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Priority Research and Management Issues for the Imperiled Great Basin of the Western United States

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Abstract

Like many arid and semiarid regions, the Great Basin of the western United States is undergoing major ecological, social, and economic changes that are having widespread detrimental effects on the structure, composition, and function of native ecosystems. The causes of change are highly interactive and include urban, suburban, and exurban growth, past and present land uses, climate change, altered fire regimes, and rapid expansion of invasive species. Cumulative effects include vegetation type conversions, loss of watershed functioning, loss of native species, and diminished economic potential. The diversity and magnitude of issues require consensus on priority issues, and new and innovative research and management approaches that address larger spatial scales and longer time scales than in the past. Primary research coupled with large-scale assessments and effective monitoring strategies is needed to understand and track the ongoing changes. Prediction and modeling of alternative futures are needed for incorporation into the planning process and use as a basis for adaptive management, and management tools are needed to aid decision-making and implementation. Historically, research and management in arid and semiarid regions such as the Great Basin have been severely under-funded and altering current trajectories will require financial resources, political support, and effective policies and institutional mechanisms. Sustaining the ecosystems, resources, and human populations of these regions will require strong collaborative partnerships among research and management organizations to reduce overlap, leverage funds, and increase efficiency. Close involvement of all stakeholders is needed to obtain the needed support for making necessary changes in policies and management activities.

Key words: altered fire regimes, human population growth, invasive species, land degradation, research and management strategies, semiarid regions.

Introduction

One third of the continental areas on Earth are arid and semiarid, and many of these regions are undergoing rapid ecological and sociological changes (Verstraete & Schwartz 1991; White & Nackoney 2003). The Great Basin of the western United States faces issues similar to other arid and semiarid regions, and is considered one of the most endangered ecoregions in the United States (Center for Science, Economics and Environment 2002; Wisdom et al. 2005). Major drivers of the changes in arid and semiarid regions are diverse and highly synergistic (Millennium Ecosystem Assessment 2005). In the Great Basin, these drivers include urban, suburban, and exurban growth, past and present land uses, climate change, altered fire regimes, and rapid expansion of nonnative invasive species (Wisdom et al. 2005; Chambers et al. 2007*a*). Cumulative effects include vegetation conversions, loss of watershed functioning, loss of native species, and loss of economic potential. Managers in the Great Basin and other arid and semiarid regions are increasingly challenged to maintain or improve ecosystem function while meeting the needs of growing human populations. Sustaining the ecosystems, resources, and human populations of arid and semiarid regions requires innovative approaches that address social, economic, and ecological issues. Although progress has been made in understanding arid and semiarid ecosystems and in developing effective management techniques, significant gaps remain in knowledge and management capacity to effect positive changes on the landscape. The diversity and magnitude of issues facing these regions call for strong collaborative partnerships among research and management organizations and other stakeholders. Improved scientific methods and institutional mechanisms are needed for prioritizing issues and addressing larger spatial and longer temporal scales than in the past.

We present the Great Basin as an illustration of the rate and magnitude of change that can occur in arid and semiarid regions, and of the types of scientific information and collaborative activities that are needed to sustain these regions. We first provide an overview of critical research

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and management issues facing the Great Basin. We then address types of scientific information needed for effective management. We conclude with a discussion of the types of activities required for more effective planning and larger-scale collaboration among research and management organizations and other stakeholders. The science information needs and required collaboration that we present are broadly applicable to other arid and semiarid regions.

Great Basin Description

The Great Basin is a vast, arid to semiarid region characterized by large expanses of salt desert, sagebrush (*Artemisia tridentata*) and pinyon-juniper (*Pinus monophylla*, *Juniperus osteosperma*, and *J. occidentalis*) ecosystems. The basin and range topography of the region results in strong gradients in both temperature and effective precipitation that determine the distribution of individual species and vegetation communities. For our purposes, we focus on the Great Basin as defined by similar climatic and floristic relationships, an area that includes most of Nevada and parts of California, Oregon, Idaho, and Utah (Fig. 1). Most land (about 72%) is under federal management with the U.S. Bureau of Land Management (BLM) (54%) and U.S.D.A. Forest Service (14%) being major landholders. Private land owners hold 22% of the area, and the remainder is managed by states, tribes, and local entities (6%). Much of the information presented here is based on literature review and has been synthesized from a more detailed technical report, "Collaborative Research in the Great Basin—Examining the Issues and Developing a Framework for Action" (Chambers et al. 2007*a*).

Great Basin Research and Management Issues

Urban, Suburban, and Exurban Growth

The human populations of arid and semiarid regions are growing worldwide (Millennium Ecosystem Assessment 2005). The population of the Great Basin is growing at one of the highest rates in the United States. In 1990, the population of the Great Basin was 2.9 million, and 9.1 million hectares of the region was uninhabited (U.S. Census Bureau 2007). The population had grown to 4.9 million by 2004 with fewer than 1.2 million hectares uninhabited. Most individuals live in urban areas (populations greater than 50,000) located at the base of watersheds on the periphery of the region (Geolytics, Inc. 2007).

The expanding human population is increasing pressure on Great Basin infrastructure and ecosystems and influencing management priorities and policies at local and regional scales. Urban, suburban, and exurban development increased by 43% from 1973 to 2000, with exurban development increasing at the highest rate (Soulard 2006). Fire prevention and wildlife–human interactions at the urban-wildland interface are increasingly problematic, and recreational pressure adjacent to cities is accelerating. Management activities are increasingly focused on urban-wildland issues, and public involvement in land management decisions is rapidly increasing (Wilmot & Brunson 2007).

As human populations grow, the region's limited water resources are being converted from agricultural to urban use, and groundwater sources are being used more extensively. Since the mid-1980s, water withdrawals for urban and suburban use have increased from 8 to 20% of all withdrawals in

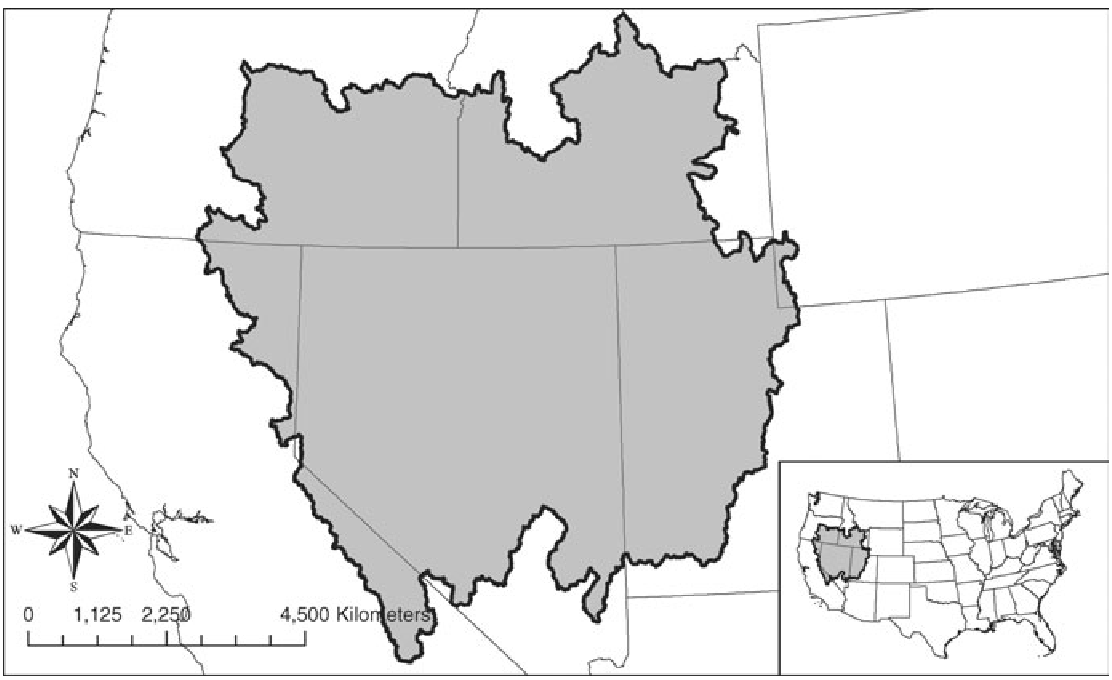

Figure 1. The floristic Great Basin of the Western United States.

the state of Nevada, and urban centers are increasingly acquiring water from distant, rural areas (U.S. Geological Survey 1999). For example, local officials in the city of Las Vegas, Nevada, and adjacent communities currently are seeking rights to a regional groundwater aquifer extending from Salt Lake City, Utah to Death Valley, California (Deacon et al. 2007). If granted, these new permits would trigger groundwater declines across about 78 basins covering 130,000 square kilometers. Such declines would negatively affect threatened, sensitive, and endangered species and thousands of rural, domestic and agricultural water users.

Land Use Change

Before settlement of the region in the mid-1800s by Anglo Americans, the Great Basin was sparsely inhabited by Native Americans who were hunter-gatherers. Since Anglo American settlement, Great Basin ecosystems have been intensively used by humans. The most common land uses include agriculture, livestock grazing, mining, energy production, urban, suburban and exurban developments, recreation, and roads (Wisdom et al. 2005). The land area devoted to agriculture has remained constant in recent decades at about 3% (U.S. Department of Agriculture 2008). Livestock grazing has been a major land use since settlement of the region, with 69% and 81% of BLM lands in Nevada and California, respectively, in grazing allotments (Torregrosa & Devoe 2007). Mining and energy exploration, development, and production are expanding rapidly because of growing demands for mineral production; the U.S. Energy Policy Act of 2005 encourages increased energy production and energy infrastructure through subsidies, tax exemptions, and other benefits (Torregrosa & Devoe 2007). The growing human population and changes in land use are resulting in a continually expanding network of roads and more motorized recreation on public land (Torregrosa & Devoe 2007). In combination, these land uses disturb extensive tracts of land, resulting in nonnative species invasions, conversion of vegetation types, fragmentation or loss of species' habitats, wildlife mortality, stream channel alteration, and declines in water quality (Weller et al. 2002; Forman et al. 2003).

Climate Change

Arid and semiarid regions are highly sensitive to climate change (Agnew & Warren 1996). The predicted changes in climate are likely to have the single greatest impact on the ecosystems and human populations of arid and semiarid regions in coming decades. In the last 100 years, the Great Basin warmed by 0.3–0.6°C and is projected to warm an additional 2–5°C by 2100 (Smith et al. 2006). Precipitation increased 6–16% in the last 50 years resulting in slightly greater stream flows (Baldwin et al. 2003). However, snowpack declined and the decreases in the Great Basin snowpack are among the greatest in the United States (Mote et al. 2005). Both the onset of spring growth and timing of snowmelt-driven streamflow are about 10–15 days earlier than 50 years ago (Stewart et al. 2004). Projected changes in precipitation in the western United States are inconsistent and vary depending on location, but average changes are near zero (Smith et al. 2006). Any increases in precipitation may be offset by higher evapotranspiration and longer growing seasons caused by increases in temperature (Seagar et al. 2007). Climatic variability and, consequently, frequency of both droughts and floods are predicted to increase.

Changes in climate will influence water resources and may cause major changes in aquatic and terrestrial ecosystems. A continuation of existing trends will result in increased winter floods in some basins, smaller warm-season reserves and rates of runoff, and warmer water temperatures in many rivers and lakes (Baldwin et al. 2003). In summer, lower flows coupled with higher variability may negatively affect water uses such as hydropower, irrigation, fisheries, and recreation. In winter, hydropower production could increase to take advantage of increased winter streamflow. Areas with increasing dryness will exhibit a decrease in groundwater recharge and longevity of groundwater resources. Changes in flow regimes will result in management challenges related to water storage, channel maintenance, floods and droughts, pollutants, and maintenance of native species.

Changes in climate in combination with increases in carbon dioxide (CO_2) will affect both agronomic and native ecosystems. Productivity of both crops and native species may be greater with higher CO_2 and longer growing seasons before temperatures substantially increase, but only if there is sufficient water (Smith et al. 2006). Some invasive plant and animal species and pathogens will have similar advantages. Low-value irrigation crops may have difficulty competing for less abundant irrigation water. As temperatures increase, species distributions are likely to shift. Inhabitants of high elevation zones likely will experience shrinking habitat area, and local extinctions will probably increase among mammalian, avian, and butterfly species (Murphy & Weiss 1992). The net effect is likely to produce significant changes in the structure and species composition of native ecosystems.

Altered Fire Regimes and Invasive Species

As in much of the western United States, dramatic shifts in fire frequency, severity, and size occurred throughout the Great Basin in recent decades (Keane et al. 2002). In low to mid-elevation shrublands, an increase in invasive annuals, especially cheatgrass (*Bromus tectorum*), resulted in major increases in fire occurrences and fire size. An annual grass-fire cycle now exists in which fire return intervals have decreased from 60–110 years to 3–5 years (Whisenant 1990; Brooks & Pyke 2001). Concurrent expansion of native pinyon and juniper species into mid-to-high elevation shrublands has decreased fire occurrences and increased fuel loads and fire severity (Miller et al. 2005). As trees mature and the canopy closes, sagebrush and its associated species are progressively eliminated from the understory (Miller et al. 2005). Low residual abundance of shrubs and herbaceous perennials, coupled with depleted seed banks because of either cheatgrass or tree dominance, alter successional dynamics following fire. In forested ecosystems, a decrease in fire frequency due largely to fire exclusion has resulted in a shift in species composition from early-seral, shade intolerant species to late-seral, shade tolerant species. Increases in vertical stand structure (fuel ladders) and biomass (fuel loads) are resulting in larger and more severe fires (Keane et al. 2002).

The shifts in fire frequency, severity, and size are likely to continue, owing to the legacy effects of past land use and management practices such as grazing by domestic livestock and fire exclusion. Climate change and warmer temperatures during recent decades have resulted in longer fire seasons, and a drying trend may be contributing to more frequent periods of extreme fire weather and increases in total area burned (Westerling et al. 2006). The net effect is an increased risk to human life and property and high fire management costs.

Cumulative Effects of Change

Vegetation Type Conversions

Past and present land uses, climate change, invasion of nonnative species, and altered fire regimes are influencing the region's ecosystems and resulting in large-scale vegetation type conversions. Sagebrush ecosystems have been identified as one of the most endangered ecosystem types in the United States (Center for Science, Economics and Environment 2002). In salt desert shrub, Wyoming sagebrush, and lower-elevation mountain big sagebrush vegetation (*Artemisia tridentata* ssp. *wyomingensis and vaseyana*) types, the annual grass-fire cycle is resulting in progressive conversion of native shrublands to homogenous grasslands dominated by nonnative invasive species (Brooks & Pyke 2001). Cheatgrass monocultures covered a minimum of 2 million hectares or 5% of the Great Basin in the 1990s (Bradley & Mustard 2005), and an additional 15 million hectares are estimated to be at high risk of invasion within the next 30 years (Suring et al. 2005). Annual grasses have recently invaded lower-elevation salt desert shrublands, and these ecosystems are burning for the first time in known history (Brooks & Pyke 2001). Nonnative forbs (e.g., knapweeds and yellow star thistle; *Centaurea* species) are spreading throughout the region, with unknown consequences for native ecosystems and fire regimes.

Ongoing expansion of pinyon and juniper trees is resulting in widespread loss of mid to upper elevation sagebrush communities. Since settlement, the area occupied by trees has increased 150–625% and stand densities have increased 10- to 100-fold depending on location (Miller et al. 2008). About half of the sagebrush communities undergoing tree expansion are projected to become relatively homogenous woodlands with sparse understories by mid-century (Miller et al. 2008). Similarly, fire exclusion in woodlands that historically experienced higher fire frequencies is resulting in increased landscape homogeneity and decreased patch diversity. Vegetation types that depend on more frequent and lower severity fires are decreasing in abundance as are associated plant and animal species (Keane et al. 2002). Aspen (*Populus tremuloides*) is declining in many mixed-conifer forests placing bird and animal species dependent on this species at risk (Keane et al. 2002). In the absence of wildfires or management treatments, the increase in fuel loads and change in stand structure will alter fire behavior, resulting in fewer moderate fires and more high intensity fires. Without active restoration after fire, many areas will be susceptible to conversion to cheatgrass and other invasive species (Chambers et al. 2007*b*).

Loss of Watershed Functioning

In many arid and semiarid areas, watershed functioning has been lost because of changes in erosion and sedimentation, biogeochemical cycling, and thermal regimes (albedo, etc.) (Millennium Ecosystem Assessment 2005). High levels of grazing by livestock, mining, energy development, and roads typically produce well-documented increases in erosion and sedimentation in uplands (National Research Council 2001). In the Great Basin, progressive conversion of the region's shrublands to invasive annual grasses or forbs also may affect watershed functioning through loss of soil nutrients, increased runoff and sediment production, siltation of streams and rivers, and increased susceptibility to flooding (Knapp 1996). Conversion to cheatgrass and other annual grasses can change biogeochemical cycling (Sperry et al. 2006) and transform the region's shrublands from carbon sinks to carbon sources (Bradley et al. 2006). A change in land cover from diverse shrublands to homogenous grasslands also can influence the region's albedo, influencing evapotranspiration across large areas and, in turn, moisture transfer, convective activity, and rainfall (Millennium Ecosystem Assessment 2005). The net effect likely will be an increase in aridity of the region.

Land use changes within watersheds coupled with water diversions, water extraction, and point and nonpoint source pollutants have altered stream flows and water quality, resulting in degradation of wetlands and riparian and aquatic ecosystems (National Research Council 2001). Portions of all Great Basin Rivers have been impounded for flood control and agricultural and municipal uses. The low-head dams that are typically constructed function as barriers to flow and reduce river connectivity (National Watersheds 2007). Regulation of stream flows has diverse effects that often include a decrease in the magnitude and frequency of downstream floods and changes in sediment loads and channel characteristics (National Research Council 2001). Water quality has been significantly affected by impoundment as well as pollution from agriculture and other sources (National Watersheds 2007).

Altered flow and groundwater regimes have decreased the areal extent of riparian areas, wetlands, and springs, and caused changes in species composition. Highly invasive perennial herbaceous species such as perennial pepperweed (*Lepidium latifolium*), and exotic shrubs and trees from Eurasia such as saltcedar (*Tamarix* spp.) are invading wetland and riparian areas, displacing native plant communities and altering stream processes (National Research Council 2001). Nonnative fish taxa and several invertebrate species introduced into the region by public or fishery management agencies are common in aquatic ecosystems (Sada & Vinyard 2002). These changes are negatively affecting trophic dynamics and energy flow of aquatic systems.

Loss of Native Species

The Great Basin has a high proportion of endemic species because of its geography (basins and ranges) and climatic history. Ecosystem degradation and climate change pose serious threats to many of these species. Populations of many sagebrush-associated species are in decline, and approximately 20% of the ecosystem's native flora and fauna are considered imperiled (Center for Science, Economics and Environment 2002). A recent risk assessment indicated that sagebrush that dominated land-cover types in the Great Basin have 207 species of concern—133 plants, 11 reptiles and amphibians, and 63 birds and mammals (Rowland et al. 2005).

Streams, springs and their associated riparian, and wetland ecosystems provide critical water sources and habitat in this semiarid region, and a high percentage of species are strongly associated with these areas. Land-cover modifications coupled with introduction of nonnative taxa have caused extinction of 16 endemic species, subspecies, or other distinctive populations (12 fishes, three mollusks, and one aquatic insect) since the late 1800s (Sada & Vinyard 2002). These modifications also affected bird migration routes, as the relatively rare wetland complexes and seasonal playas of the region represent critical resources for migrating birds (particularly shorebirds and waterfowl). Federal, state, and private land managers are increasingly concerned about the fate of Great Basin ecosystems and their associated species and are actively seeking approaches to restore and maintain them.

Science Information Needs

Many of the science information needs in the Great Basin parallel those in other arid and semiarid regions, especially those influenced by invasive annual grasses and altered fire regimes. Synthetic scientific information is needed to address research and management issues in the Great Basin (Table 1). The diversity and magnitude of issues currently facing these regions require consensus on priority issues, and new and innovative research and management approaches that cross administrative boundaries and address larger spatial scales and longer time scales than in the past. Overarching research and management areas are discussed below.

Science-Based Information and Large-Scale Monitoring

Historically, research and management activities in the Great Basin and many other arid and semiarid regions have lacked political commitment and been severely under-funded (Agnew & Warren 1996). For example, resource assessments for the Great Basin, including soil surveys, are among the sparsest in the United States. Basic scientific information is needed on the interacting effects of ecosystem drivers including urbanization, other changes in land use, climate change and fire and invasive species on vegetation type conversion, watershed function, and species richness. To complement this information, large-scale assessments are needed of the resource base and current ecological conditions, and effective monitoring schemes are needed to track changes occurring on the landscape and evaluate responses to management interventions. Data on the geographical areas most heavily affected by the ongoing changes, ecosystems most susceptible to different types of disturbances, and ecosystems with the greatest resistance and resilience to change are necessary to establish both management priorities and strategies.

Prediction and Modeling

Effective management requires the ability to accurately predict change, incorporate those predictions into the planning process as management alternatives, and use adaptive management strategies based on outcomes. Thus, prediction and modeling are critical for understanding rates and magnitude of change, areas affected, and consequences for the future. In the Great Basin, large-scale prediction and modeling efforts have focused primarily on areas of core habitat for species under consideration for listing under the U.S. Endangered Species Act and on major threats to the habitat of those species such as the cheatgrass-fire cycle (Wisdom et al. 2002, 2005; Meinke et al. 2009) and groundwater withdrawal (Deacon et al. 2007). These types of efforts need to be expanded to use a more holistic approach that addresses the interacting effects of urbanization, land use change, and climate change.

Management Tools

New and innovative management tools for planning, decision-making, and implementation are needed to address ongoing and predicted changes in arid and semiarid regions. Required planning tools include standardized spatial coverages of the resource base at management scales that cross administrative boundaries. In addition, decision support systems are needed, which provide likely outcomes to different management scenarios and assist in project planning and implementation. For example, decision support systems specific to the Great Basin are needed for evaluating fuels and fire behavior, for determining appropriate restoration approaches following wildfire and other land perturbations, and for establishing and implementing effective fuels treatments. Finally, science-based approaches and methods are needed for implementing land and water management actions (Chambers et al. 2007*a*).

Planning and Collaboration Needs

Policy Issues

Effective research and management require financial resources and political support as well as effective policies and institutional mechanisms. In the Great Basin, awareness of critical

Table 1. Summary of science information needed to address research and management issues in the Great Basin and similar arid and semiarid regions. Information sources include meetings on regional issues, agency planning documents, current literature, and the Web.

Urbanization and changing land use

- Current extent of urban, suburban, and exurban development, rates of change and trends for the future, and current and future effects on ecosystems and water resources
- Current status, rates of change, and future trends for major economic sectors
- Current and projected relationships among major economic sectors, ecosystems, and water resources
- Extent of roads and off-road trails, and effects of roads, off-road trails, and vehicular use on ecosystems and watersheds
- Relationships among future demographic trends, economic and land use trends, and environmental sustainability

Climate change

- Effects of climate change on land use and ecosystem function, and the capacity of landscapes to support communities and economies
- Effects of changes in the capacity of landscapes to supply ecosystem services and societal willingness to support active restoration and management
- Effects of changes in climate and climate variability (duration of droughts, frequency, and magnitude of extreme events) on water resources, water management, and aquatic and riparian ecosystems
- Effects of changes in climate and climate variability on the frequency, severity, and extent of wildfire
- Relationships among elevation, climate change, and range expansion or contraction of native species including sensitive plant and animal species
- Effects of changes in climate and climate variability on invasion of nonnative species
- Effects of changes in climate and climate variability on infectious disease and insect outbreaks

Altered fire regimes

- Past and present fuel loads and fire regimes of the dominant ecosystems, current rates of change, and predictions for the future
- Effects of altered fire regimes on vegetation communities, watershed function, and native species
- Disturbance regime (wildfire or fuels management treatments) required to reinstate a landscape-mosaic in areas currently dominated by woody species that will maintain watershed functioning and native species
- Abiotic and biotic thresholds beyond which ecosystems will not recover from wildfires and fuels treatments without active restoration
- Relationships among fuel loads, fire management, and biogeochemistry including carbon budgets
- Effectiveness of fuels reduction and restoration treatments in different vegetation types and under varying climatic conditions
- Effectiveness of postfire treatments and management actions for restoring and maintaining ecosystems

Nonnative invasive species

- Current status of invasions of nonnative species, rates of change, and predictions for the future
- Effects of land use change and management activities including livestock grazing and fire management on invasion rates
- Ecosystems at greatest risk of invasion and ecosystem properties and processes that affect resistance to invasion
- Attributes of invasive species that increase the probability of successful colonization and establishment
- Effects of invasive species on vegetation communities, watershed functioning, and native species
- Effects of invasive species with different life forms (annual grasses, forbs, and woody species) on fire regimes
- Integrated methods for controlling priority invasive species that address the appropriate scales and stages of invasion
- Methods for reestablishing native species while controlling invasive species
- Effects of efforts to control invasive species on native plant communities and species

issues needs to be increased by developing the linkages between local natural resources and associated national interests. Policies and institutional mechanisms need to be developed for improving the use of science-based information in land and water use decisions, and ensuring that planning and land management decisions affect positive changes on the landscape (Torregrosa & Devoe 2007). Existing networks of stakeholders (agencies, academia, community groups, special interest groups) need to be expanded and viable mechanisms need to be determined for educating and engaging stakeholders in land use decision-making that results in sustainable ecosystems.

Research and Management Collaboration

Sustaining the ecosystems, resources, and human populations of the Great Basin and other arid and semiarid regions requires strong collaborative partnerships among research and management organizations (Chambers et al. 2007*a*). Close involvement and improved communication with the public and other stakeholders can increase acceptability of management decisions and actions. In the Great Basin, current collaborative efforts, and information sharing both among existing organizations and with stakeholders, often are limited in scope. Effective research and management collaboration and information sharing among all organizations and stakeholders require a transparent organizational structure and include several elements such as follows: (1) a mechanism for obtaining consensus on priority issues; (2) science working groups that develop syntheses of priority issues, identify information gaps and collect needed information, and develop science-based recommendations for management actions; (3) technical working groups that develop research and management experiments that are used to evaluate science-based recommendations at larger, management scales and serve as the basis for adaptive management; (4) a mechanism to monitor and communicate results to citizens, managers, and policy makers; and (5) comprehensive funding mechanisms to support all elements of the collaboration between research and management, and among all local, state, federal, private, and tribal partners and stakeholders. A logical mechanism for increasing communication includes a Web-based clearinghouse with the following components: (1) searchable databases of existing research and management organizations and collaborative programs, and individuals with relevant scientific or technical expertise; (2) research catalog of projects being conducted in the region, that is, who is doing what and where; (3) bibliography of literature applicable to regional issues; (4) metadata server for sharing information on regional projects; (5) links to upcoming meetings and workshops; and (6) listserve to facilitate communication and chat rooms for working groups.

Increased collaboration and communication among the region's researchers, managers, and stakeholders can ensure that accurate and reliable information is available to resource managers and to decision makers and that management decisions are acceptable to the public. Effective collaboration also can facilitate the best use of funds should they become available.

Implications for Practice

Great Basin ecosystems are changing rapidly, over vast areas, and in undesirable ways. These large-scale changes appear difficult or impossible to halt or mitigate with current knowledge and limited human and financial resources. Holistic approaches, sufficiently funded to address critical research and management issues, are needed to achieve positive changes in ecological conditions and ecosystem functions.

- Larger scale and more comprehensive analyses of these ecosystems are needed, including changes occurring and their future implications, as the basis for research activities and management actions.
- Prioritization of restoration and management activities needs to be based on an understanding of both the causes of the changes and potential for recovery based on the inherent resistance and resilience of ecosystems to current and future disturbance.
- A closer alliance between research and management is needed to effect positive change on the landscape. This can occur through regional working groups that identify critical issues, develop viable approaches for addressing these issues, and conduct "restoration experiments" at management scales that serve as the basis for adaptive management.
- A strong focus on effective collaboration and increased communication among research and management organization and the region's stakeholders is necessary to gain public and political support for adaptive management and ecosystem sustainability. Continuing the current piecemeal approach to research and management, with low levels of funding, will ensure that ongoing, undesired trends will progress largely unabated.

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