important, people also support assessing the value of nature in terms other than dollars. Consideration of the impacts on nearby communities also is very worthwhile. There is a need for collaboration among all agencies, Tribes, industry, universities, and NGOs on a unified mission of climate change to reduce conflicting approaches and redundancies. In other breakouts sessions, it was mentioned that the Natural Resources Conservation Service has a nationwide process for private lands that features a data-collection partnership, including information on soils, hydrology, and ecosystem functions. These data possibly can be rolled up into eco-regional assessments and LCC efforts to improve agency cooperation.

More effective use of resources and integrated funding is needed to answer management-related research questions. We need to promote engaged scholarship, where all parties (policy and decision-makers, civic leaders, managers, nonprofits, and scientists) collaborate on a project from start to finish. Several Federal agencies are developing collaborative programs and partnerships (for example, the Environmental Protection Agency's Ecosystem Services Research Program). Existing and future collaborative programs should include identifying key scientific questions, shaping the research effort, discussing the implications of findings, and deciding how to best communicate the results, explaining complex research in non-technical language.

Monitoring for Climate Induced Change

Major Challenges

During two breakout sessions, several issues were identified as being a challenge related to monitoring for climate change. Some of these challenges were related to data access and compatibility and other challenges included identifying and implementing monitoring strategies. One of the primary areas of concern was that, especially in geographic areas that are being covered by multiple agencies, any monitoring plan would benefit from broader coordination by establishing a common set of protocols and data quality assurance procedures, common databases, and access portals among agencies to avoid duplication of efforts and ease data transfer between agencies. Despite monitoring networks being present, data appear to be scattered, collected with different protocols or formats, and monitored parameters are not always comparable, making it challenging to link data among existing monitoring networks. Development and implementation of monitoring plans would greatly benefit from the establishment of a clear set of management objectives because this could focus monitoring efforts to better help with adaptive management. It is important to recognize that these objectives will vary by region, because regions are likely to differ in plant and animal species composition and climate. However, in establishing monitoring and management objectives, care has to be taken that monitoring goals and objectives are attainable; otherwise large amounts of programmatic resources may be wasted. Ideally, explicit management objectives will result in identification of specific data needs and subsequently data gaps.

A role was identified for using models to identify data needs and conduct risk assessments associated with climate change as a means of planning and prioritizing monitoring activities. However, short-term agency funding cycles result in short-term monitoring efforts that cannot assess long-term changes. The inherent multi-decadal timescale of climate change will require monitoring to focus on longer term time scales of 50 years or more. In order to achieve this, a commitment and/or new administrative processes from the agencies involved with the monitoring effort have to be made. Participants recognized that a large challenge will be to provide long-term funding for these efforts.

Another challenge related to the longer time scale is that in order to evaluate whether changes occur, baseline conditions have to be established, recognizing that baselines are not expected to be stable. Archived data could be useful in helping to identify prior baseline conditions. Given the relatively slow environmental changes associated with climate change, detecting changes in ecological processes that unequivocally can be ascribed to climate change will be difficult and challenging. To better focus monitoring programs, and for any monitoring practice to be effective, it would be advisable to concentrate monitoring efforts on areas or ecosystems that are most likely to be sensitive to climate change. Dissimilarity indices can be used to focus on areas that have changed or are expected to change substantially. Current transition zones may be good focal areas for measuring change in an attempt to constrain the amount of monitoring needed to detect change. In addition, key indicators have to be identified that can help focus monitoring efforts rather than using a 'laundry list' of parameters that ultimately may have little practical application to adaptive management. A high priority goal should be to identify cheap, easily measurable parameters that can be used as proxies for parameters that are difficult and expensive to monitor.

Monitoring strategies, despite the need for establishing clear objectives and identifying associated monitoring parameters, need to be prepared to expect the unexpected. Establishing rigid monitoring criteria may carry the inadvertent risk that changes in ecological parameters may occur, yet happen undetected as they may not be included in the monitoring protocols. In addition to focusing on change, the monitoring community should be cognizant that a non-event or absence of change is just as important to identify and document. Monitoring protocols must be flexible and adaptable to avoid both the error of failing to detect a change that occurred and failing to establish the absence of change.

Research Needs

For monitoring to be effective in informing adaptive management several issues need to be resolved, some of which are fundamental research questions while others relate to the interaction between monitoring and adaptive management. An example of the latter is the relationship between fire in different ecosystems, invasive plant species, and management actions. In many ecosystems within the Great Basin and Mojave Desert, fire is an important determinant of ecosystem function. However, the role of fire is not uni-directional among all ecosystems. For instance, fire-exclusion may have caused undesirable changes in ecosystems including Piñon-Juniper woodlands (fig. 6) while other systems have been experiencing unnaturally intense and more frequent fire, sometimes due to increased presence of invasive species such as cheatgrass. As a result, fire management objectives are different depending on the ecosystem context. Monitoring the changes in fire frequency in response to climate change is critical in both situations. Interpretation of these data and associated management practices depends on local conditions. Given the importance of invasive species as a driver for ecosystem function, a clear definition of what constitutes an invasive species is critical. An unambiguous definition has to be developed to prevent native species shifts in response to climate change being interpreted as invasions by non-native species. This may require monitoring programs to be spatially extended outside of the range for which they were originally established so it is easier to anticipate what changes in species composition can be expected.

Figure 6. Wildfire near Winnemucca, Nevada, on April 1, 2009, at the edge of Piñon-Juniper woodland habitat that may have resulted from past fire suppression management practices and expanding annual grasses related to increased fire frequency. Photograph by Bureau of Land Management.

In addition to these fundamental questions regarding uncertainties in process responses to climate change, there are needs regarding the practical implementation of monitoring strategies. One is the degree of acceptable change. For monitoring to be effective in informing adaptive management, there has to be some agreement on how much change must occur before management action is taken. Because ecological thresholds are difficult to define, management assessment points are often based on management perceptions of resource conditions (Bennetts and others, 2007). Differences in perception in the absence of established thresholds or tipping points can limit the management applicability of monitoring data. Another practical challenge to implementing monitoring is unanticipated changes in land management objectives. For example, many arid ecosystems represent prime locations for alternative energy including solar and wind energy. However, to date impacts of renewable energy use have not been included in management modeling tools. In light of the recent interest in renewable energy, monitoring protocols should include areas targeted for development in addition to remaining flexible to accommodate future objectives.

Given that on-the-ground monitoring often can be very labor-intensive, and thus expensive, monitoring protocols should rely more on remotely sensed data where possible. Still, ground-based observations are critical; perhaps a sampling strategy can be adopted that makes use of sensor-intensive centralized hubs with distributed sampling locations that only focus on selected parameters. Currently, management and monitoring activities appear to be somewhat disconnected. For monitoring to be effective in informing adaptive management, managers and monitoring specialists have to work closely together to ensure that there is a tight feedback loop between their activities. That way monitoring strategies can be responsive to changes in adaptive management practices.

Existing Monitoring Program Examples

— BLM National Assessment, Inventory, and Monitoring

The Bureau of Land Management (BLM) National Assessment, Inventory, and Monitoring program (NAIP) is a national strategy to manage the collection, storage, and use of data on resource conditions, resource uses, and the BLM's management actions to inform its mission for multiple uses of public land under its management. This strategy establishes a limited set of resource indicators that are common to most or all BLM field offices, and that are comparable or identical to measures used by other government agencies and non-governmental organizations. Data collection, quality assurance, and reporting are standardized to improve the quality of the BLM's land use planning and other management decisions. The program will establish a baseline of land health condition at a national level and assess trends over time. Rapid Ecoregional Assessments (REAs) address the existing condition of western landscapes and how conditions might be altered by environmental changes and land uses. The REAs examine ecological values, conditions, and trends within seven ecoregions spanning administrative boundaries.

— National Park Service Inventory and Monitoring

The National Park Service (NPS) Inventory and Monitoring (I&M) program was established to scientifically inform the management of natural resources under National Park Service stewardship and determine their status and trends. The program monitors park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environments. Monitoring protocols are implemented as standard practice throughout the National Park system to integrate natural resource information into NPS planning, management, and decision making. The NPS intends to share information with other natural resource organizations and form partnerships for attaining common goals and objectives.

— Forest Service Forest Inventory and Analysis National Program

The U.S. Forest Service (FS) Forest Inventory and Analysis (FIA) program is an annual survey of status and trends in forest area and location. Information collected and managed by this program includes species, size, and health of trees, total tree growth, mortality, removals by harvest, and wood production and utilization rates categorized by various products. Data also are collected on soil, understory vegetation, tree crown conditions, coarse woody debris, and lichen community composition on a subset of plots.

Integration

In order to effectively monitor long-term changes in response to climate change, a long-term, interagency perspective has to be implemented. This requires commitments and funding mechanisms to be set up at high levels within Federal agencies. Currently (2011), various agencies are involved in addressing climate change impacts on Great Basin and Mojave Desert ecosystems. However, connectivity between agencies is lacking, resulting in disparate monitoring protocols and ultimately inefficient use of resources. Resources could be used more effectively if the various agencies coordinated their monitoring efforts, avoiding duplication and ensuring interagency data sharing.

In addition, other agencies can be brought into these monitoring efforts, such as resource Conservation Districts. Within agencies, there is a need to communicate up and down the hierarchical chain to ensure that those involved, including decision makers, are properly informed of monitoring activities. Data are often aggregated to a coarse scale for analyses that are then used to set policies. This may create the risk of having large-scale management decisions being made that are not addressing local, site-specific needs. Consequently, management decisions may become ineffective or inadequate. Given that impacts of climate change can vary across the landscape, monitoring programs may benefit from involvement of multiple stakeholders in the monitoring efforts including NGOs and citizen groups. For these local monitoring efforts to be effective, standardized protocols have to be developed so monitoring data can be compared across larger scales.

Recommendations Summary

- Establish clear management objectives before setting up monitoring protocols.
- Establish common monitoring protocols among agencies.
- Allow for data accessibility among agencies.
- Focus monitoring efforts on areas that are most likely to be affected by climate change.
- Expand the time-window for monitoring activities.
- Involve multiple stakeholder groups including local NGOs and citizens.
- Have close feedback loops between monitoring and adaptive management activities so changes in adaptive management can drive changes in monitoring activities.
- Avoid data roll-up as much as possible to allow for site-specific management activities to occur.
- Expect the unexpected.

Species and Habitat Assessment

Terrestrial Ecosystems

Breakout sessions on terrestrial species and habitat assessment in the Great Basin and Mojave Desert were attended by about 60 people representing Federal or State agencies and NGOs or universities in roughly equal proportions. The following is a synopsis of discussions of the three key questions addressed in the two terrestrial breakout sessions.

Major Challenges

Institutional constraints were identified as a major challenge. Four general areas of concern were identified:

1. Agency missions that differ and are often in conflict,
2. Management differences across administrative boundaries,
3. Inflexible land-use and resource-management plans, and
4. Differences among agency policies.

These issues are summarized above in the breakout session on “Management Across Boundaries.” The discussion in this breakout session focused on the general areas of concern (3) and (4). Land-use and resource-management plans are often outdated and lack flexibility. As a result, some activities, such as the recent rapid change in renewable energy development in the Great Basin and Mojave Desert, was neither foreseen nor adequately planned for. This lack of planning forces consideration of natural resource conservation into a reactive mode which in many, if not most, cases leads to suboptimal outcomes. Policy differences among agencies also can impede interagency efforts to adaptively manage.

There was general agreement that monitoring is needed for terrestrial species and habitats in the Great Basin and Mojave Desert. Baseline conditions reflect a point in time in which the existing conditions already may have been affected by climate change. Because conditions are likely to be dynamic and already may be outside of the historical range of variability, long-term trend monitoring is needed. Efficient implementation of trend monitoring requires that the questions of what, where, when, and who be addressed. For optimal efficiency, trend monitoring should be consistent across agencies. Participants in the breakout session agreed that scale was important and management actions that are appropriate at one scale may not work at another. There was no general agreement on what scale is most appropriate to address climate change. Some participants felt that the ecosystem was the appropriate scale and that the emphasis should be on functionality, diversity, and redundancy. Other participants felt that the focus should be on habitats but not individual species. Elevational gradients can provide an appropriate context for assessing the effects of climate change. Clear protocols were needed for decision-making about at-risk species. The protocols should include a method for deciding how much money to spend to benefit any single species versus money spent on actions that benefit multiple species. A triage response may be necessary based on the predicted effects on species and habitats. The decision support process needs to provide guidance on when to allow species to go extinct.

Competing resources uses, in particular for water and energy development, were considered to present a significant challenge to biological resources conservation in the Great Basin and Mojave Desert. The uncertainties about future water supply calls for an immediate need to conserve and manage available water. There appeared to be imperfect linkages between water management agencies, permit issuers, and researchers. There also is a disconnection between water law and resource conservation both within and across State boundaries. Differences across State boundaries exist for surface water and groundwater resources, but cross-boundary groundwater flow is commonly poorly understood. The importance of water issues in these arid environments was highlighted by this discussion in the breakout session "Terrestrial Ecosystem" and further summarized in the breakout session "Aquatic Ecosystems." Energy development not only competes for scarce water resources but also has direct effects on habitat within the footprint of projects and associated facilities. These developments can displace existing land uses, such as recreation, into less disturbed areas thereby increasing their impacts.

Numerous challenges to adaptive management were identified. As noted above, fixed management frameworks are often in conflict with adaptive management. The mechanisms for management change may be non-existent or lack expediency. Moreover, it can be difficult to make quick decisions in the face of political obstacles. Adaptive management needs to be informed by quality data. In particular, managers need threshold criteria both to evaluate impacts and to know when to change management. Recommendations to address the challenges of adaptive management included building system resiliency by removing the known current threats to species and their habitats and recognizing that uncertainty will exist along the way. Climate change will exacerbate some stressors and create new interactions among stressors. Finally, it is necessary to recognize that community composition and dynamics will shift and, in cases where species can neither expand nor shift their range, adaptive management may not be possible. Conversion of natural landscapes to alternative uses, such as large-scale renewable energy development (fig. 7), also is likely to preclude adaptive management options. Other challenges identified included the need to mitigate climate change by reducing our carbon footprint, the need for information technology necessary to share data and models, the necessity of an overall communication strategy for outreach and education, and issues related to adequate funding, especially for long-term studies.

Figure 7. Parabolic mirror solar thermal energy generating plant at Kramer Junction, California. Increasing demand for alternative energy could result in conversion of presently undisturbed public land to solar and wind turbine electricity production (Flint, 2010).

Research Needs

Initial discussion in this breakout session focused on climate in general. Participants identified a need to conduct a critical review of past and existing species, habitat, and climate models including an assessment of their shortcomings. In particular, the relationship between model generality and model accuracy needs to be examined. Predictive models are needed that are based on the environmental physiology of individual species and focus on critical functions such as reproduction, recruitment, and where relevant, ecological interactions, such as pollinator relationships. Empirical studies are needed that examine the relationship between such functions and habitat quality under different climate change scenarios. It also was suggested that there was a need to include species other than those currently deemed to be at-risk, although no rationale was provided to support this. Other needs identified include paleoecological research to understand current and future species ranges and the dynamics of species assemblages. With respect to habitat models, there is a need for alternative future scenarios of vegetation change that incorporate uncertainty. The necessity of validating models also was emphasized.

A need for better conservation strategies informed by our current knowledge of priority habitats and migration corridors was identified, especially for strategic approaches that transcend management boundaries. A need for new research exists on the identification and prioritization of areas that can provide connectivity in fragmented landscapes and serve as migration corridors. This research would need to include risk analysis on specific species to inform existing regulatory frameworks as well as better understanding of habitat diversity gradients. A specific need for additional research on the effects of energy and water development projects was identified, including controlled studies of development impacts, cumulative impacts of local- versus large-scale energy projects, engineering design studies on how to maintain habitat values in energy development areas, and research directed toward a better understanding of the effects of groundwater drawdown, especially using watershed approaches. Finally, a need for socioeconomic research on how people affect ecosystems was expressed. Other research topics that were identified during this session included monitoring, restoration goals and guidelines, data sharing and communication, outreach and education to improve the public perception of the value of all natural resources, and methods to identify the best return on what is likely to be limited funding.

Integration

Because agencies have different missions, there will be a need to identify and focus on a common ground and vision with respect to climate change. Agency missions should perhaps be aligned around the issue of climate change. There also is a potential for conflict between collaboration and competition for funding. As in other aspects of government work, there is an issue related to the loss of institutional knowledge due to retirement. An effort to capture this institutional memory is required. Policy changes are needed if agencies are transitioning from being reactive to being proactive. More programmatic approaches are needed where specific information is lacking. Participants emphasized the need for an inclusive collaboration that includes Tribes, industry, other private sector entities, and NGOs. NGOs are good at moving policy forward and enacting change, because NGOs have fewer restrictions and can be more fluid.

With respect to LCCs, participants felt that the management teams needed to be representative of the partnerships and address regional climate change issues. A key role for such cooperatives is to provide land managers with information on how important the lands they manage are and how they fit into larger ecosystems. Coordinators and facilitators are key to communication among the collaborators and quality leadership is needed to fully engage partners and break down barriers among groups. It was emphasized that these cooperatives should rely on existing collaborative partnerships rather than creating entirely new structures. The Natural Resources Conservation Service nationwide process for private lands was highlighted as a model partnership for data collection. Data on soils, hydrology, and ecosystem function are collected by contractors who are provided with training. These data can be rolled up into ecoregional assessments while maintaining individual privacy. The evaluation is conducted at the national level by a team of statisticians.

There was some discussion of research needs related to coordination across agencies. It was suggested that demonstration landscapes be established within which agencies could experiment. Research in these demonstration landscapes would be enhanced if scientists had the opportunity to conduct their research across management boundaries. It also was recommended that data from existing reserves serve as a basis for predicting the results of management actions to other landscapes. Other topics discussed included species-at-risk, monitoring, information needs and technology, public outreach and education, and funding. Many of the points raised during the discussion are mentioned elsewhere, but several novel issues were identified in this breakout session related to streamlining the funding process, perhaps through the Cooperative Ecosystems Studies Units. Although added support will not solve every problem, predictability about long-term funding is particularly important.

Aquatic Ecosystems

Breakout sessions on aquatic species and habitat assessment in the Great Basin and Mojave Desert were each attended by about 30 people primarily representing Federal agencies, the State of Nevada, a few universities, and NGOs with approximately 50 percent overlap in attendance between the two sessions. Participants were well-acquainted with the nature of aquatic systems in the Great Basin and Mojave Desert and the various stressors currently acting on these ecosystems. The following is a synopsis of discussion in the two aquatics breakout sessions.

Major Challenges

A major challenge voiced by the participants involves dealing with variability and changing seasonality of weather patterns influenced by climate change. Models indicate that farther south in the Mojave Desert precipitation patterns are likely to become not only drier but more variable with more intense or more frequent drought and floods. Farther north in the Great Basin, precipitation may increase on average but shift from snow to rain. Changes in seasonality of precipitation are projected and this will have differential effects on systems and species. Vegetation communities may shift to higher elevation and latitude, changing water flow and extent and composition of riparian habitats. The human population is a primary driver of change in aquatic systems. Continued population growth in cities and suburbs overlain on non-stationary hydrologic systems is likely to increase demands placed on groundwater resources and degrade small but ecologically important wetlands. Changes in aquatic systems may come about quickly as increasing demand for diminishing water resources concentrates use and impact in these areas. Over the past decade, managers in the Great Basin have watched springs drying while being impacted by increasing numbers of feral equines. Non-native ungulates are correlated with increasing invasive plant species in many Great Basin aquatic habitats, often resulting in altered hydrologic function of these systems.

Public perception was seen by the participants to be both a challenge and an opportunity. Despite an education and outreach effort sustained over several years, in addition to increasing frequency of extreme weather events, the percentage of the American public that believes climate change is real and is related to human activity has declined substantially (for example, Hanson, 2010; Jasanoff, 2010). Communication about changing climate and resulting impacts on resources apparently is a significant challenge. Simply providing information and facts is ineffective at changing public opinion so connections between aquatic ecosystem change and climate need to be reinforced. Water use policy and regulation was briefly discussed by participants. Concern was expressed over the way water policy is set and that it is often use-based as opposed to conservation-based. Water policies are developed on the basis of assumptions about stationarity in hydrologic systems without incorporating adaptations for non-stationarity that are now becoming evident. Finally, a primary management challenge identified by participants was how to allocate insufficient and decreasing staff time and budget resources in an increasingly stressful and challenging management environment.

Research Needs

Jon Sjoberg, Nevada Department of Wildlife, offered an example to place research and management into context. The rock shelf in Devils Hole where the Devils Hole pupfish survives may be one of the smallest critical habitat ecosystems in the World (fig. 8). Yet despite having been studied intensively for nearly 40 years, researchers still do not know how this restrictive system functions. In this situation, waiting for research to provide all the answers could lead to management paralysis. New approaches are required, including adaptive management, to fill the gap between the unknown and full deterministic understanding of climate related changes now impinging upon aquatic ecosystems of the Great Basin and Mojave Desert. The following are research needs and recommendations identified by participants. Recommendations for adaptive management are summarized in the final section.

Hydrologic and Groundwater Basin Characterization.—Baseline characterization and research of hydrologic resources in many groundwater basins in the Desert Southwest is limited or lacking. Even in the absence of adequate baseline data, these basins supply water for existing wells and are being targeted by new water extraction proposals. Although large-scale groundwater extraction has been ongoing for decades, recharge is poorly understood, difficult to estimate, and uncertainties are compounded by changing precipitation patterns. The long-term consequences of aquifer drawdown on surface-water resources under climate change scenarios remain uncertain. Full wetlands inventories combined with improved estimates and locations of recharge need to be combined with groundwater extraction and discharge data into refined, regional-scale groundwater flow models. Such models could be used to forecast the spatial and temporal distribution of available surface water and evaluate the consequences of groundwater extraction and reduced recharge.

Climate Models.—Although global circulation models (GCMs) are central to our understanding of anthropogenic climate change, there is a widely recognized need to reconcile the broad range of variability in the models and their coarse scale of representation with local management practices. Much research is needed on downscaling models, model coupling, and validation, especially as it relates to species and habitat distributions. The relationship between GCMs and regional-scale groundwater flow models is largely unexplored—how will climate change affect hydrology?

Paleoclimate Proxies.—There is a need for long-term datasets to characterize and better constrain the concept of ecological baselines. Speleothems (mineral deposits in caves formed by water), tree rings, packrat middens, lake levels, and other proxies of past climatic conditions can guide conceptual modeling of ecosystems in other climatic regimes and undergoing rapid change.

Figure 8. A shallow submerged shelf in Devils Hole that provides the only habitat for the critically endangered Devils Hole pupfish (*Cyprinodon diabolis*). (Photograph by National Park Service, January 2006).

Ecosystem Function and Ecosystem Drivers.—Fundamental gaps in knowledge and understanding exist about drivers and stressors of even the simplest aquatic systems. Without this understanding, system dynamics can change and managers will not know why (for example, why did the recent rapid population decline of Devils Hole pupfish occur?) How will climate change affect the distribution of plants? How will species invasions be affected? Are species invasions already driving system change, affecting ecosystem resiliency and function? Are there effective methods and strategies for managing invasive species and restoring ecosystem functionality? What connectivity with the surrounding landscape is required for species migrations? How does the spatial and temporal availability of surface water factor into landscape connectivity? What is the net change as species immigrate and emigrate? What are the ecosystem dynamics on the leading and withdrawing edges of migration/invasion?

Inventory and Monitoring.—Basic information and datasets are needed for aquatic systems including land cover, soil, water location and temporal persistence and water rights information. An inventory should begin with a data mining exercise identifying existing spatial and tabular data followed by data syntheses. Such an effort should build on existing work to compile, synthesize and manage data across the Great Basin and Mojave Desert bioregions. Legacy data need to be shared and protected for future use, and efforts should be made in preserving data as systems are updated and workforce turnover occurs. Long-term monitoring and study plots need to be established specifically for indicators of climate change. Monitoring must include partnerships to be long-term and comprehensive. Better data transfer is needed, such as online monitoring databases, to get information to managers and the public. There needs to be better coordination and standardization of aquatic monitoring so that the methods and protocols are comparable across the region. Metadata and data management must be standardized and institutionalized. Metadata must be maintained with originating data. Regular summaries need to be provided to managers and the public summarizing the findings and management implications. Special effort should be placed on the edges of species ranges and environmental tolerances where we are most likely to see early trends.

Fire Regimes.—How climate change will alter fire regimes in the Great Basin and Mojave Desert is an important and largely unanswered question. To what extent will climate change effect woody vegetation, fuel loading, and watershed hydrology? Relationships between human population growth and resource requirements may overwhelm other stressors. Managers need an anthropogenic focus and assistance with triage decisions.

Integration

Recommendations from the aquatics breakout group for addressing climate change generally fall into the categories of public education, communication, and coordination between managers and scientists, and adaptive management. Scientists and land managers in this breakout group felt that the agencies could not simply ignore the disconnection between climate science and public perceptions.

- Communication (education) needs to occur at a local level between communities and agency staff. The climate change topic needs to be reframed, avoiding accumulated political baggage and addressing issues of direct public impact, such as water rights impacts, water use impacts, and recreational impacts. Involving stakeholders in conservation efforts on public lands may be an effective means of communication.
- The value of species and ecosystems in a changing environment must be effectively communicated so the public understands how it relates to their concerns and needs. The value of the environment and aquatic ecosystems must be tied to water quality and availability. The importance of ecosystems and ecosystem services should be included in outreach programs to build support for environmental protection.
- Communication frameworks and tools are needed to share scientific information with the public and to increase public understanding of the unique effects of climate change in desert ecosystems.

The need for effective communication and coordination across agencies, universities, Tribes, NGOs, management, and science partners to address climate change was discussed extensively by participants. A number of existing collaborations and approaches linking scientists and managers were identified, such as the Great Basin Research and Management Partnership, the Great Basin Joint Fire Science Learning Together Project, and the Cooperative Ecosystem Studies Units. Participants felt that it was important that the new DOI-led climate change initiatives build upon existing collaborations as opposed to developing new and competing efforts. The following focal components for collaboration were identified by participants.

- A central framework of communication between the managers and scientists to provide unbiased, peer-reviewed information for setting research and management priorities. Priorities of various agencies and NGOs need to be communicated in order for resources to be effectively pooled. Multiple stakeholder mission statements would help to clarify priorities. Centrally served datasets would facilitate communication.
- Adaptive management is the application of the scientific method to dealing with difficult problems of public resource management. Participants in this aquatics workgroup endorsed the use of adaptive management but believed it to be infrequently and inadequately used.
- Inflexibility in management plans for water resources was thought to hinder rather than help sustain these resources. The management planning process should start with the best available scientific information clearly and transparently communicated to both the managers and the public. Communication is a key in the beginning so that all stakeholders are aware of research findings, available data, data needs, and management issues. A process for updates should be built into plans including budgetary and regulatory constraints. Steps for keeping plans current and including new research findings should be included along with employee performance standards to provide for flexibility given new information and changing conditions. The planning and management process is important for maintaining flexibility to update and adapt water resource management plans.
- Monitoring is an essential component of adaptive management that is missing from many of the aquatic resource management actions in the Great Basin and Mojave Desert. Monitoring needs to be implemented in a standard way to enable comparisons across organizations and ecosystems. Monitoring should include, and in some cases focus on, physical functioning and systems management—not just specific species or components. Monitoring needs to be tied to periodic reviews of management plans and communicated to stakeholders consistently.

- It was clear to the group that scientific information on desert groundwater and aquatic systems will always be incomplete. Although more research is needed, managers also need to act in the absence of complete knowledge. Managers and policy makers need to make decisions and implement management actions in the framework of adaptive management, using the outcomes and monitoring as input to adaptation. Politics and public input may help with setting priorities but managers need to focus on scientific data for adapting to climate change.
- Adaptive management on a large scale has been implemented in the Glen Canyon Dam Adaptive Management Program. Great Basin and Mojave Desert managers can learn from the successes and failures of this and other existing plans. Designs should be scalable as, for example, the Incident Command System, so that adaptive management programs can be applied to climate change-related resource management issues appropriate to the size of the problem and various constraints.
- Adaptive management may be made more effective through partnerships. Strengthening partnerships with academia will help to improve the interdisciplinary scientific bases for adapting management actions. Public-private partnerships are indispensable as some of the most important aquatic ecosystems occur on private lands.

Conclusions

Managers of public lands and natural resources in the Great Basin and Mojave Desert foresee significant challenges ahead in coping with the consequences of a changing climate. Modified hydrologic conditions in the Colorado River basin, for example, will compound adverse ecosystem impacts through complex interactions between decreasing water supplies and increasing urban populations. Adaptation, both proactive and reactive, was a term frequently used to characterize approaches to managing the effects of climate change on the terrestrial and aquatic ecosystems of this arid ecoregion. The formal methods of Adaptive Management are widely perceived to be applicable but underutilized. An essential component often missing in practice is monitoring to assess the effectiveness of management actions. Adaptive Management and ecosystem monitoring require data maintenance and access, both of which are areas with much room for improvement. Strategic planning is necessary to coordinate agency actions across boundaries at a landscape scale. Many obstacles to effective management at the bureaucratic level are exemplified by conflicting missions, conflicting policy mandates, and asynchronous budget cycles. Sufficient funding is a prerequisite to effective management, but constraints on the way funding can be used are often more restrictive than the total available budget. Substantial improvements in management efficiency are possible by modifying the way public funds can be used by land management agencies, for example, by facilitating the partnerships that are essential for ecosystem-scale management of public lands. Strategic restructuring of agency goals should include incentives for collaboration at both the individual employee and agency levels.

Although many workshop participants identified a need for coordinated funding and cooperation among agencies and partners, others pointed out that existing collaborative mechanisms are underutilized and that better communication between managers and scientists in identifying research needs and management issues was needed. Improved information and data sharing was perhaps the most common recommendation for facilitating communication. Several partnerships and data sharing websites, summarized in "Collaborations and Partnerships," were mentioned in presentations as excellent examples of communication. Working together in cooperative partnerships, sharing data and research results, and communicating lessons learned in both successes and failures will not alone be sufficient to meet the challenges posed by global climate change, but these are essential components of any successful approach.

This workshop revealed areas where much is known about the impact of climate change but also highlighted important information needs. Based on repeated comments from land managers, an assessment of information needs and research priorities should begin with an inventory of basic datasets such as species distributions and current ecological conditions. New research projects should be designed in consultation with managers and be oriented ultimately towards providing decision support tools. Absence of information, however, is not an excuse for inaction but rather should motivate natural resource professionals, scientists, and the public to collaborate and implement Adaptive Management so that we learn from our efforts. The participants of the workshop repeatedly called for political and agency obstacles to be removed so that collaborations and partnerships can address climate change at an ecosystem scale. Future directions must involve collaboration among scientists, managers, partners, community stakeholders, and the public for applying scientific knowledge to the management of public lands. Collaboration is an equal and shared responsibility, with managers helping scientists to identify the highest priority research questions, scientists conducting research to assist managers with problem solving, and both working closely to communicate with the public.

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Glossary

Adaptation Actions by individuals or systems to avoid, withstand, or take advantage of current and projected climate changes and impacts. Adaptation decreases a system's vulnerability, or increases its resilience to impacts (Pew Center on Global Climate Change, 2009).

Adaptive Management Adaptive Management is a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals; increases scientific knowledge; and reduces tensions among stakeholders (Williams and others, 2009)

Ecological threshold The point at which an ecosystem does not return to its original state via natural processes following disturbance but instead transitions to a new alternative state.

Engaged scholarship Empirical research conducted in partnership with public and private stakeholders, with the goal of addressing critical social issues and contributing to the public good. Often, community partners are included in the research process, either as informants, in collecting data, in analyzing the data, or all of the above (UCLA Center for Community Partnerships, 2008).

Mitigation Any action taken to permanently eliminate or reduce the long-term risk and hazards of climate change.

Resilience The ability of ecosystems to absorb recurrent disturbances while retaining essential structures, processes, and feedbacks (Sugden, 2001; Craig, 2009).

Restoration The act of returning a disturbed area, ecosystem, or natural process to a former, original, normal, or unimpaired condition.

Stationarity A random or stochastic process is said to be stationary if its statistical properties, (for example, mean, variance, and autocorrelation) do not change in time or space.

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