The Southern Nevada Agency Partnership Science and Research Synthesis:

Science to Support Land Management in Southern Nevada

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Rocky Mountain Research Station

General Technical Report RMRS-GTR-303

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Abstract

This synthesis provides information related to the Southern Nevada Agency Partnership (SNAP) Science and Research Strategy Goal 1 – to restore, sustain and enhance southern Nevada's ecosystems – and Goal 2 – to provide for responsible use of southern Nevada's lands in a manner that preserves heritage resources and promotes an understanding of human interaction with the landscape. The Science and Research Strategy has nine Sub-goals that address the topics of water and water use, fire, invasive species, biological diversity, restoration, cultural resources, historic content, recreation, and science-based management. This synthesis summarizes the state-of-knowledge related to each of these Sub-goals, addresses knowledge gaps, and provides management implications. It builds on previous efforts to develop the necessary scientific understanding for adaptive management of southern Nevada ecosystems.

Keywords: Mojave, Great Basin, anthropogenic disturbance, climate change, invasive species, altered fire regimes, water resources, species of conservation concern, restoration, heritage resources, recreation, ecosystem resilience, science-based management

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Chapter 1

An Overview of the Southern Nevada Agency Partnership Science and Research Synthesis

Jeanne C. Chambers, Matthew L. Brooks, Kent Turner, Carol B. Raish, and Steven M. Ostoja

Management Challenge

Southern Nevada is characterized by an arid to semi-arid environment with numerous cultural resources and a high level of biological diversity. Since 1980, the human population of the region has increased at unprecedented rates largely due to the expansion of suburban areas (Hughson 2009). The various human activities associated with this growth and the interactions of those activities with the generally dry and highly variable climate result in numerous stresses to ecosystems, species, and cultural resources. In addition, climate models predict that the rate of temperature increase and, thus, changes in ecological processes, will be highest for ecosystems with low topographic variability including deserts like the Mojave (Loarie and others 2009). These stresses vary in scale and can be characterized as global (e.g., large scale climatic processes and fluctuations), regional (e.g., atmospheric pollution sources from the southwest), and local (e.g., land use practices) (Fenstermaker and others 2009; Chapter 2). Although global and regional stresses have long-term and lasting effects, local stresses are often the most apparent. Human development in the region is increasing the number of roads and utility corridors, resulting in dust generation and desert trash, and causing an expansion of recreational activities. Past and present grazing by livestock, wild horses, and burros is having widespread effects on native vegetation. The spread of invasive non-native plants is altering fire regimes and causing the conversion of native ecosystems to invasive plant dominance. Groundwater pumping and water diversions coupled with invasive aquatic organisms are degrading many of the region's spring, stream, and riparian ecosystems. The cumulative effects of these stresses are placing the region's cultural and biological resources at risk, and causing the loss of habitat for the region's native plant and animal species. There are multiple species of concern in the region, 17 of which are already listed as threatened. Maintaining and restoring the complex variety of ecosystems and resources that occur in southern Nevada in the face of such rapid socio-economic and ecological change presents numerous challenges to Federal land managers.

Southern Nevada Agency Partnership

In 1999, the Southern Nevada Agency Partnership (SNAP) was established to enhance cooperative management among the Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, and USDA Forest Service. SNAP agencies work with each other, the local community, and other partners to address common issues pertaining to public lands in southern Nevada (http://www.SNAP.gov). The vision of

SNAP is public lands and resources management in southern Nevada that provides for sustainable ecosystem goods and services for both present and future generations. SNAP agencies develop interagency programs and projects to enhance services to the public, improve stewardship of public lands, and increase the efficiency and effectiveness of their management activities.

SNAP agencies manage more than seven million acres of public lands in southern Nevada (95 percent of the land in southern Nevada). Federal land includes two national recreation areas, two national conservation areas, four national wildlife refuges, 18 congressionally designated wilderness areas, five wilderness study areas, and 22 areas of critical environmental concern. The partnership's activities are mainly centered in southern Nevada's Clark County (fig. 1.1). However, SNAP partner agencies also manage portions of the Lake Mead National Recreation Area in Mohave County, Arizona, U.S. Fish and Wildlife Service and USDA Forest Service-managed lands in Lincoln and Nye Counties, Nevada, and all lands and activities managed by the Southern Nevada District Office of the Bureau of Land Management. These lands encompass nine distinct ecosystem types (fig. 1.2; table 1.1), support multiple species of management concern and 17 listed species (table 1.2), and are rich in cultural and historic resources.

Science and Research Strategy

The SNAP managers share an interest in development of an interagency science program that is consistent across agency boundaries and that serves to inform management decisions regarding natural resources, cultural resources, and human use of public lands. To meet that objective, the SNAP managers established a science and research team that was charged with development of an interagency science program. The science and research team published the SNAP Science and Research Strategy (Strategy) in 2009 (Turner and others 2009). The Strategy's overall goal is to integrate and coordinate scientific research programs in southern Nevada and to improve the efficiency and effectiveness of these programs. The Strategy is intended to inform and guide SNAP agencies in identifying and articulating the highest priority science and research needs, sharing resources and funds to implement research addressing those needs, communicating research needs to potential research partners, and eliminating redundancy between agency research programs.

Key components of the Strategy are a periodic SNAP science needs assessment and a SNAP Science and Research Synthesis Report (Synthesis Report). The purpose of the needs assessment is to communicate SNAP's immediate science and research needs to the broader scientific research community and to potential research partners. The needs assessment is prepared by the SNAP science and research team based on input from agency managers, resource staff, and scientists and documents high priority regional and management needs. The Synthesis Report summarizes the state of knowledge and key science findings related to the SNAP Science and Research Strategy Goals, identifies knowledge gaps, and provides management implications. It is prepared every 5 years and is used to guide the periodic SNAP science needs assessments. This General Technical Report (GTR) constitutes the first Synthesis Report.

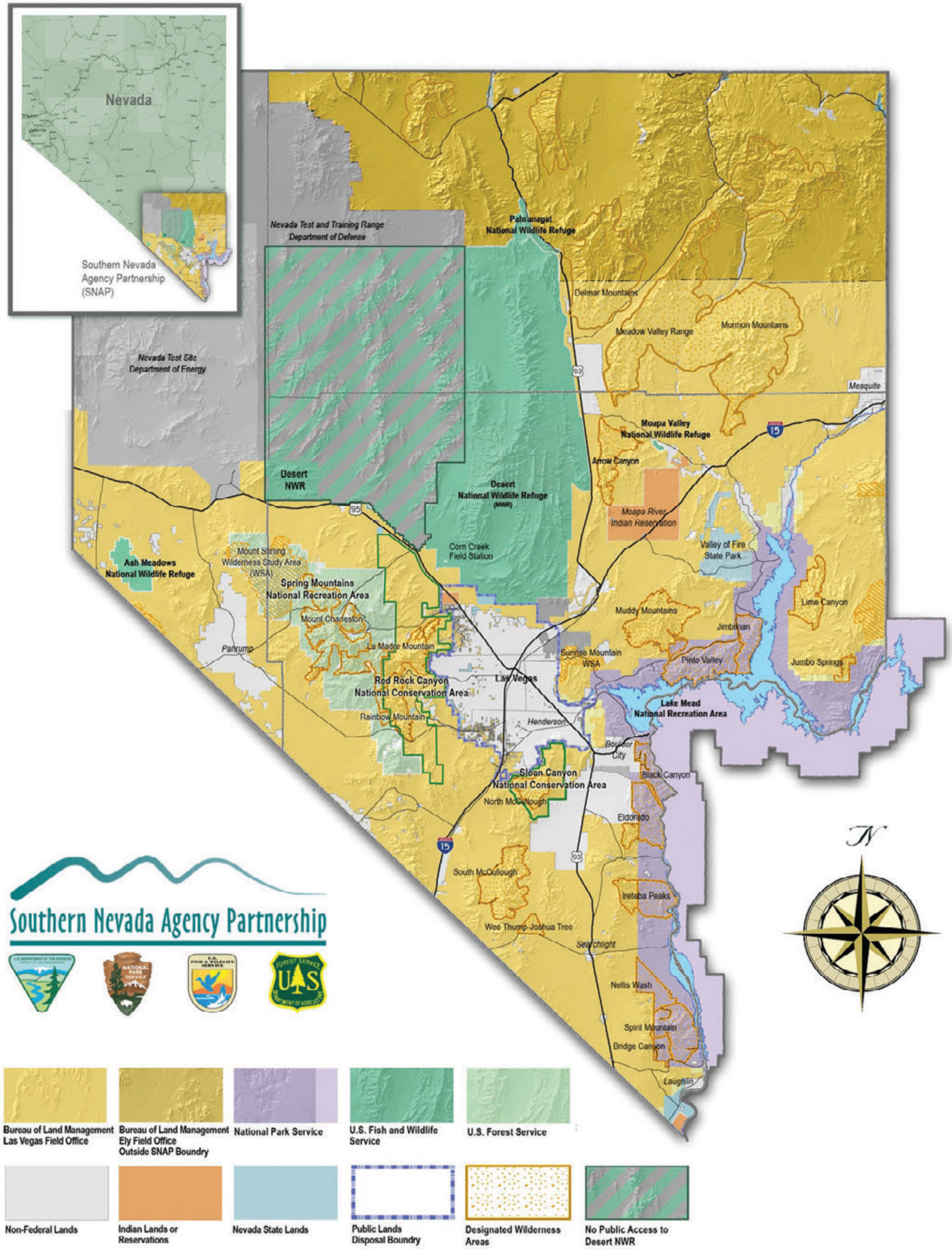

Figure 1.1—Map of the SNAP area illustrating land ownership within the region.

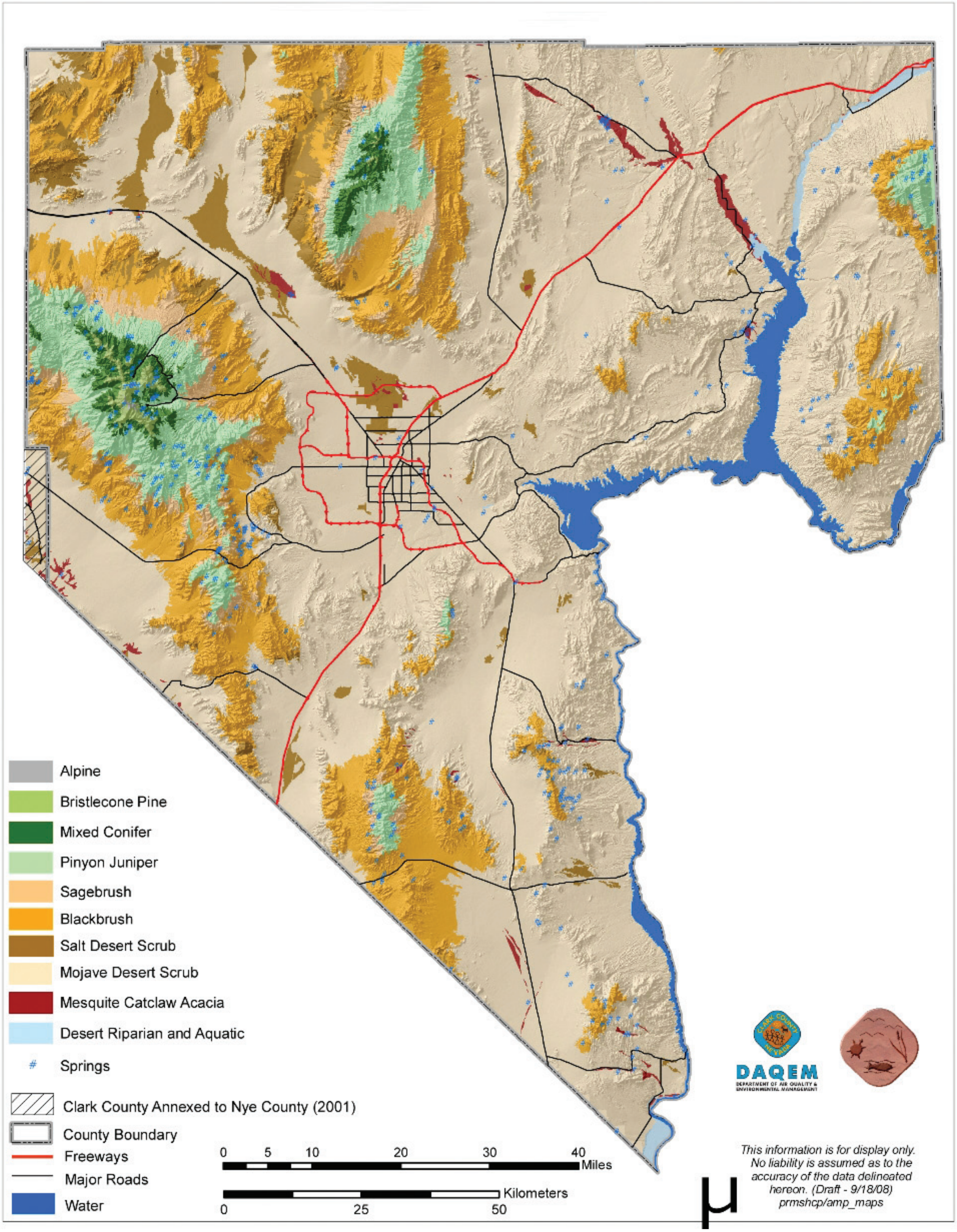

Figure 1.2—Map of the SNAP area illustrating the southern Nevada ecosystem types recognized in the Clark County MSHCP.

Table 1.1—Ecosystem types of southern Nevada defined based on climate, soils, water availability, and vegetation composition and relative abundance. The Clark County Multiple Species Habitat Conservation Plan (MSHCP) recognizes 11 ecosystem types in southern Nevada (RECON 2000). Here, we combine the upland shadscale (*Atriplex confertifolia*) component of the salt desert scrub type with blackbrush (*Coleogyne ramosissima*) and the saltbush (*Atriplex* spp.) component of the salt desert scrub type that occurs in alkaline soils of lowland basin areas with Mojave Desert Scrub.

Ecosystem	Elevation	Location	Description	Reference
Alpine	3,500 m (11, 483 ft)	Spring Mountains on Mt. Charleston	Alpine fell-fields on exposed rocky, dry soils and alpine meadows that occur in swales where moisture and fine-textured soils accumulate. The isolated nature of this system has facilitated development of a unique assemblage of plants, including several endemics.	Clokey 1951
Bristlecone pine	2,600 m (8,530 ft)	Spring and Sheep mountain ranges	Evergreen forest dominated by widely-spaced bristlecone pine (*Pinus longaeva*). Limber pine (*Pinus flexilus*) can be abundant at lower elevations within this zone. Associated shrub species include dwarf juniper (*Juniperus communis*), Clokey mountain sage (*Salvia dorrii* var. *clokeyi*), and sagebrush (*Artemisia* spp.)	Ackerman 2003; Pase and Brown 1982; RECON 2000
Mixed conifer	Between 1,200 m (3,937 ft) and 3,200 m (10,498 ft)	Spring and Sheep mountain ranges	Tree and shrub communities dominated by (1) white fir (*Abies concolor*) at higher elevations and (2) Ponderosa pine (*Pinus ponderosa*) or (3) Ponderosa pine/mountain shrub at mid-low elevations. Associated species at mid-low elevations are single-leaf piñon (*P. monophylla*), Utah juniper (*Juniperus osteosperma*) and mountain mahogany (*Cercocarpus* spp.). Understory shrubs include Gambel oak (*Quercus gambelii)*, manzanita (*Arctostaphylos* spp.), and snowberry (*Symphoricarpos albus*).	Ackerman 2003; RECON 2000
Piñon -juniper	From 1,500 m (4,921 ft) to 2,500 m (8,202 ft)	Spring, Sheep, and Virgin mountain ranges with island communities in the Delamar, McCullough, Papoose, and Parahnagat ranges (fig.1.2).	Tree and shrub communities dominated by singleleaf piñon, Gambel oak, mountain mahogany, and sagebrush (*Artemisia* spp.) at upper elevations, and Utah juniper, Rocky Mountain juniper (*Juniperus scopulorum*), western juniper (*Juniperus occidentalis*), rabbitbrush (*Chrysothamnus* spp.), and sagebrush at lower elevations. Associated perennial grass species include (*Agropyron* spp.), bluegrass (*Poa* spp.), and needlegrass (*Achnatherum* spp.).	RECON 2000
Sagebrush	From 1,500 m (4,921 ft) to 2,800 m (9,186 ft)	Spring, Sheep, and Virgin ranges in Clark County and in ranges farther north in Lincoln County (fig. 1.2). Co-occurs with several ecosystem types.	Several different community types that are dominated by three subspecies of big sagebrush (*Artemisia tridentata* ssp. *tridentata, A. tridentata* ssp. *wyomingensis and A. tridentata* ssp. *vaseyana*), low sagebrush (*A. arbuscula*), Bigelow sagebrush (*A. bigelovii*), and black sagebrush (*A. nova*). Other shrub species characteristic of these communities include rabbitbrush (*Chrysothamnus* and *Ericamera* spp.), snakeweed (*Gutierrezia sarothrae*), spiny hopsage (*Grayia spinosa),* and cliffrose (*Purshia neomexicana*). Associated perennial grass species include (*Agropyron* spp.), bluegrass (*Poa* spp.), and needlegrass (*Achnatherum* spp.).	RECON 2000
Blackbrush/ shadscale	Between 1,200 m (3,937 ft) and 1,800 m (5,905 ft)	Wide-spread below the piñon and juniper and sagebrush zones, and above the Mojave Desert scrub zone (fig. 1.2)	Blackbrush (*Coleogyne ramosissima*) tends to dominate areas with shallow limestone-derived soils, whereas shadscale (*Atriplex confertifolia*) tends to dominate on heavy, rocky soils. Other subdominant shrub species include cliffrose, budsage (*Artemisia spinescens*), Mormon tea (*Ephedra* spp.), snakeweed, wolfberry (*Lycium* spp.), and spiny hopsage. Additional species include Utah juniper, Joshua tree (*Yucca brevifolia*), banana yucca (*Yucca baccata*), Indian ricegrass (*Achnatherum hymenoides*), needlegrass, and galleta grass (*Pleuraphis jamesii*).	Brooks and others 2007

(continued)

Table 1.1—(Continue)

Ecosystem	Elevation	Location	Description	Reference
Mojave Desert scrub (most common ecosystem)	Below 1,200 m (3,937 ft)	Wide-spread in southern Nevada	Dominated by thermophile vegetation types characterized by creosotebush (*Larrea tridentata*) in upland areas and saltbush species (*Atriplex* spp.) in alkaline soils of lowland basin areas. *Bajadas,* the most common landform, are dominated by creosotebush and white bursage (*Ambrosia dumosa*); subdominants include desert thorn (*Lycium andersonii*), bladder sage (*Salazaria mexicana*), indigo bush (*Psorothamnus fremontii*), blackbrush, brittlebush (*Encelia farinosa*), and burro bush (*Hymenoclea salsola*). *Sand dunes, gypsum soils, cliff/rock outcrops, and steep slopes* occur as isolated patches that support unique plant and animal communities. Dominant vegetation in these patches include Joshua tree (*Yucca brevifolia*), prickly pear cactus (*Opuntia* spp.), yucca (*Yucca* spp.), cholla (*Cylindropuntia* spp.), and hedgehog cactus (*Echinocereus* spp.). *Areas with perennial groundwater* not more than 10 m from the surface are characterized by the mesquite/catclaw community which occurs in patches (1 to over 1000 ha; 2.5 to over 2,500 acres) on diverse soils in scattered clumps on valley floors and near desert springs. Dominant tree species are screwbean mesquite (*Prosopis pubescens*), honey mesquite (*P. glandulosa*), catclaw acacia (*Acacia greggii*), and smoke tree (*Psorothamnus spinosa*); associated shrubs are fourwing saltbush (*Atriplex canescens*), quailbush (*A. lentiformis*), arrowweed (*Pluchea sericea*), creosotebush, burro bush (*Hymenoclea salsola*), bebbia (*Bebbia juncea*), and sandpaper plant (*Petalonyx nitidus*).	Clokey 1951; Schoenherr 1992; Crampton and others 2006
Riparian/ aquatic	Below 1200 m (3,937 ft)	Lowland riparian/ aquatic systems occur in southern Nevada, along the Virgin and Muddy Rivers, Las Vegas Wash, and the Colorado River. Mountain riparian/ aquatic systems occur in high elevations of Spring Mountains.	Riparan/aquatic ecosystems are characterized by flows that are either persistent or intermittent, particularly during summer. Under natural, unregulated conditions, the aquatic component is relatively harsh because of seasonally high water temperatures, harsh water chemistry, high turbidity, scouring floods, and sandy substrates. In perennial reaches, the riparian community includes woody, deciduous, and emergent obligatory and facultative wetland vegetation. Principal native woody vegetation includes Fremont cottonwood (*Populus fremontii*), black cottonwood (*Populus trichocarpa*), sandbar willow (*Salix exigua*), Gooding willow (*S. gooddingii*), velvet ash (*Fraxinus velutina*), desert willow (*Chilopsis linearis*), and honey mesquite. Mountain riparian/aquatic ecosystems are characterized by streams with highly variable base flows that have low to nonexistent discharges in dry years.	RECON 2000; Chapter 3
Springs		Throughout Clark County	Small-scale aquatic systems that occur where ground water reaches the soil surface. Several hundred springs are scattered throughout Clark County that are generally supported by mountain block, local, or regional aquifers. They range widely in size, water chemistry, morphology, landscape setting, and persistence. Springs support diverse aquatic communities and riparian zones. Spring environments are most influenced by the type of aquifer and amount of flow, landscape position, and disturbance regime (see Chapter 3).	Chapter 3

Table 1.2—Southern Nevada Agency Partnership species of management concern.

Common name	Species name
Amphibian	
Relict leopard frog	*Rana onca*
Birds	
Northern Goshawk	*Accipiter gentilis*
Western Yellow-billed Cuckoo	*Coccyzus americanus occidentalis*
Southwestern Willow Flycatcher	*Empidonax trailii extimus*
American Peregrine Falcon	*Falco peregrinus anatum*
Bald Eagle	*Haliaeetus leucocephalus*
Blue Grosbeak	*Passerina caerulea*
Phainopepla	*Phainopepla nitens*
Summer Tanager	*Piranga rubra*
Vermillion Flycatcher	*Pyrocephalus rubinus*
Yuma Clapper Rail	*Rallus longirostrus yumanensis*
Arizona Bell's Vireo	*Vireo bellii arizonae*
Fishes	
Meadow Valley Wash desert sucker	*Catostomus clarki* ssp. 2
Devils Hole pupfish	*Cyprinodon diabolis*
Ash Meadows Amargosa pupfish	*Cyprinodon nevadensis mionectes*
Warm Springs pupfish	*Cyprinodon nevadensis pectoralis*
Pahrump poolfish	*Empetrichthys latos latos*
Pahranagat roundtail chub	*Gila robusta jordani*
Virgin River chub	*Gila seminuda*
Virgin River chub (Muddy River pop.)	*Gila seminuda* pop. 2
Virgin River spinedace	*Lepidomeda mollispinis mollispinis*
Moapa dace	*Moapa coriacea*
Woundfin	*Plagopterus argentissimus*
Moapa speckled dace	*Rhinichthys osculus moapae*
Ash Meadows speckled dace	*Rhinichthys osculus nevadensis*
Pahranagat speckled dace	*Rhinichthys osculus velifer*
Meadow Valley speckled dace	*Rhinichthys osculus* ssp. 11
Razorback sucker	*Xyrauchen texanus*
Reptiles	
Western redtail skink	*Eumeces gilberti rubricaudatus*
Agassiz's Desert tortoise	*Gopherus agassizii*
Banded Gila monster	*Heloderma suspectum cinctum*
Invertebrates	
Ash Meadows naucorid	*Ambrysus amargosus*
Warm Springs naucorid	*Ambrysus relictus*
Acastus Checkerspot	*Chlosyne acastus robusta*
Spring Mountains dark blue	*Euphilotes ancilla purpura*
Morand's checkerspot	*Euphydryas chalcedona morandi*
Spring Mountains Comma Skipper	*Hesperia colorado mojavensis*
Charleston ant	*Lasius nevadensis*
Nevada Admiral	*Limenitis weidemeyerii nevadae*
Amargosa naucorid	*Pelocoris shoshone amargosus*
Spring Mountains icarioides blue	*Plebejus icarioides austinorum*
Mount Charleston Blue	*Plebejus shasta charlestonensis*
Giuliani's dune scarab beetle	*Pseudocotalpa giulianii*
Moapa pebblesnail	*Pyrgulopsis avernalis*
Blue Point pyrg	*Pyrgulopsis coloradensis*
Spring Mountains pyrg	*Pyrgulopsis deaconi*
Corn Creek pyrg	*Pyrgulopsis fausta*

(continued)

Table 1.2 (Continued).

Common name	Species name
Invertebrates	
Southeast Nevada pyrg	*Pyrgulopsis turbatrix*
Carole's fritillary	*Speyeria carolae*
Moapa Warm Spring riffle beetle	*Stenelmis moapa*
Mammals	
Pale lump-nosed bat	*Corynorhinus townsendii pallescens*
Spotted bat	*Euderma maculatum*
Allen's big-eared bat	*Idionycteris phyllotis*
Silver-haired bat	*Lasionycteris noctivagans*
Pahranagat Valley montane vole	*Microtus montanus fucosus*
Fringed myotis	*Myotis thysanodes*
Palmer's chipmunk	*Neotamias palmeri*
Hidden Forest Uinta chipmunk	*Neotamias umbrinus nevadensis*
Big free-tailed bat	*Nyctinomops macrotis*
Bighorn sheep	*Ovis canadensis nelsoni*
Plants	
Rough angelica	*Angelica scabrida*
Charleston pussytoes	*Antennaria soliceps*
Sticky ringstem	*Anulocaulis leiosolenus* var. *leiosolenus*
Las Vegas bearpoppy	*Arctomecon californica*
King's rosy sandwort	*Arenaria kingii* spp. *rosea*
Clokey milkvetch	*Astragalus aequalis*
Threecorner milkvetch	*Astragalus geyeri* var. *triquetrus*
Clokey eggvetch	*Astragalus oophorus* var. *clokeyanus*
Spring Mountains milkvetch	*Astragalus remotus*
Ash Meadows milkvetch	*Astragalus phoenix*
Upswept moonwort	*Botrychium ascendens*
Dainty moonwort	*Botrychium crenulatum*
Slender moonwort	*Botrychium lineare*
Spring-loving centaury	*Centaurim namophilum*
Las Vegas cryptantha	*Cryptantha insolita*
Jaeger whitlowgrass	*Draba jaegeri*
Charleston draba	*Draba paucifructa*
Ash Meadows sunray	*Enceliopsis nudicaulis* var. *corrugate*
Nevada willowherb	*Epilobium nevadense*
Pahrump Valley buckwheat	*Eriogonum bifucatum*
Las Vegas buckwheat	*Eriogonum corymbosum var. nilesii*
Sticky buckwheat	*Eriogonum viscidulum*
Clokey greasebush	*Glossopetalon clokeyi*
Ash Meadows gumplant	*Grindelia fraxinopratensis*
Charleston ivesia	*Ivesia cryptocaulis*
Jaeger ivesia	*Ivesia jaegeri*
Ash Meadows ivesia	*Ivesia kingii* var. *eremica*
Ash Meadows blazingstar	*Mentzelia leucophylla*
Amargosa niterwort	*Nitrophila mohavensis*
White-margined beardtongue	*Penstemon albomarginatus*
Bicolored beardtongue	*Penstemon bicolor* ssp. *bicolor*
Rosy two-colored beardtongue	*Penstemon bicolor* ssp. *roseus*
Jaeger beardtongue	*Penstemon thompsoniae* spp. *jaegeri*
Clokey's catchfly	*Silene clokeyi*
Charleston tansy	*Sphaeromeria compacta*
Charleston kittentails	*Synthyris ranunculina*
Charleston grounddaisy	*Townsendia jonesii* var. *tumulosa*
Charleston violet	*Viola charlestonensis*

The SNAP Science and Research Strategy established several goals for interagency science and research that is conducted in support of resource management in southern Nevada. The goals were developed based on individual agency goals, the SNAP Board vision, the interagency science and research team's charter goals, the input of individual agency specialists, and input from interdisciplinary scientists that was obtained during several planning workshops. Each major goal has a set of Sub-goals and questions that address specific science needs. The three main Goals are:

Goal 1. Restore, sustain, and enhance southern Nevada's ecosystems.
Goal 2. Provide for responsible use of southern Nevada's lands in a manner that preserves heritage resources and promotes an understanding of human interaction with the landscape.
Goal 3. Promote scientifically informed and integrated approaches to effective, efficient, and adaptive management.

Science and Research Synthesis Report

The Goals and Sub-goals of the SNAP Science and Research Strategy provide key focal areas for both the periodic science needs assessments and the Synthesis Report. The Synthesis Report addresses information related to Goals 1 and 2 and their associated Sub-goals (table 1.3). The Sub-goals address the topics of fire, invasive species, landscapes and watersheds, biological diversity, cultural resources, historic content, recreation, land uses, and education. The Synthesis Report provides a summary of the state of knowledge related to each of the nine Sub-goals, addresses knowledge gaps, and provides management implications. It builds on previous efforts to develop the necessary scientific understanding for adaptive management of southern Nevada ecosystems, such as the Multi Species Habitat Conservation Plan (MSHCP) (RECON 2000) and a 2007 workshop on the characteristics of southern Nevada ecosystems and the threats to ecosystem health (Desert Research Institute 2008). The Synthesis Report is organized around the topics addressed in the Sub-goals, and table 1.3 provides a crosswalk between the chapters in this document and the Goals and Sub-goals in the SNAP Strategy. An overview of the biophysical setting and cultural resources as well as the management concepts discussed in the report follow.

Biophysical Setting of Southern Nevada

Southern Nevada straddles a broad ecotone between the Central Basin and Range of the Cold Desert ecoregion to the north and the Mojave Basin and Range of the Warm Desert ecoregion to the south (U.S. Environmental Protection Agency 2002, 2010; fig. 1.2). The topography is characterized by broad basins separated by isolated mountain ranges that are punctuated by steep environmental gradients. These local environmental gradients mirror large-scale latitudinal gradients and result in Cold Desert and mesic forest conditions occurring at higher elevations on mountains within the Warm Desert ecoregion.

Climate within the region is spatially and temporally variable, and slope, aspect, and especially elevation—which ranges from 170 m (557 ft) at Laughlin, Nevada, to 3,632 m (11,913 ft) at Charleston Peak in the Spring Mountains—strongly influence both precipitation and temperature. Recorded precipitation ranges from a long-term yearly mean of 10.5 cm (4.1 in), with a minimum of 1.4 cm (0.6 in) and maximum of 27.1 cm (10.7 in) at 662 m (2,170 ft) elevation in Las Vegas, to a mean of 60.1 cm (23.6 in), with a minimum of 30.8 cm (12.1 in) and maximum of 90.0 cm (35.4 in) at 2,289 m (7,510 ft) at Mt. Charleston Lodge in the Spring Mountains (Western Regional

Table 1.3—A crosswalk relating the chapters in this document to the Goals and Sub-goals in the SNAP Science and Research Strategy.

Goal/Chapter	Sub-goal
Goal 1. Restore, sustain, and enhance southern Nevada's ecosystems	
Chapter 1. An Overview of the southern Nevada Agency Partnership Science and Research Synthesis	
Chapter 2. Southern Nevada Ecosystem Stressors	
Chapter 3. Water and Water Use in Southern Nevada	*Sub-Goal 1.3.* Restore and sustain proper function of southern Nevada's watersheds and landscapes
Chapter 4. Invasive Species in Southern Nevada	*Sub-Goal 1.2.* Protect southern Nevada's ecosystems from the adverse impacts of invasive species
Chapter 5. Fire History, Effects, and Management in Southern Nevada	*Sub-Goal 1.1.* Manage wildland fire to sustain southern Nevada's ecosystems
Chapter 6. Species of Conservation Concern and Environmental Stressors: Local, Regional, and Global Effects	*Sub-Goal 1.4.* Sustain and enhance southern Nevada's biotic communities to preserve biodiversity and maintain viable populations
Chapter 7. Maintaining and Restoring, Sustainable Ecosystems in Southern Nevada	*Sub-Goal 1.3.* Restore and sustain proper function of southern Nevada's watersheds and landscapes
Goal 2. Provide for responsible use of southern Nevada's lands in a manner that preserves heritage resources and promotes an understanding of human interaction with the landscape	
Chapter 8. Human Interactions with the Environment through Time in Southern Nevada	*Sub-Goal 2.1.* Develop an understanding of human interactions with the environment through time
Chapter 9. Preserving Heritage Resources through Responsible Use of Southern Nevada's Lands	*Sub-Goal 2.2*. Preserve heritage resources through responsible use of southern Nevada's lands
Chapter 10. Recreation Use on Federal Lands in Southern Nevada	*Sub-Goal 2.4.* Provide for appropriate (type and location), quality, and diverse recreational experiences, resulting in responsible visitor use on federal lands in southern Nevada
*Chapter 11***.** Science-based Management of Public Lands in Southern Nevada	*Sub-Goal 2.3.* Manage current and future authorized southern Nevada land uses in a manner that balances public need and ecosystem sustainability
	Sub-Goal 2.5. Promote an effective conservation education and interpretation program to improve the quality of resources and enhance public use and enjoyment of southern Nevada public lands

Climate Center 2011). Most of the yearly precipitation falls during the winter months, but the southeastern part of the region receives relatively more summer precipitation than the northern or western areas. Temperatures in the region range from a long-term yearly mean of 19.5 °C (67.1 °F), with a minimum of 12.3 °C (54.1 °F) and a maximum of 27.0 °C (80.6 °F) at Las Vegas, to a mean of 7.8 °C (46.0 °F) with a minimum of 0.2 °C (32.3 °F) and maximum of 15.8 °C (60.4 °F) at Mt. Charleston Lodge (Western Regional Climate Center 2011).

The elevation/climate gradients in combination with the local topography of the region strongly affect soil characteristics, plant species composition, and productivity of vegetation communities and, consequently, animal species distributions. Lower elevation soils are typically classified as Entisols, Aridisols, or Inceptisols while higher elevation soils are Mollisols and, when derived from carbonate substrates, Alfisols (U.S. Environmental Protection Agency 2010). Wetland soils are Inceptisols or Mollisols (U.S. Environmental Protection Agency 2010). The diverse Warm and Cold Desert ecosystem types have been present in southern Nevada at least since the end of the last ice age and the beginning of the Holocene 10,000 years ago (Van Devender 1977; Van Devender and Spaulding 1979), although the ecotones between the major ecosystem types are presently higher in elevation than they were at the beginning of the Holocene (Spaulding 1990). Low elevation basins and the toeslopes of mountain ranges have warmer and more arid climates typical of warm deserts and are dominated by Warm Desert Mojave Desert Scrub ecosystems (table 1.1). Less common cold desert shrublands (blackbrush and sagebrush), woodlands (pinyon and juniper), forest stands (mixed conifer), and even bristlecone pine and alpine ecosystem types have cooler and more mesic climates and occur with increasing elevation within these mountain ranges. Spring and riparian ecosystems occur across the elevation/climate gradient, but spring ecosystems occur where local geology and hydrology result in water flowing to the surface, and riparian/aquatic ecosystems are associated with streams and rivers that flow during the majority of the year. These ecosystems differ in soil characteristics, water chemistry, and species composition depending on topographic location and setting.

The strong topographic differences and diverse ecosystem types result in a high number of species in southern Nevada (Kolter and Brown 1988). Also, the degree of habitat diversity and geographic isolation of similar habitat types like mountain ranges has produced a high degree of endemism. For example, there are many species of endemic butterflies (Fleishman and others 2001; Forister and others 2004). Finally, the climatic history of the region also has contributed to high levels of endemism. The region is much drier today than it was even 10,000 years ago, and this has resulted in highly isolated aquatic remnant habitats that support a large number of endemic pupfish (*Cyprinodon* spp.) and other species (Brown 1971; Miller 1950).

Cultural Setting

Southern Nevada is rich in irreplaceable cultural and historical resources that include archaeological remains, historic sites, cultural landscapes, and other areas of significance to Native American and other cultural groups. There is evidence of human occupation of southern Nevada from about 12,000 years ago. These early residents were nomadic hunters of large Pleistocene fauna who also used both small game and plant resources (Harper and others 2006). Climate change during the early Holocene resulted in broad adaptation to a range of resources, and small, mobile groups of hunter-gatherers moved between ecological zones utilizing plant resources and small game (Ezzo and Majewski 1996). Agriculture began prior to 2350 years ago and increased in intensity until ca. 750/650 years ago (AD 1200/1300). Exploitation of wild resources and seasonal movement continued during this time period. Southwestern Puebloan peoples that were characterized by agriculture and the use of pit structures, the bow and arrow, ceramics, above-ground rooms, and pueblos occupied the region during this period (Lyneis 1995). After about 650 years ago, archeological remains reflect a return to a more nomadic foraging way of life, supplemented by smaller-scale agriculture (Altschul and Fairley 1989; Ezzo and Majewski 1996). This adaptation is associated with the Southern Paiute who were residents of the region during European contact and who continue to live in southern Nevada today. European contact began in the 1700s with the Spanish and continued with the well-documented establishment of Mormon settlements in the mid-1800s (Sterner and Ezzo 1996). The now seemingly inhospitable desert has a long history of change and has provided diverse ecosystems from which native people and later historic immigrants have been able to sustain themselves.

Concepts for Management

Management aimed at maintaining sustainable ecosystems is essential if public lands in southern Nevada are to continue to support both public needs and habitat for the region's diverse assemblage of plants and animals. Sustainable or "healthy" ecosystems supply important ecological services and goods. Over the normal cycle of disturbance events, sustainable ecosystems retain characteristic processes including hydrologic flux and storage, geomorphic processes, biogeochemical cycling and storage, biological activity and productivity, and biotic population regeneration and reproduction (modified from Chapin and others 1996 and Christensen and others 1996). Thus, managing for sustainable ecosystems in southern Nevada requires maintaining or restoring the ecological processes that structure the region's ecosystems.

A large number of studies have revealed a tight connection between ecosystem sustainability and ecological resilience to stress and disturbance and resistance to invasive species (see Folke and others 2002). Resilience is defined as the capacity of an ecosystem to regain its fundamental structure, processes, and functioning (or recover) when subjected to stressors or disturbances like drought, livestock grazing, or wildfire (e.g. Allen and others 2005; Hollings 1973; Walker and others 1999). A reduction in resilience can increase the vulnerability of an ecosystem and reduce its ability to recover following stress or disturbance. The inherent resilience of southern Nevada ecosystems to stress and disturbance differs due to the strong elevation/climate gradients in the region and the large differences in abiotic and biotic characteristics along these gradients. In general, the resilience of intact desert ecosystems tends to increase along gradients of increasing available resources (water and nutrients) and annual net primary productivity (Brooks and Chambers 2011; Chambers and others 2007; Wisdom and Chambers 2009). Thus, higher precipitation and more moderate temperatures at moderately high elevations result in greater productivity and can increase the capacity of native communities to recover following stress or disturbance.

Non-native invaders are having major effects on the sustainability of southern Nevada's terrestrial and aquatic ecosystems and are a major management concern. Resistance is the capacity of an ecosystem to retain its fundamental structure, processes, and functioning (or remain largely unchanged) despite stresses, disturbances or invasive species. Resistance to invasion is a function of the biotic and abiotic factors and ecological processes in an ecosystem that limit the establishment and population growth of an invading species (D'Antonio and Thomsen 2004). Resistance of ecosystems to widely distributed invasive species like cheatgrass (*Bromus tectorum*) and red brome (*Bromus madritensis*) often reflects the climate suitablility of the species or its ability to establish and persist under a given set of environmental conditions. In general, resistance to annual invaders tends to be higher in the most stressful environments (true desert and alpine ecosystems) because only a limited suite of species is adapted to establish and persist due to the harsh conditions. For example, establishment of the invasive annual grass, cheatgrass, in the Great Basin is limited in salt desert shrub types at the low end of the precipitation gradient due to insufficient water availability (Meyer and others 2001), while growth and reproduction is limited in mountain brush types at high elevations due to insufficient degree days (Chambers and others 2007).

Several factors interact to influence resilience to stress and disturbance and resistance to invasive species in desert ecosystems. Climate, topography, and soils determine the abiotic and biotic attributes of an ecosystem and thus the potential to support a given ecosystem type or community. The abiotic attributes that characterize ecosystems are hydrologic flux and storage, biogeochemical cycling and storage, and geomorphic processes, while biotic attributes are biological productivity, composition and structure, and population regulation and regeneration. Climate change, disturbance and stress act on these attributes and influence the relative resilience and resistance of the ecosystem over time. Changes in resilience and resistance are indicated by factors like soil stability and past or present erosion, the composition and abundance of native plants and animals, seed banks and seed sources, and the composition and abundance of invasive species. The severity and frequency of disturbance can alter resilience to stress and disturbance and resistance to invasive species and, consequently, the capacity of a site to support desirable alternative states (Briske and others 2008). In the deserts of North America, inappropriate grazing by wild horses, burros, and livestock has significantly influenced resilience and resistance by reducing a major structural and functional component, specifically native perennial herbaceous species, and by serving as a dispersal agent for non-native invaders (Milchunas and others 1988; Van de Koppel and others 2002). Loss of perennial herbaceous species decreases the resistance of desert ecosystems to invasion (Chambers and others 2007) and resilience to disturbances like drought and wildfires (D'Antonio and others 2009). Once established, invasive species promote shorter fire return intervals and larger fire sizes than southern Nevada deserts experienced historically. These changes can result in positive feedbacks for the invader and negative effects on native species, especially woody perennials and succulents (Brooks and others 2004).

Adaptive management that is aimed at maintaining or increasing resistance and resilience can reduce the uncertainty associated with management decisions and increase the region's capacity to deal with stresses without losing options for the future (Folke and others 2002). Key aspects of adaptive management are a scientific understanding of the underlying processes structuring southern Nevada ecosystems, the effects of the numerous stresses on these ecosystems and their associated species, and the factors that influence their resilience to stress and disturbance and resistance to invasion. Routine monitoring of the effects of stresses, disturbances, and management actions on the ecological conditions of the Region's diverse ecosystems can provide the necessary feedback for adaptive management. Periodic science syntheses, such as those in this GTR, give information on the current state of knowledge, the ecological trajectories of the region's ecosystems and species, and needed information for effective management.

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Chapter 2

Ecosystem Stressors in Southern Nevada

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Introduction

Southern Nevada ecosystems and their associated resources are subject to a number of global and regional/local stressors that are affecting the sustainability of the region. Global stressors include elevated carbon dioxide (CO_2) concentrations and associated changes in temperature and precipitation patterns and amounts, solar radiation, and nutrient cycles (Smith and others 2009b). Global stressors are ubiquitous in nature and interact both directly and indirectly with regional or local stressors. Regional/local stressors in southern Nevada include: population growth and urbanization and associated increases in nitrogen deposition, energy development, water development, and recreation; increased effects of insects and disease; ongoing effects of livestock, wild horse and burro grazing; new and expanding invasive species; and altered fire regimes. This chapter provides background information on the stressors affecting southern Nevada's ecosystems that is needed to address Goal 1.0 in the SNAP Science Research Strategy, which is to restore, sustain, and enhance southern Nevada's ecosystems (Turner and others 2009).

Human population growth and changes in land use strongly affect the type and magnitude of local/regional stressors. From 1960 to 2010, Nevada's growth rate was the highest in the nation (www.census.gov/prod/cen2010/briefs/c2010br-01.pdf). Clark County has experienced particularly high growth, with a population increase of greater than 40 percent since the 2000 census. Factors like land ownership, historic and current land use, proximity to human and energy developments, and desirability for recreation all influence the level of human-caused stress.

The strong elevation/climate gradients and large differences in the environmental characteristics of southern Nevada ecosystems (fig. 1.2; Chapter 1) have a major influence on both patterns of land use and the dominant stressors for different ecosystem types. Shifts in land use related to population growth, urbanization, and energy development are largely focused in lower elevation ecosystems including sagebrush, blackbrush and shadscale, and Mojave Desert scrub. Water diversions influence riparian/aquatic ecosystems and springs, while groundwater pumping also has the potential to affect ecosystems that characterize lower valleys including Mojave Desert scrub. Recreational uses influence all ecosystems, and wild horse and burro use and livestock grazing affect all but alpine and subalpine ecosystems. Insects and disease, as well as invasive species are widespread stressors. Fire is limited to ecosystems with sufficient fuels to carry fire and is strongly influenced by invasive species in lower elevation Mojave Desert scrub, blackbrush and shadscale, and sagebrush ecosystems.

This chapter addresses aspects of several of the Goals and Sub-goals listed in the SNAP Science Research Strategy (table 1.3; Turner and others 2009). Altered fire regimes, invasive species, land use practices, and management actions are addressed in Goal 1—Sustain, Restore, and Enhance Southern Nevada's Ecosystems. The effects of these stressors on sensitive species and habitats are specifically addressed in Sub-goal 1.4—Sustain and Enhance Southern Nevada's Biotic Communities to Preserve Biodiversity and Maintain Viable Populations. Anthropogenic factors, such as recreation and urbanization, are referred to in Goal 2—Provide for Responsible Use of Southern Nevada's Lands in a Manner That Preserves Heritage Resources and Promotes an Understanding of Human Interaction with the Landscape.

Global Stressors

Climate Change and Elevated CO_2 Concentrations

Natural disturbance regimes of arid systems are characterized by resource pulses. Rainfall is infrequent and variable in amount, while fire and drought can temporarily increase available soil nitrogen (White and others 2006). Changes in the frequency and/or magnitude of these pulses associated with altered precipitation patterns may have profound effects on vegetation (Smith and others 2009a). For example, climate predictions include an increase in intense, short-duration rainfall events, which could temporarily increase plant productivity, facilitate plant invasions (Chapter 4), and episodically promote the spread of fire (Chapter 5). Similarly, enhanced levels of CO_2 may increase the rate and extent of invasive annual grass invasions, leading to unprecedented frequency in wildfires (Smith and others 2009b). Increasing levels of CO_2 are continuous and cumulative, representing a fundamentally different kind of stress from pulsed disturbance regimes (Smith and others 2009a; Stohlgren and others 2000).

Climate regimes are defined by patterns of both temperature and precipitation. Bioclimatic modeling has been used to estimate both the effects of climate change on the distribution of vegetation types, as well as to predict future distribution of individual species. Loarie and others (2009) predict shifts in plant community climate regimes based on temperature on the order of 1.26 km yr^{-1} (0.78 mi yr^{-1}) upward in elevation or latitude for desert systems. Work by Notaro and others (2012) project a region-wide decline in vegetation cover, a reduction in plant species richness in high-elevation evergreen forests, and a northward shift of the Sonoran Desert. Rehfeldt and others (2006) modeled current and projected climate profiles for 25 biotic communities of the western United States. Projections estimate that by the end of the century, 55 percent of western land area would not support present-day vegetation communities (as described by Brown and others 1998). Projections for individual species, however, do not necessarily follow those of the community as a whole. Consequently, community types (associations) that remain may not be comprised of the same species as are present today and may not have historical analogs (Williams and Jackson 2007). For example, arid shrublands may remain the same shrubland vegetation formation type but be comprised of different dominant species (vegetation alliances) or combinations of dominant and/or sub-dominant species (vegetation associations). Also, approximately half of the western United States, including most of southern Nevada, may have climate regimes not currently found there, likely resulting in completely novel community types (Rehfeldt and others 2006).

Atmospheric CO_2 increased approximately 32 percent during the last century (Wagner 2009), and is expected to double from today's levels by the end of the current century (Houghton and others 2001). This rise is predicted to affect ecosystems in two separate ways, through direct effects on plant physiology and indirect effects on the global climate (Smith and others 2009a). Increased concentrations of CO_2 have been shown to increase the rate of carbon assimilation by plants through photosynthesis, while decreasing water loss through transpiration (Smith and others 2009b and references therein). The net effect is one of increased water-use efficiency, potentially resulting in increased productivity of arid systems. However, potential gains in productivity will likely be mitigated by changes in climate. For example, plants are less responsive to elevated levels of CO_2 when soils are dry.

By far the most problematic effect of the rising atmospheric CO_2 concentration is its linkage to global warming and climate change. Over the last 150 years, average temperatures have risen globally in tandem with increasing CO_2 (Smith and others 2009a). Temperatures in the American Southwest are estimated to have risen 1.2-1.7 ^{o}C (2.2-3.1 ^{o}F) during the last century (Sprigg and others 2000), outpacing the global average. Data for Nevada show even greater warming, with temperatures having risen 2.0 ^{o}C (3.6 ^{o}F) since 1908 (Saunders and others 2008). Regional projections of climate change, based on general circulation models (GCMs), predict a further increase of 2-6 ^{o}C (3.6-10.8 ^{o}F) by the year 2100 (Saunders and others 2008; Wagner 2009). Moreover, nighttime temperatures have risen more than daytime maxima and will likely continue to do so (Wagner 2009). Nighttime temperatures limit the northern distribution of many warm-desert species (Beatley 1974; Pockman and Sperry 1997). Consequently, the potential range of these species is projected to expand northward (Smith and others 2009a). Temperature also influences snow pack accumulation, water storage, and the timing of spring runoff (Mote and others 2005).

Precipitation patterns also are influenced by rising levels of atmospheric CO_2 through changes in oceanic temperatures and global circulation patterns such as El Niño events. As global warming continues, longer and more intense droughts (Saunders and others 2008), and an increase in the frequency and intensity of extreme weather events (Archer and Predick 2008) are expected to occur throughout the West. Simulation model projections for the Mojave region vary, but many suggest reduced precipitation in general for the Southwest (Seager and others 2007; Wagner 2009). Other models predict an increase in El Niño events as well as increased summer precipitation (Smith and others 2009b). However, evapotranspiration will increase with increasing temperatures, likely resulting in overall drier conditions and an increase in the Palmer Drought Severity Index. In addition to expected changes in the amount and timing of precipitation, rising temperatures will likely decrease snowpack levels and increase the rate of snow-melt, resulting in lower mid-summer stream flows (McCabe and Wolock 2009). As of 2008, Lake Mead was only 50 percent full following consecutive years of below-average inflow (Saunders and others 2008). Continued drought and reduced runoff will result in increased competition for the limited water resources of southern Nevada.

Local and Regional Stressors

Population Growth and Urbanization

Nevada is currently the fastest growing state in the country. According to the 2010 U.S. Census, the population grew by 35 percent since 2000 and by 66 percent during the previous decade (1990-2000). In addition, Nevada is the only state that has maintained an average growth rate of 25 percent or greater over the last three decades, and is the fastest growing state for five straight decades (http://www.census.gov/prod/cen2010/briefs/c2010br-01.pdf). In southern Nevada, the population of Clark County in 2010 (1,951,269) was 42 percent higher than the 2000 census. The cities of Las Vegas, Henderson, and North Las Vegas have all posted impressive growth rates since 2000. Even the smaller, more rural communities of Mesquite, Pahrump, Overton, and Boulder City have had significant populations increases during this time frame (Chapter 10).

Rapid growth does not happen without significant impacts on the flora and fauna of native ecosystems. The vast majority of urban development has taken place in the Mojave Desert scrub ecosystem. Between 2001 and 2007, Clark County lost 56,512 acres of native ecosystems to urban development (Clark County 2008). Also, a significant amount of salt desert scrub located in Henderson/Green Valley and in northwest Las Vegas has been lost to urbanization (Burton Pendleton, personal observation of urbanization patterns since the 1960s in the Las Vegas Valley, Nevada).

The soil and vegetation disturbances taking place at the urban-desert interface and beyond constitute a major problem for public land managers. Issues created include dust generation, trash and materials dumping, off-road travel and resulting unauthorized roads, destruction of cultural resources, creation of dispersal corridors for invasive species, human-caused wildfires, and land degradation caused by uncontrolled recreation and ORV (off road vehicle) use. Vegetation communities at higher elevations are not as directly impacted by urbanization, but are impacted by recreational activities of the large urban population.

Nitrogen Deposition

Industrialization and urbanization have led to increased production of atmospheric nitrogen emanating from coal-fired power plants and vehicle exhaust along major highways and in metropolitan areas and deposited across broad regions downwind from their sources. Deposition levels near major cities like Las Vegas can be as high as 40 kg ha^{-1} yr^{-1} (35.2 lbs $acre^{-1}$ yr^{-1}; Smith and others 2009b). Levels away from metropolitan areas are on the order of 3-12 kg ha^{-1} yr^{-1} (2.6-10.6 $acre^{-1}$ yr^{-1}; Allen and others 2006). After water, productivity of desert systems is most limited by nitrogen. Increased levels of nitrogen may result in higher biomass production if accompanied by sufficient moisture. Invasive annual grasses are particularly responsive to increased levels of nitrogen. Allen and others (2006), working at Joshua Tree National Park, reported increased biomass of invasive grasses following even low levels of N-fertilization and theorized that continued N-deposition could cause a community shift from shrubland to one dominated by invasive grasses. Brooks (2003) also found increased biomass of invasive grasses following N-fertilization in a Mojave Desert ecosystem. Increased levels of soil N are also expected to alter nutrient cycling, but little empirical data are available to evaluate this potential effect.

Urbanization and human-caused disturbances also affect air quality in southern Nevada. Dust and other pollutants from energy development, housing development, and recreation result in increases in particulate matter. Of particular concern to humans and wildlife are particles smaller than 10 micrometers in diameter (PM-10). Particles of this size, when breathed into the lungs, can cause serious health effects (http://epa.gov/air/particlepollution/basic.html). In southern Nevada, most particulate emissions come from wildfires and windblown dust. A study by the Desert Research Institute found that windblown dust accounted for 89-90 percent of the PM-10 occurring in Clark County (http://www.clarkcountynv.gov). Control measures currently being implemented are expected to offset increases in vehicular and construction project dust emissions that accompany population growth.

Energy Development

There is an almost universal consensus among the international scientific community that greenhouse gas emissions must be reduced in order to slow the rate of global warming (Abbasi and Abbasi 2010; Dincer 2000). As fossil fuel costs and the impact of their use have become more readily apparent, there has been increased industry investment and government support for the development of renewable energy sources (Kunz and others 2007). Southern Nevada has been the focus of many recent renewable energy projects, partially due to the abundance of sun and wind needed as energy sources for the generation of electricity.

Solar Energy—The arid Southwest contains a large amount of Federal lands that receive significant amounts of solar radiation, and the majority of large-scale solar facilities in the United States are slated for development on these lands. All energy development requires water, and the amount varies with the type of energy facility (Sovacool and Sovacool 2009). There are two types of utility-scale solar energy developments: solar voltaic and concentrating solar. Solar voltaic facilities require minimal water use (3.8-7.6 liters or 1-2 gallons per MWh_e). In contrast, concentrating solar facilities concentrate solar energy to generate steam for power production and require 2,850 liters (750 gallons) of water per MWh_e (Pate and others 2007), an amount four times as much as a natural gas-fueled power plant and twice as much as a coal-fired or nuclear plant (Glennon 2009). Two new solar facilities slated for construction on BLM land in southern Nevada were approved in fall of 2010 (BLM 2011a). The Amargosa Farm Road Solar Project, a concentrating solar facility, will occupy 2,558 ha (6,320 acres) just east of Amargosa, Nevada, and will consume significantly more water resources than existing photovoltaic systems operating in southern Nevada. Construction of the Silver State North Project is almost complete and occupies 250 ha (618 acres) east of Primm, Nevada. Both are located in Mojave Desert scrub. An additional project, Silver State South, is undergoing environmental analysis with a decision anticipated in 2012. Both Silver State Projects use photovoltaic technology.

Boulder City has developed a 3,200-ha (8,000-acre) solar energy zone in Eldorado Valley, an area southwest of the town but within the city limits. The largest two operational utility scale solar facilities in southern Nevada are located in this zone (Acciona Solar's Solar One concentrated solar facility and Sempra Generation's Copper Mountain photovoltaic solar facility). Additional facilities are planned for this area (BLM 2011a). Grouping all of the solar facilities in one area creates a larger impact locally, but reduces energy sprawl, fragmentation of habitat, and impacts from transmission lines and service roads on a landscape level. The BLM is examining a similar approach and is coordinating public input in an effort to determine appropriate areas to locate solar energy zones (BLM 2011a). An updated list of operational and proposed alternative energy facilities in Nevada is located under alternative energy on the BLM website (www.blm.gov/nv). While new solar facilities produce far fewer CO_2 emissions than traditional power plants, their construction and operation are not without environmental impacts. These facilities also can use tremendous amounts of already limited groundwater. The Nation's limited experience with large-scale solar facilities means that there is little on-the-ground understanding of potential impacts (McDonald and others 2009; Tsoutsos and others 2005; Turner 1982). Attention during the planning, construction and operational phases could help to minimize the potential environmental impacts listed below (Tsoutsos and others 2005).

- Facilities must be kept free of vegetation for worker safety and to prevent the possibility of heat-induced wildfires. This results in large areas devoid of vegetation.
- Dust emissions from construction, resulting in un-vegetated areas, and roads will likely increase, even though chemical dust-control agents may reduce the total amount generated. Little is known regarding potential off-site movement of chemical dust-control agents or their effect on surrounding vegetation.

- The impact of solar energy development on wildlife has not been well studied. Effects on migration corridors and genetic linkages, as well as effects on resident species are largely unknown (USGS 2010).
- Maintenance roads may serve as corridors for dispersal of invasive plant species, increased unsupervised recreational uses, and augmented food supply for ravens.

Wind Energy—Wind energy is increasingly important as a means of alternative energy production. As with solar installations, new and much larger wind farms are planned or under development. For example, the Searchlight Wind facility is planned for 780 acres of BLM land east of Searchlight, Nevada, and if approved, would include 89 wind turbines and a substation (draft EIS not yet released).

The technology to develop energy from wind on a large scale is a more mature technology than that of large-scale solar development. However, our understanding of potential ecosystem impacts of proposed large-scale wind farms in southern Nevada is severely lacking (Drewitt and Langston 2006). Studies on the effects on wildlife are particularly lacking (Lovich and Ennen 2011). Habitat types most likely affected by wind energy production in southern Nevada are Mojave Desert scrub and adjacent sparsely vegetated rocky foothill habitats. As with fossil fuel production, impacts on wildlife from wind turbines will largely come from habitat fragmentation, wildlife avoidance behavior, and bird and bat mortality, rather than from direct effects from installation (McDonald and others 2009). Recent monitoring studies indicate large numbers of bat fatalities associated with wind energy facilities (Kunz and others 2007). Potential effects on birds, including raptors and eagles, are collision mortality, displacement due to disturbance, alteration or loss of migration flyways and local flight paths, and habitat change or loss (Drewitt and Langston 2006). To date, there have not been multi-region studies of bat and bird deaths related to wind power generation.

Water Development

Water is a very critical resource in the southwest, and in southern Nevada. The municipal and county water districts in southern Nevada united to form the Southern Nevada Water Authority (SNWA) in 1991, with the goal of managing existing water resources, developing new ones, and promoting conservation (SNWA 2009). Ninety percent of the water provided by the Las Vegas Valley Water District is from Colorado River water impounded in Lake Mead. Ten percent of the water budget comes from approximately 100 municipal groundwater wells (Cohen 2011). Ongoing drought conditions have reduced the amount of flow into Lake Mead, reducing the amount of stored water to 52 percent of capacity by early 2009 (SNWA 2009). Since then, the water level of Lake Mead has continued to fall and was at 51.22 percent of a full pool on October 30, 2012 (http://lakemead.water-data.com). Climate change is expected to further deplete reservoirs due to decreased streamflow and increased evaporation rates. Based on current and projected demands, a long-term non-Colorado River water supply is needed.

The Water Resource Plan projects the need for additional groundwater resources to be brought on-line by 2020 (SNWA 2009). This has prompted the SNWA to seek further development of in-state groundwater resources, including applications to the BLM to construct a 525-km (326-mile) pipeline and drill additional groundwater wells to extract approximately 217 billion liters (57 billion gallons) of water per year from north-eastern central Nevada. The application and approval process for developing and transporting this water began in 2003. The aquifers in question are deep and extend across state lines. There are questions as to what effect groundwater pumping to provide additional water to southern Nevada will have on wells that service central Nevada and western Utah, as well as effects to surface vegetation and the wildlife that depend on this resource. Groundwater development studies are underway. The 90-day review of the draft is scheduled to be completed by spring 2013. Date for the final EIS publication has not yet been determined (BLM 2011b). In 1997, the SNWA developed the Las Vegas Valley Groundwater Management Program to protect and manage groundwater resources. Activities include development of a permanent recharge program, plugging unused wells in the valley, conservation education and increased groundwater quality monitoring. Conservation and management activities have led to a reduction in per capita water use. Between 1990 and 2008, use declined from 1,317 to 912 liters (348 to 241 gallons) per capita per day (Cohen 2011). The SNWA has adopted a goal of 753 liters (199 gallons) per capita per day by 2,035, a 17 percent decrease, yet total water usage is still projected to increase some 40 percent by that date due to population growth (SNWA 2009).

Colorado River basin water, utilized by much of the southwest, is not adequate to support increased regional populations, especially during a period of increased temperature and more frequent drought. This will put pressure on other water resources, including aquifers that support southern Nevada springs. There are three classes of aquifers in the SNAP area, mountain block, local, and regional. The three are not equally affected by ground water pumping, but all are affected by a number of above-ground stressors. The Clark County, Nevada, MSHCP Ecosystem Health Workshop, sponsored by the Desert Research Institute, was held January 29-31, 2008, in Las Vegas. Workshop participants developed a list of stressors based on previous research, past workshops, and the combined experience of the managers and researchers in attendance (Sada 2008). Most important stressors by aquifer type are given below.

- Mountain block aquifers: freezing, periodic drying from drought, low seasonal flow, avalanche, fire, and compaction and trampling by animal and human activity.
- Local aquifers: trampling and compaction by human activity and animals, water diversion, human recreational activity, and ground water removal.
- Regional aquifers: agricultural activities, pesticide contamination, water diversion, ground water pumping, grazing, and non-native aquatic species.

Work by a number of scientists in the last decade has been synthesized by Sada (2008) into a comprehensive system for prioritizing the management and restoration of Nevada springs. The Forest Service is currently developing a similar program (Solem and others 2012).

In 2010, the Spring Mountains National Recreation Area, Humboldt-Toiyabe National Forest, initiated a comprehensive Level II survey of the springs in the SMNRA. Forty-seven springs were surveyed in 2010 and 2011. This work identified over 25 types of disturbance, all of which stress the system. The most common disturbances, those found at a minimum of 30 percent of the springs sampled, consisted of:

- Soil compaction, including animal and human trails, trampling, and other ground disturbance;
- Erosion around springs and water channels;
- Large mammal disturbance from grazing (cattle are absent from the SMNRA), hoof disturbance (horses and elk), and other wild animal disturbance; and
- Water extraction effects on water availability.

There were a number of other disturbances that occurred at over 15 percent of the springs sampled, including fire, vehicle tracks, tree cutting, and flooding. The complete results are reported in Solem and others (2012).

The Mojave Inventory and Monitoring Network of the National Park Service is also beginning to monitor springs on Park Service land within the SNAP area. This work will also document stressors as more springs are sampled.

Recreation

The emergence of Las Vegas as a metropolitan area created significant needs for public lands to meet public uses. As the population in southern Nevada continues to grow, so too will the use of public lands, especially for recreation. Meeting recreational needs of both citizens and visitors to the area must be balanced with maintaining natural and cultural resources, conserving the unique biodiversity of southern Nevada's ecosystems, and maintaining the very qualities that are attractive for recreation. The majority of southern Nevada's population is concentrated in the major cities of Las Vegas, North Las Vegas, Henderson, Mesquite, Overton, Pahrump, and Boulder City. Public lands near these cities, such as the Spring Mountains and Lake Mead National Recreation Areas, and the urban/desert interface experience intense use.

According to the SNAP Recreation Team report, the most popular recreation activities are hiking, camping, viewing natural features and wildlife, and rock climbing (Holland and others 2010). Popular water activities are swimming, fishing, and boating (NPS 2009). Unregulated ATV (all-terrain vehicle) and ORV (off road vehicle) use are also favorite desert activities. A more complete review of southern Nevada's recreational opportunities is given in Chapter 10.

Population growth and accompanying increases in use of public lands for recreation puts added strain on Nevada's natural and cultural resources. The impacts of unrestricted use can be considerable, but determination of sustainable use levels is problematic, particularly under a changing climate. Insufficient funds for adequate management, staffing, and educational programs compound the problem. The most cost-efficient means of mitigating environmental damage are two-fold: the development and implementation of sound management plans and public education. For example, the BLM develops Recreation Area Management Plans (RAMPs) that identify goals and actions for recreation in designated areas. The Nevada Division of State Parks regularly updates its Comprehensive Outdoor Recreation Plan (DeLoney 2004). Public involvement helps to identify facility, infrastructure, and interpretive needs to accommodate the ever-increasing use levels. The difficulty is in providing reasonable access while still protecting cultural and natural resources. Problems accompanying recreational use include:

- Erosion from trail cutting;
- Human waste and trash from camping in undesignated areas;
- Declines in wildlife populations due to habitat fragmentation and avoidance behavior;
- Dispersal of invasive species;
- Land degradation due to off-road vehicle use and unrestricted camping; and
- Competition for scarce water resources.

Of major concern is rampant degradation from unrestricted camping and ORV use, particularly in Mojave Desert scrub. The BLM, NPS, FWS, and USFS all consider this issue of high importance (see Chapter 10). Programs are needed to educate those who consider the desert areas to be 'wasteland' of no particular value. Although ORV use is restricted to existing roads and trails in many areas, and existing roads, trails, and dry washes in some areas with specific regional restrictions), illegal ORV use occurs and damages vegetation and destroys biological soil crusts that hold the soil in place. Disturbing desert soils generates dust, reducing visibility and creating health problems.

Additionally, ORV use causes erosion, disperses invasive species, and fragments habitat for wildlife.

Public education and outreach programs are instrumental in teaching visitors about the importance and fragility of the desert environment. Most recreationists care about the environment and understand the need to balance recreation with resource conservation (DeLoney 2004). Given sufficient information, most will observe good visitor practices. For those that don't, additional monitoring and mitigation, as well as enforcement of regulations, are needed.

Insects and Disease

Insect and disease issues are not currently among the primary concerns of land managers in southern Nevada. The presence of pneumonia in Nevada populations of Desert bighorn sheep (*Ovis canadensis nelsoni*) was first reported in 1978 (McQuivey 1978). The disease appears to affect both native and domestic sheep, though not to the same extent. Stress from blowing dust and human proximity may aggravate the symptoms (Jessop 1981). Chronic wasting disease in deer and white nose syndrome in bats have the potential to occur in southern Nevada, but have not been detected within the state. Upper respiratory tract disease in the desert tortoise (*Gopherus agassizii*) is one of several factors contributing to the population decline of this threatened species. Issues associated with the decline and recovery of the desert tortoise are discussed in Chapter 6. Mistletoe and rust diseases affect conifer species in mountain areas, with white fir being the hardest hit (Guyon and Munson 1998). White-spored gall rust, found only in the Spring Mountains, affects the ponderosa pine growing there, complicating management of that species (Guyon and Munson 1998). Bark beetles cause the most insect damage, affecting bristlecone pine (*Pinus longaeva*), singleleaf piñon pine (*Pinus monophylla*), twoneedle pine (*Pinus edulis)*, ponderosa pine (*Pinus ponderosa*), and white fir (*Abies concolor*). In 2009, the Humboldt-Toiyabe National Forest conducted an aerial survey of bark beetle damage. Of the over 80,000 ha (200,000 acres) surveyed, tree mortality from mountain pine beetles occurred on 47 ha (117 acres), from western pine beetles on 5 ha (13) acres, and from piñon ips beetle on 1.6 ha (4 acres). Tree mortality from the fir engraver beetle decreased from 184 ha (461 acres) in 2007 to only 4.8 ha (12 acres) in 2009 (USFS 2009). The Humboldt-Toiyabe Aerial Insect Disease Detection Survey of 2011 (http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5349313.pdfcitation) also found a limited number of trees with indications of insect damage. Less than 210 ponderosa pines in 15 locations exhibited signs of bark beetle damage. Less than 30 true firs at two locations were damaged by fir engraver beetles. Given the large forested area of the SMNRA, these numbers did not indicate a significant insect problem in early 2011. However, during the fall of 2011, SMNRA and I&M staff noted a large number of newly infected trees within the Kyle and Lee fuel treatment areas. The extent of this beetle outbreak should be quantified during the 2012 Aerial Insect Disease Detection Survey.

In all cases, mortality increases when trees are under stress, particularly drought stress. Projected increases in temperature may allow more beetles to overwinter or complete two life cycles in one year (Lange and others 2006; Raffa and others 2008). High temperatures and prolonged drought conditions will create conditions under which outbreaks are more likely to occur. Bark beetle and rust in conifers are of greatest concern in the Spring Mountains as plant communities migrate up in elevation. Conifer communities of the future may contain species not currently found together, putting disease vectors or insect pests into new context. Plants and pathogens that have been previously separated by distance may come into contact (Flores 2008). The potential for large-scale die-offs of key species and the consequences for ecosystems can be illustrated by the recent widespread mortality of two needle piñon. In 2002-2003, 40-80 percent of piñons in a four-state region died following prolonged drought and unusually high temperatures (Breshears and others 2009). Mortality was apparently driven by protracted water stress, leading to carbon starvation and an associated increase in susceptibility to beetles (Breshears and others 2009). Regional mortality of key species has the potential to rapidly alter vegetation composition and associated ecosystem properties for decades.

Grazing

The Mojave Desert has not supported large numbers of native grazing animals since horses and other ungulates became extinct at the end of the Pleistocene, approximately 10,000 to 14,000 years before present (Grayson 1993; Thorne 1986). Horses first reappeared in North America as domesticated European stock with the second voyage of Christopher Columbus in 1493, and introductions continued in earnest throughout the Spanish colonial period through the 1700s (De Steiguer 2011). Cattle and sheep were also introduced during the same time period. At the beginning of the 1800s, bands of free roaming horses associated with the Spanish missions and rancheros in California had grown so large that efforts were initiated to reduce their numbers to protect forage for the emerging livestock industry. Western explorers, such as Lewis and Clark and Jedediah Smith, noted many bands of wild horses during the first decades of the 1800s, although their sightings were mostly from the northern Great Plains and Intermountain West. Thus, it appears that horses and livestock have likely been present in western North America for at least the past 200 years, although their historical abundance in the Mojave Desert is less well documented.

It is generally agreed that present day Mojave ecosystems did not evolve with significantly selective pressure from large-bodied herbivores (Beever and others 2003; Brown and McDonald 1995; Grayson 1987; Hall 1946), and desert vegetation is very slow to recover if overgrazed or disturbed (Abella and others 2007; Tueller 1989). Grazing, regardless of source, produces impacts on the ecosystems within the SNAP agencies' boundaries, and the greater the number of animals, the more extensive the impacts. Some disturbance impacts are common to all grazers, while others are unique to the particular grazer. These impacts are not uniform in their severity or in associated recovery times. The most significant impacts of both past and present grazing within the SNAP agencies' boundaries are disruption of soil crusts, alteration of carbon and nitrogen cycles, soil compaction, changes in vegetation cover and composition, reduction in soil seed banks, and disturbance of soil around springs (Beever and others 2003). Springs are particularly susceptible to disturbance effects. A more detailed discussion of these issues is contained in the following sections.

Livestock—Currently, livestock (cattle and sheep) grazing in the SNAP area is extremely limited and stocking rates on the few remaining allotments are well below allowable numbers. Few long-term impacts would be expected from the limited grazing occurring under current permits. No grazing is allowed in critical desert tortoise habitat (USFWS 2011). However, trespass grazing continues to be a problem in some areas (Fred Edwards, personal communication).

Despite the limited amount of grazing currently allowable, the area does carry a legacy of effects from past grazing practices when large numbers of cattle and sheep were introduced into southern Nevada. Determination of the effects of past grazing history in the Mojave can be difficult. Very few areas of truly ungrazed land exist; most areas have been extensively grazed in the past and records are either incomplete or nonexistent (Beever and Brussard 2000). Protected areas, such as military bases, can provide a reference frame for assessing the effects of historic grazing (Tueller 1989).

Historic photos and records also provide some context. Exclosures can be used to monitor recovery (e.g. Brooks 1995; Courtois and others 2004), but carry the legacy of past grazing, limiting their usefulness (Fleishchner 1994). Although most researchers agree that grazing negatively impacts desert ecosystems, there is some disagreement as to the level of these impacts (Brown and McDonald 1995 and references therein; Courtois and others 2004). This may be attributed, at least in part, to the reference community used by each author. For example, not all southwestern deserts are the same ecologically as the Mojave, and there are even subtle differences within sections of the Mojave. Also, impacts vary depending on grazing intensity (Brown and McDonald 1995).

Although the large-scale effects of grazing are typically of greatest concern, available information about livestock grazing in the Mojave Desert is in relation to localized effects (Brooks and others 2006). Grazing affects composition and production of the vegetative plant community through selective foraging. For example, at the Nevada Test Site, where grazing has been excluded for over 50 years, the blackbrush community has a healthy understory of desert needlegrass (*Stipa speciosa*) that is lacking in blackbrush sites that have been grazed (Tueller 1989). An early study by Webb and Stielstra (1979) described deteriorating range conditions due to sheep grazing, including a 60 percent reduction in understory herbaceous biomass and disruption of the soil surface. Brooks (1995) also reported increased forb biomass, shrub cover, and seed biomass following 12-14 years of livestock exclusion at the Desert Tortoise Research Natural Area. Densities of small mammals, lizards, and insects can also be affected (Fleischner 1994 and references therein; Brooks 1995).

Water sites are centers of grazing activity and are typically completely denuded of vegetation and have highly compacted and eroded soils. The effects beyond this high impact zone can extend hundreds of meters into the surrounding desert in roughly concentric gradients of impact referred to as a piosphere. In the west-central Mojave Desert, cover of invasive annual plants was shown to increase with proximity to watering sites, whereas cover and species richness of native annual and perennial plants decreased (Brooks and others 2006). Effects were most pronounced within 200 m of the watering sites, suggesting that control of invasive annual plants and restoration of native plants should be focused within the central part of the piosphere. A similar study was conducted to evaluate effects of piospheres on ant communities in the eastern Mojave Desert, but other than finding that total ant abundance was higher immediately at the high impact zone within the watering site, no gradient away from those sites was detected (Nash and others 2004).

A significant and long-lasting effect of grazing comes from soil compactions and disruption of the cryptobiotic soil crust, leading to erosion and disruption of nitrogen and carbon cycles. Biological soil crusts, present on desert soils, contribute to soil stability, nitrogen fixation, and water-holding capacity. These crusts are extremely susceptible to surface disturbance, including trampling by livestock. The recovery rate from disturbance, trampling, and compaction is long and can exceed 100 years (Belnap and Lange 2003).

Given changes in vegetative cover as described above, concurrent loss of seed banks (Brooks 1995), the advent of invasive weeds (Abella 2008), and accompanying fires (Brooks and Chambers 2011), these systems may have passed a threshold such that recovery to a pre-settlement condition is impossible, no matter how long grazing is excluded (Tueller 1989).

Wild Horses and Burros—There are five active wild horse and burro herd management areas (HMAs) in the BLM Southern Nevada District (BLM 2012). Muddy Mountain and Gold Butte HMAs have burros only, the Nevada Wild Horse Range has horses only, and the Johnnie and Red Rock HMAs have both horses and burros. The Muddy Mountain and Gold Butte HMAs, managed by the BLM, are adjacent to Lake Mead NRA, and the Wild Horse and Burro Protection Act does not apply to lands managed by the National Park Service (NPS). The NPS does not recognize HMAs and sets management prescriptions for minimal burro use on NPS lands. The NPS recognizes, however, that a certain amount of incidental use occurs from adjacent HMAs, and coordinates with the BLM on joint activities for burro management on NPS lands under the 1995 Lake Mead Burro Management Plan. The Nevada Wild Horse Range lies within the Nellis Air Force Test and Training Range, but is administered by the Las Vegas BLM Pahrump Field Office.

On BLM and USFS public lands, wild horses and burros are managed as self-sustaining populations of healthy animals with the goal of maintaining a balance with other multiple uses, including providing critical habitat for focal, threatened, and endangered species This is also called minimal management since resources are not added to the HMA in order to maintain a herd (Wild Horse and Burro Act of 1971). The issue in southern Nevada is not one of maintaining herds but rather herd overpopulation. Wild horses and burros have very high reproductive rates of 17-20 percent per year, and herds can double in size every 4 to 5 years. West-wide, as of February 2012, the BLM estimated wild horse and burro numbers at 37,300 (BLM 2012), nearly 11,000 more than the existing appropriate management level (AML). Funding for gathers (roundups) must be appropriated by Congress. Insufficient funding means that horse and burro numbers multiply beyond appropriate management levels. Also, public opinion generally runs against wild horse gathers, generating negative publicity (Resource Concepts, Inc. 2001). In a relatively new effort to control horse numbers, on March 3, 2011, the BLM announced the initiation of a 4-year study of the birth control vaccine PZP to test if the effects of the vaccine can be extended from 22 months to 3 to 4 years (BLM 2011c).

Although wild horses and burros are managed as a part of the cultural landscape, they can also have impacts that may threaten other resources. Their status as non-native species, and their potential to impact native natural resources, could lead to them being considered invasive species (Chapter 4). Wild horses and burros primarily consume herbaceous vegetation and some parts of woody vegetation in a wide variety of vegetation types in the Mojave Desert (Abella 2008), with use in southern Nevada concentrating at springs/seeps in the SMNRA. Their means of foraging differs from that of domestic livestock in a number of ways. Horses and burros are less selective in diet than domestic cattle, consuming a broad spectrum of plant species (Beever and others 2003). They are able to crop forage much closer to the ground than cattle due to the presence of upper front incisors (Beever and others 2003). Their use of lower quality forage may result in the consumption of 20-65 percent more forage than a cow of similar body mass (Hanley 1982; Menard and others 2002). Excessive use of grasses and forbs decreases the regeneration capability of these plants, resulting in decreased forage availability in successive years. Effects are concentrated at watering sites, decreasing vegetative cover by up to 90 percent and species richness by 70 percent (Beever and Brussard 2000; Beever and others 2008).

Wild horses and burros also differ in the amount of territory covered, often roaming over large areas (Abella 2008; Beever and Brussard 2000). Horses are known to roam farther from water than cattle, utilizing ridge tops and steeper slopes and making conspicuous trails (Beever and Brussard 2000). Beever and others (2003) found that several disturbance-related variables, including soil surface hardness and total plant cover, distinguished horse-occupied and non-occupied sites better than presence of palatable plant species. Ground disturbance caused by trampling, particularly in areas surrounding sensitive springs and seeps, creates conditions favorable to invasive species such as cheatgrass or red brome, or noxious weeds such as knapweed or perennial pepperweed. These weedy species out-compete native species and alter ecosystem function (BLM 2012; Cummings 2010; ENTRIX, Inc. 2008).

Non-native ungulates affect ecosystems in other ways as well, including nutrient cycling (Hobbs 1996) and diversity of small mammals and reptiles (Beever and Brussard 2004). The lack of time for ecosystems, particularly springs, to recover from the high pre-gather herd numbers is also of concern.

Wild horse and burro management is a difficult challenge and will likely be made more difficult in coming years. An examination of multiple climate change models for the southwest reveals almost universal agreement that the area managed by SNAP agencies will be warmer and dryer in the coming decades. Longer periods of drought are also predicted (Notaro and others 2012). In the context of these drying and warming trends, managers must address two relatively recent phenomenon that significantly impact the resources available for wild horse and burro herds: an increase in the biomass of exotic annual grasses and the accompanying changes in the size and frequency of wildfires.

Elk—Elk were introduced to the Spring Mountains beginning in the 1930s, with subsequent releases in the 1980s. Elk are found at higher elevations in piñon-juniper, mixed conifer, and bristlecone pine vegetation types. They prefer grasses and forbs, which are common on burned areas. Elk create trampled areas around springs and seeps, which are home to a number of rare species. Elk-created disturbance, therefore, has the potential to impact rare snails, moonworts, and other rare species (Solem and others 2011). Elk populations within the SMNRA were estimated at 246 in 1996, but subsequently declined to 130 in 2009. Reasons cited for the decline include increased recreational and off-road vehicle (ORV) use within the herd unit area, habitat degradation caused by excessive numbers of horses and burros, and extended periods of drought (Nevada Department of Wildlife 2011). An aerial survey conducted in 2010 reported sighting only 122 elk. The level of reproduction currently appears insufficient to sustain the population.

Invasive Species

Invasive Plants—Non-native invasive plants often produce large numbers of seeds that can spread rapidly across the landscape along road corridors, in contaminated animal feed, and by wind, animal, and human dispersal (Chapter 4). Invasive plants out-compete native species due to an ability to thrive on many different soil types and to utilize increased CO_2 and higher nitrogen levels that result from nitrogen deposition (Allen and others 2006; Ziska and others 2003). Invasive plants produce biomass and fine fuels that will carry fire in the interspaces between shrubs, resulting in large, relatively frequent wildfires in desert shrub ecosystems that are not fire adapted (Chapter 5). Many invasive plants respond positively and quickly after fire, limiting the recovery of the native community (Abella 2009). In addition, invasive species can alter wildlife habitat and decrease native forage species (Brooks and Pyke 2001; Chapter 4). Restoration of communities dominated by invasives is difficult and costly. In the Mojave, management of invasive plants and fire must be integrated due to the linkages between the two issues (Brooks and Pyke 2001).

Wetland and Aquatic Invasives—The problem of wetland and aquatic invasive species is on the rise in southern Nevada (Chapter 4). Saltcedar (*Tamarix* spp.) and other riparian weeds alter streambanks and lower water tables, reducing the biodiversity of critical wetland communities (Sada 2008; Howell 2011). The release of nonnative fish into springs, quagga mussels (*Dreissena rostriformis*) into lakes, and nonnative bullfrogs (*Lithobates catesbeianus*) and crayfish (*Procambaras clarkia*) into lakes, rivers, and springs are impacting the native and endemic fish, amphibians, and snail species (Sada 2008). Removal of these problematic nonnatives is often not possible, and always extremely difficult and expensive (Chapter 4).

Altered Fire Regimes

Altered fire regimes are a significant cause of concern to managers in southern Nevada. In 2005, over 400,000 ha (1 million acres) of the Mojave Desert burned, much of it in southern Nevada (Brooks and Matchett 2006; McKinley and others, in press). The introduction of non-native invasive grasses has provided the fine fuel biomass needed to carry fire across large areas of Mojave Desert scrub, including blackbrush and Joshua tree communities. The size and frequency of these wildfires are a function of precipitation and the resulting annual invasive grass fuel load. Years of high winter and spring precipitation result in a flush of invasive annual grass biomass. The shrub communities of the Mojave Desert are generally not well adapted to large-scale fire (Chapter 5). Some species, such as blackbrush, do not form a persistent seedbank (Meyer and Pendleton 2005), requiring seeds to disperse from unburned patches of surviving individuals and hindering their recovery following fires. Only a small proportion of shrub species are physiologically able to resprout following fire, and their ability to resprout is further affected by fire temperature, soil moisture levels prior to fire, and post-fire drought (Brooks and Minnich 2006; Chapter 5). In contrast to native shrubs, invasive annual grasses can more easily survive fires as seeds, especially when they are lying on the surface of the mineral soil with little to no fuels immediately adjacent to them. The post-fire shrub community is less diverse with increased fine fuel loads that are prone to more frequent fire, and thus can reset the fire cycle outside of the timeframe under which these communities evolved.

Several factors complicate post-fire revegetation efforts. Aerial seeding has had limited success, in part due to the variability and timing of precipitation (Brooks and Klinger 2012; Chapters 5 and 7). Native seed is often not available as needed for large-scale restoration projects or may be cost-prohibitive. Post-fire reduction in the number of small mammals and other species that disperse seeds also inhibits natural reestablishment of pre-fire shrub communities (Beatley 1976). Thus, restoration of the post-fire landscape is problematic. Seeding success is species and situational specific (Abella and Newton 2009). Research on both the establishment needs of desert restoration species and techniques/equipment for planting and seeding is sorely needed. A comprehensive review of Mojave Desert restoration and rehabilitation is discussed in Chapter 7.

Suppression of naturally occurring fires at upper elevations also has created a problem for land managers. Some of the high elevation ecosystem types within the southern Nevada mountain ranges are fire-adapted (Provencher 2008; Chapters 5 and 7), and have been affected by fire exclusion. Fire suppression efforts have been particularly aggressive in the Spring Mountains because of the number of residences located within the canyons. Fire within steep canyons can pose a significant danger to residents as there is typically only one egress route down-slope. A hazardous fuels reduction project was proposed in 2007 to reduce fuels adjacent to the Spring Mountain communities and to facilitate the protection of important resource values. The fuels reduction project was conducted from 2008 through 2010. An implementation and monitoring audit conducted in the fall of 2010 looked at how closely the objectives were achieved. The recommendations will be useful in implementing the 10-Year Multiagency Fuel Treatment Plan, which was completed in 2010 (METI 2010). Under this plan, six areas of the SMNRA have been identified for future fuel treatment projects. The objectives for future projects include (1) coordinate treatment of right of ways and private facilities; (2) improve egress for residents, visitors, and staff and ingress for fire crews and equipment; (3) slow or prevent the spread of fires ignited along roadways; and (4) reduce the fuel loads in chaparral and mesquite so that fire can be reintroduced as a management tool (METI 2010). Understanding fire's history and behavior in the region under different conditions would help managers effectively and efficiently manage future wildland fires and provide insight regarding the role of fire within upper-elevation communities. See Chapter 5 for a more complete discussion of fire issues and Chapter 7 for restoration associated issues.

Knowledge Gaps and Management Implications

Southern Nevada is experiencing both a novel suite of stressors and a historically unprecedented rate of climate change. With the introduction of new stressors, rapid climate change, and increased frequency and size of disturbances, the interactions among all of these stressors will drive ecosystem change in potentially unknown directions. Managers are faced with situations for which we have no current answers.

- What can be done to control the new and existing invasive species?
- How should we manage fire size and frequency?
- Where should we try revegetation and what plant materials do we use given estimates of species migration due to climate change?
- How will human impacts on water use, recreation, and energy development affect regional ecosystem stability?
- How can we prevent the loss of endemic species that have specific habitat requirements such as desert springs and "Sky Islands" in the Spring and Sheep Mountains?
- Are species resilient enough, genetically variable enough, or are their specialized habitats protected enough for them to persist in place?
- Do they have life history features that will enable them to move with changing conditions?

These questions embody some of the big issues facing managers and provide a general overview of knowledge gaps. Gaps are discussed in more detail in subsequent chapters. Additional information needs that can be obtained through research and monitoring are:

- Species-specific climate profiles and projected ranges under different climate change scenarios; methods to detect geographic shifts in plant communities and individual species.
- Effects of drought, warmer winter temperatures, and changes in precipitation amount and timing on the type and extent of insect and disease outbreaks.
- Interactive effects of naturally occurring disturbances with global change drivers such as rising levels of CO_2 and N deposition.
- Effects of N deposition and increased CO_2 levels on biogeochemical cycles including biological soil crust function.
- Appropriate plant materials and planting techniques for use in reclamation and restoration of disturbed sites under expected climate change scenarios.
- Criteria for selecting the most appropriate and least deleterious sites for energy development.

- Information on the environmental impacts of large-scale power development (including wind and solar) on animal mortality, migration corridors, seed movement, and potential off-site effects of dust and chemical dust control agents.
- Improved techniques for tracking available forage given the increase in the biomass of exotic annual grasses and the accompanying changes in the size and frequency of wildfires.

Development of education programs has the potential to mitigate many of the stressors caused by human activity. Education can point out rather simple and strait forward approaches that can minimize human impacts on the desert, while still permitting the recreational activities citizens enjoy. Educational outreach to teach citizens the economic and ecological value of energy efficiency and conservation is a step toward reducing the sprawl of energy developments in the western United States. Educational approaches in which the benefits of behavior changes are placed in an ecological context—for example, how the pieces, including humans, fit together to form the ecosystem—can instill a better sense of stewardship and a more developed conservation ethic.

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Chapter 3

Water and Water Use in Southern Nevada

Wayne R. Belcher, Michael J. Moran, and Megan E. Rogers

Introduction

Water and water use in southern Nevada is an important issue. The scarcity of water resources for both human and biologic communities often leads to intense competition for both surface and groundwaters. Anthropogenic and climate change impacts on scarce water resources need to be understood to assess human and ecosystem health for the study area.

This chapter outlines the state of the science for hydrology in southern Nevada—groundwater, surface water, and water quality. A brief summary of the knowledge of hydrology of southern Nevada is presented and recommendations for filling gaps in knowledge of the hydrology are proposed. This chapter serves as a synthesis of information to aid in meeting Sub-Goal 1.3 of the SNAP Science and Research Strategy, which is to restore and sustain proper function of Southern Nevada's watersheds and landscapes (table 1.3; Turner and others 2009).

Habitats greatly influenced by groundwater in the Mojave Desert include streams, riparian areas, and wetlands. These habitats are a relatively small fraction of the landscape, but are extremely important by any biologic measure (Miller and others 2007). These "wet" habitats contain a great deal of biodiversity, possess a relatively high vegetative density, are relied on by terrestrial mammals, and support diverse aquatic species. The conceptual model of these habitats in the Mojave Desert is that they are largely supported by groundwater (Miller and others 2007).

Study Area

The Southern Nevada Agency Partnership (SNAP) study area lies within the southern part of the Basin and Range physiographic province (Planert and Williams 1995) with most of the study area being within the internally drained Great Basin subprovince (Fenneman 1931). The very eastern edge is in the Colorado River drainage formed by the Virgin, Muddy, and Colorado Rivers (fig.1.1). The SNAP study area includes several large valleys, including the Amargosa Desert, Pahrump Valley, Las Vegas Valley, and Pahranagat Valley. The region also includes several major mountain ranges including the Spring Mountains, the Sheep and Pahranagat Ranges. Late Cenozoic tectonic activity accounts for much of the observed topographic relief across the study area (Grose and Smith 1989).

The relief between valleys and adjoining mountains locally exceeds 1,500 m (Bedinger and others 1989). Principal mountain ranges in the southern one-half of the study area trend northwest-southeast. Throughout the study area the trends of intermediate-scale topographic features are quite variable (fig.1.1).

Land Use

Most of the land in southern Nevada is owned by the U.S. Government and is administered by numerous Federal agencies, such as the Bureau of Land Management, the U.S. Fish and Wildlife Service, the National Park Service, the U.S. Forest Service, the Department of Energy, and the Department of Defense. Privately owned land is scattered throughout the region, but most private ownership is concentrated near the urban areas of Las Vegas Valley and agricultural centers of Amargosa Desert and Pahrump Valley. The major land-use activities in the region are recreation, mining and agriculture along the river corridors.

From January 1951 through September 1992, 828 underground nuclear tests were conducted at the Nevada National Security Site (NNSS; formerly the Nevada Test Site). Depths of these tests ranged from 30 to 1,500 meters below the ground surface with approximately one-third of these tests being at or below the groundwater table. This resulted in some radioactive contamination of the groundwater at the NNSA. The Department of Energy's (DOE) National Nuclear Security Administration (NNSA) has funded the Underground Test Area (UGTA) program to assess the nature, extent, and future migration of contaminants at the NNSS. Since there is no feasible method to remediate deep groundwater contamination at the NNSS, the UGTA program has a long-term strategy consisting of developing computer models to simulate groundwater flow and contaminant migration, developing a groundwater monitoring system, and establishing institutional control to limit access to contaminated groundwater in and around the NNSS.

Water Use

Water in southern Nevada is used mostly for domestic, commercial, and to a lesser extent agricultural, wildlife groundwater, military, and mining purposes. Water resources in the SNAP area include water resources for biological resources with adjudicated water rights for their protection. A significant example is the endangered Devils Hole pupfish (*Cyprinidon diabolis*) whose continued existence depends on naturally occurring spring discharges and stable pool levels in Devils Hole within Death Valley National Park. Water resources also include a number of local and regional spring sources that add greatly to the biodiversity of the area.

The study area is subdivided into hydrographic areas that generally consist of valleys separated by surface-water drainage divides (Rush 1968). The USGS and the NDWR systematically delineated hydrographic areas in Nevada for scientific and administrative purposes (Cardinalli and others1968; Rush 1968) for both surface water and groundwater. Official hydrographic-area names, numbers, and geographic boundaries continue to be used in USGS and other agency's scientific reports and NDWR administrative activities pertaining to Nevada.

Ground-water rights in Nevada are assigned according to these hydrographic areas. Where perennial yield is less than the water use, certain hydrographic areas have been "designated," meaning that certain administrative strategies have been applied to these "over allocated" (pumping is greater than the perennial yield) basins. Table 3.1 presents the hydrographic areas in the SNAP area with The Nevada State Engineer's estimated perennial yield, water use, and designation status for ground water.

Table 3.1. Water Use for Southern Nevada Agency Partnership Study Area by Hydrographic Area.

Hydrographic Area No.	Hydrographic Area Name	Designated?	Annual perennial yield (acre ft)	Annual perennial yield use (m^3)	Annual water use (acre ft)	Annual water use (m^3)
141	RALSTON VALLEY	Y (all)	6,000	7,401,715	4,306	5,311,409
145	STONEWALL FLAT	N	100	123,362	12	14,532
146	SARCOBATUS FLAT	Y (all)	3,000	3,700,858	3,535	4,361,362
147	GOLD FLAT	N	1,900	2,343,876	414	510,792
148	CACTUS FLAT	N	300	370,086	248	306,160
149	STONE CABIN VALLEY	Y (all)	2,000	2,467,238	11,532	14,226,528
157	KAWICH VALLEY	N	2,200	2,713,962	0	0
158A	EMIGRANT VALLEY-GROOM LAKE VALLEY	N	2,800	3,454,134	12	15,198
158B	EMIGRANT VALLEY-PAPOOSE LAKE VALLEY	N	10	12,336	0	0
159	YUCCA FLAT	N	350	431,767	0	0
160	FRENCHMAN FLAT	N	100	123,362	0	0
161	INDIAN SPRINGS VALLEY	Y (portion)	500	616,810	1,392	1,717,124
162	PAHRUMP VALLEY	Y (all)	12,000	14,803,430	62,597	77,220,713
163	MESQUITE VALLEY (SANDY VALLEY)	Y (all)	1,500	1,850,429	386	476,004
164A	IVANPAH VALLEY-NORTHERN PART	Y (all)	700	863,533	1,913	2,359,988
164B	IVANPAH VALLEY-SOUTHERN PART	Y (all)	250	308,405	781	963,148
165	JEAN LAKE VALLEY	Y (all)	50	61,681	340	419,875
166	HIDDEN VALLEY (SOUTH)	Y (all)	NA	NA	67	82,541
167	ELDORADO VALLEY	Y (all)	500	616,810	2,256	2,783,094
168	THREE LAKES VALLEY (NORTHERN PART)	N	3,700	4,564,391	3,700	4,564,391
169A	TIKAPOO VALLEY-NORTHERN PART	N	2,600	3,207,410	2,594	3,199,626
169B	TIKAPOO VALLEY-SOUTHERN PART	N	1,700	2,097,153	1,700	2,097,153
170	PENOYER VALLEY (SAND SPRING VALLEY)	Y (all)	4,000	4,934,477	15,083	18,606,247
171	COAL VALLEY	N	6,000	7,401,715	32	38,958
172	GARDEN VALLEY	N	6,000	7,401,715	558	688,804
173A	RAILROAD VALLEY-SOUTHERN PART	N	2,800	3,454,134	3,931	4,849,382
181	DRY LAKE VALLEY	N	12,700	15,666,964	1,066	1,314,495
182	DELAMAR VALLEY	N	2,550	3,145,729	7	8,931
197	ESCALANTE DESERT	N	1,000	1,233,619	71	87,698
203	PANACA VALLEY	Y (all)	25,000	30,840,480	29,201	36,022,729
204	CLOVER VALLEY	N	25,000	30,840,480	2,768	3,414,843
205	LOWER MEADOW VALLEY WASH	Y (all)	25,000	30,840,480	21,483	26,501,261
206	KANE SPRINGS VALLEY	N	1,000	1,233,619	1,000	1,233,619
208	PAHROC VALLEY	N	21,000	25,906,003	39	48,037
209	PAHRANAGAT VALLEY	NA	25,000	30,840,480	12,800	15,790,498
210	COYOTE SPRING VALLEY	Y (all)	1,900 to 1,8000	2,343,877 to 22,205,146	16,200	19,984,631
211	THREE LAKES VALLEY (SOUTHERN PART)	Y (portion)	4,500	5,551,286	4,500	5,551,619
212	LAS VEGAS VALLEY	Y (all)	25,000	30,840,480	95,631	117,971,794
213	COLORADO VALLEY	Y (all)	200	246,724	4,557	5,621,023
214	PIUTE VALLEY	Y (all)	300	370,086	5,039	6,216,331
215	BLACK MOUNTAINS AREA	Y (all)	1,300	1,603,705	6,048	7,460,509
216	GARNET VALLEY	Y (all)	400	493,448	3,366	4,151,795
217	HIDDEN VALLEY (NORTH)	Y (all)	200	246,724	2,275	2,805,953
218	CALIFORNIA WASH	Y (all)	2,200	2,713,962	10,568	13,036,283
219	MUDDY RIVER SPRINGS AREA (UPPER)	Y (all)	100 to 3,6000	123,362 to 44,410,291	14,557	17,958,399
220	LOWER MOAPA VALLEY	Y (all)	50	61,681	5,721	7,057,930
221	TULE DESERT	N	2,100	2,590,600	5,004	6,172,562
222	VIRGIN RIVER VALLEY	Y (all)	3,600	4,441,029	12,343	15,226,056
223	GOLD BUTTE AREA	N	500	616,810	1	1,382
224	GREASEWOOD BASIN	N	300	370,086	4	4,996
225	MERCURY VALLEY	N	24,000	29,606,861	0	0
226	ROCK VALLEY	N	24,000	29,606,861	0	0
227A	FORTYMILE CANYON-JACKASS FLATS	N	24,000	29,606,861	58	71,969
227B	FORTYMILE CANYON-BUCKBOARD MESA	N	24,000	29,606,861	0	0
228	OASIS VALLEY	Y	24,000	29,606,861	1,296	1,598,869
229	CRATER FLAT	N	24,000	29,606,861	681	840,539
230	AMARGOSA DESERT	Y (portion)	24,000	29,606,861	25,479	31,431,211

Groundwater

The current understanding of regional groundwater flow in the Great Basin came from the basin studies done under the U.S. Geological Survey and the State of Nevada cooperative groundwater program. Maxey and Eakin (1949) compared recharge and discharge estimates of individual basins and realized that many basins were not closed to groundwater transfer to or from adjacent basins. Eakin (1966) identified a system of interconnected basins of the White River and Muddy River springs area. The water budget imbalances within and between basins was useful in discerning interbasin flow and defining the basins of the White River flow system (part of the Colorado River flow system).

In southern Nevada, groundwater flow is strongly influenced by the physical framework of the system, which is characterized by aquifers, confining units, and flow barriers. Groundwater flows through a diverse assemblage of rocks and sediments in the region, and geologic structures exert significant control on groundwater movement as well (Faunt and others 2010).

The groundwater hydrology of southern Nevada, as in all flow systems, is influenced by geology and climate and varies with time. In general, groundwater moves through permeable zones under the influence of hydraulic gradients from areas of recharge to areas of discharge in the regional system. The topography produces numerous local subsystems within the major flow system (Freeze and Cherry 1979). Water that enters the flow system in a recharge area may be discharged in the nearest topographic low, or it may be transmitted to a regional discharge area (Faunt and others 2010).

Aquifers

An aquifer is "a geologic unit that can store and transmit water at rates fast enough to supply reasonable amounts to wells" (Fetter 2001: 95). The Basin and Range aquifers are located in an area that comprises most of Nevada. The water-yielding materials in this area are in valleys and basins, and consist primarily of unconsolidated alluvial-fan deposits, although locally flood plain and lacustrine (lake) beach deposits may yield water to wells. Also, the consolidated volcanic and carbonate rocks that underlie the unconsolidated alluvium are a source of water if the consolidated rocks are sufficiently fractured or have solution openings. Many of these valleys and basins are internally drained; that is, water from precipitation that falls within the basin recharges the aquifer and ultimately discharges to the land surface and evaporates within the basin. Groundwater is generally unconfined at the margins of the basins, but as the unconsolidated deposits become finer grained toward the centers of the basins, the water becomes confined. The current conceptual model of interbasin flow suggests that basins are hydraulically connected in the subsurface by fractures or solution openings in the underlying bedrock. These multiple-basin systems end in a terminal discharge area, or sink, from which water leaves the flow system by evapotranspiration. Also, several basins or valleys may develop surface-water drainage that hydraulically connects the basins, and groundwater flows between the basins, mostly through the unconsolidated alluvial stream/floodplain sediments (Planert and Williams 1995).

Three principal aquifer types exist within southern Nevada: volcanic-rock aquifers, which are primarily tuff, rhyolite, or basalt of Tertiary age; carbonate-rock aquifers, which are primarily limestones and dolomites of Mesozoic and Paleozoic age; and basin-fill aquifers, which are primarily unconsolidated sand and gravel of Quaternary and Tertiary age. Any or all three aquifer types may be in, or underlie, a particular basin and constitute three separate sources of water; however, the aquifers may be hydraulically connected to form a single source. Other rock types within the region have low permeability and act as boundaries to the flow of fresh groundwater (Planert and Williams 1995).

Regional Groundwater Flow Systems

The ground-water flow systems of southern Nevada are in individual basins and/or more hydraulically connected basins through which groundwater flows to a terminal discharge point or sink. Except for relatively small areas that drain to the Colorado River, water is not discharged to major surface-water bodies but is lost primarily through evapotranspiration. Each basin has essentially the same characteristics: the impermeable rocks of the mountain ranges serve as boundaries to the flow system, and the majority of the groundwater flows through basin-fill deposits and permeable rock formations of the mountain ranges. In the area where carbonate rocks underlie the basins, substantial quantities of water can flow between basins through the carbonate rocks and into the basin-fill deposits, but this water also is ultimately discharged by evapotranspiration. Most recharge to the basin-fill deposits originates in the mountains as snowmelt, and, where the mountain streams emerge from bedrock channels, the water infiltrates into the alluvial fans and replenishes the basin-fill aquifer. Intense thunderstorms may provide some direct recharge to the basin-fill deposits, but, in most cases, any rainfall that infiltrates the soil is either immediately evaporated or taken up as soil moisture. Thus, little water percolates downward through the unsaturated zone to reach the water table in the valleys. In mountain areas underlain by permeable carbonate rocks, most of the recharge may enter the carbonate rocks and little water remains to supply runoff (Planert and Williams 1995).

Groundwater flow in southern Nevada is dominated by interbasin flow with several relatively shallow and local flow systems that are superimposed on deeper intermediate and regional flow systems (fig. 3.1). The regional groundwater flow patterns do not coincide with local topographic basins. Regional groundwater flow generally follows the regional topographic gradient as water moves toward the lowest point in the region at Death Valley, California, for groundwater flow systems in the Great Basin (Faunt and others 2010) or toward the Colorado River for those groundwater flow systems in the Colorado River drainage (Harrill and others 1988).

Interbasin flow has been established by scientific studies over the past century. Interbasin flow, although it is not uniform between all basins, is common and is a function of the hydraulic gradient between basins and hydraulic conductivity of the intervening rocks. Several decades of geologic and hydrologic work in the Great Basin province led to the conclusion that groundwater flow results from an interconnected, complex groundwater flow system (Carpenter 1915; Eakin 1966; Eakin and Moore 1964; Eakin and Winograd 1965; Harrill and others 1988; Hunt and others 1966; Mendenhall 1909; Mifflin 1968; Mifflin and Hess 1969; Winograd and Thordarson 1975). Knowledge of interbasin groundwater flow through bedrock and basin-fill deposits of the region is the basis for regional groundwater management and water-resource planning in the Great Basin province. The concept and development of interbasin flow is summarized in Belcher and others (2009).

In the prevailing conceptual model of interbasin flow, water enters the system as interbasin underflow and as recharge from precipitation in upland areas. Because of present-day arid conditions, present-day recharge is restricted to higher altitudes; virtually no recharge occurs and no perennial surface water flows in the lowlands and valley floors (Winograd and others 2005). Groundwater flow paths within the system diverge from the highlands and are superimposed on deeper regional flow paths that are controlled largely by flow in the regional carbonate-rock aquifer. The SNAP area

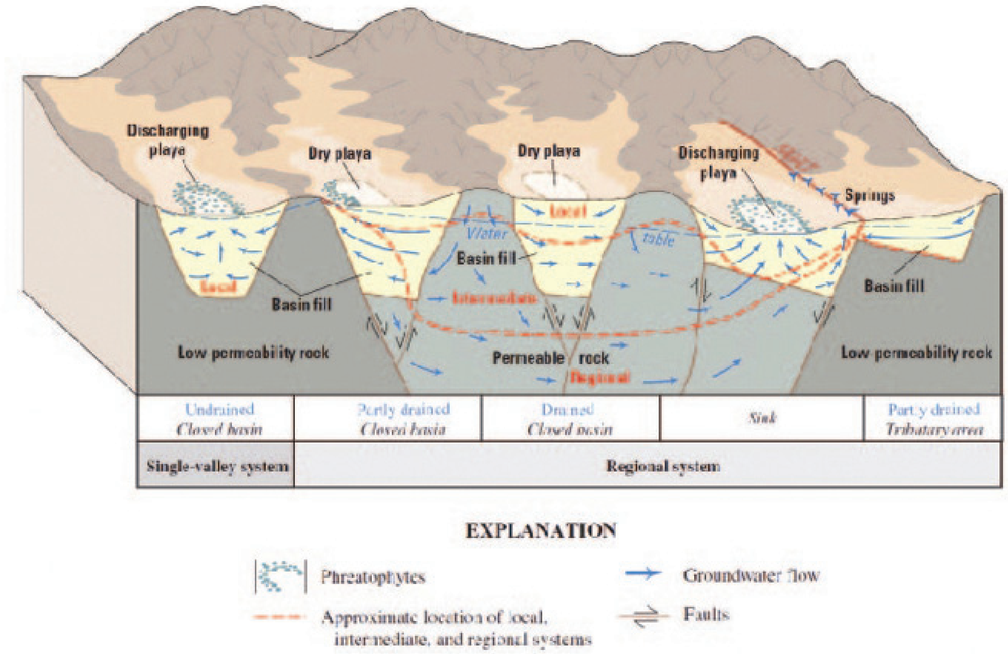

Figure 3.1—Schematic block diagram illustrating the structural relations between mountain blocks, valleys, and groundwater (interbasin) flow (Faunt and others 2010; modified from Eakin and others 1976).

is contained within two regional groundwater flow systems: the Death Valley flow system and the Colorado flow system (Harrill and others 1998; fig. 3.2). The Death Valley flow system is located in the southern part of the Great Basin province and is approximately 100,000 km^2 in area; it consists of recharge areas in the mountains of central and southern Nevada and discharge areas of wet playas and springs south and west of the Nevada National Security Site and in Death Valley, California. The Colorado flow system is located in the Colorado River drainage system just east of the southern part of the Great Basin and is approximately 42,000 km^2 in area. Recharge areas are in some mountainous areas within the flow system, but recharge to the system is also from groundwater flow from adjacent flow systems. The Virgin and Colorado Rivers are the major discharge areas of the system.

Water Budgets

A basic way to evaluate the occurrence and movement of groundwater in an aquifer system is to develop a water budget accounting for the aquifer system's inflows (recharge) and outflows (discharge) (Laczniak and others 2007). A water budget is developed to evaluate the balance between the flow into and flow out of a groundwater flow system. The primary components of a regional water budget are natural discharge (evapotranspiration and spring flow), pumpage, recharge, and lateral flow into and out of an area (estimated by using Darcy calculations or existing water budgets). The introduction of pumping as a discharge from the flow system initially decreases hydraulic heads and ultimately affects one or more flow components by decreasing natural discharge or by increasing recharge, as well as by removing groundwater from aquifer storage (San Juan and others 2010).

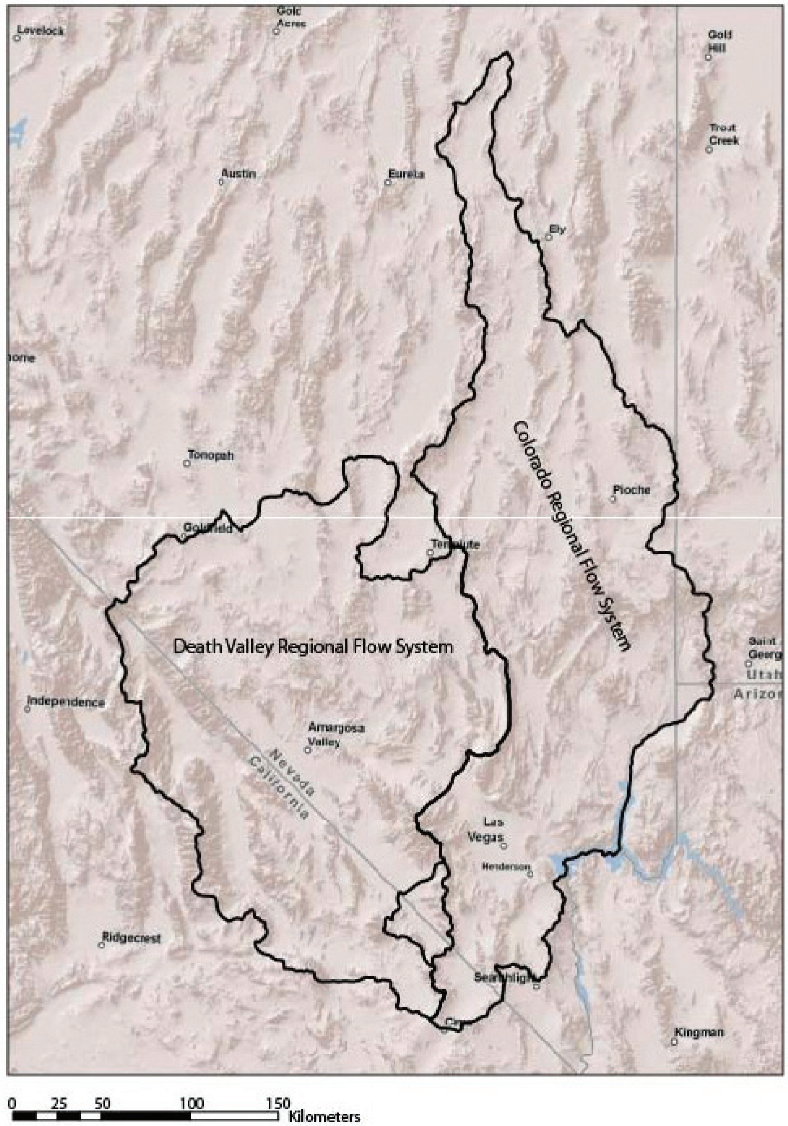

Figure 3.2—The Death Valley and Colorado regional groundwater flow systems (Harrill and others 1998).

The relation between precipitation and evapotranspiration is a major factor in water availability. Generally, if annual precipitation exceeds annual potential evapotranspiration, then there is a net surplus of water and streamflow is perennial. However, annual potential evapotranspiration can exceed annual precipitation, which causes a net deficit of water. A net annual moisture deficit occurs almost everywhere in Nevada. Water is available to recharge aquifers only at times when precipitation or snowmelt is greater than actual evapotranspiration (Planert and Williams 1995).

Current sources of groundwater flow in the region are (1) recharge from precipitation in the mountains (usually winter storms) within the model domain, and (2) lateral flow into the study area, predominantly through the carbonate-rock aquifer via interbasin flow. Most groundwater recharge results from infiltration of precipitation and runoff on the mountain ranges (Bedinger and others 1989). Water may infiltrate from melting snowpack in the mountains primarily on volcanic or carbonate rocks or adjacent to the mountains from streams flowing over alluvium (fans and channels) (Harrill and Prudic 1998).

Groundwater discharge in the region is from:

1. seeps and spring flow from the regional carbonate-rock aquifer and local systems;
2. evapotranspiration (ET);
3. pumpage for irrigation, mining, public supply, commercial, and domestic uses; and
4. subsurface flow in or out of the groundwater basins of the study area (Harrill and others 1988).

Most natural groundwater discharge today originates as spring or seep flow caused by variations in permeability created by geologic structures and varying lithologies (Winograd and Thordarson 1975). In particular, many of the regional (larger volume and higher temperature) springs occur along major faults. For example, at Ash Meadows, a high concentration of springs exists. More than 30 springs and seeps are aligned in an approximate linear pattern spanning about 10 miles. Spring discharge varies substantially across the area with a maximum measured discharge of nearly 3,000 gal/min at Crystal Pool. The combined measured discharge has been estimated at about 10,500 gal/min. More than 80 percent of the measured springflow discharges from nine of the springs (Laczniak and others 1999). Groundwater flow is impeded by the presence of one or more buried faults (Gravity fault) that down drop the carbonate bedrock block beneath and west of Ash Meadows. The contrast in hydraulic properties between the more permeable faulted and fractured carbonate rock and the juxtaposed, less permeable basin-fill deposits hinders southwestwardly flowing groundwater forcing it upward to the surface, producing the springs at Ash Meadows (Winograd and Thordarson 1975). Pohlmann and others (1998) concluded that springs in Black Canyon south of Hoover Dam included components from local, sub-regional, and Lake Mead sources. These local springs are unrelated to large, regional groundwater flow systems like those in the carbonate-rock aquifer. Justet and others (in preparation) reach similar conclusions with these springs being from locally derived groundwater most likely driven by the hydrostatic pressure of Lake Mead.

Most regional spring discharge is ultimately consumed by evapotranspiration. Major discharge areas primarily occur in the lower part of intermontane valleys where the potentiometric surface is near or above land surface.

In addition to direct spring flow measurement, natural groundwater discharge in the SNAP area is estimated by calculating ET. The underlying assumption of this approach is that most of the groundwater issuing from springs and seeps within a discharge area ultimately is evaporated or transpired locally and therefore is accounted for in estimates of ET. Evapotranspiration (ET) refers to water evaporated or transpired from the regional groundwater flow system, not water evapotranspired from precipitation infiltrating into the shallow flow system. ET estimates in the SNAP area includes work presented in reports by Laczniak and others (1999, 2001) and DeMeo and others (2003, 2006) for Ash Meadows and the Death Valley flow system and DeMeo and others (2008) for the Colorado River flow system. These investigations were similar in that continuous micrometeorological data were collected to estimate local ET rates, and remotely sensed multispectral data were used to distribute measured ET rates over the area evaluated.

Discharge also occurs as pumping for irrigation, mining, public supply, commercial, and domestic uses (Bedinger and others 1989; Moreo and Justet 2008; Moreo and others 2003). Since 1959, pumpage inventories have been conducted almost annually by the NDWR in Pahrump Valley, and since 1983, almost annually in all valleys with irrigation (NDWR 2011, http://water.nv.gov/data/pumpage/, last accessed May 26, 2011). Moreo and Justet (2008) compiled pumpage estimates for the Death Valley regional flow system, which comprises a large part of the SNAP study area.

Lateral flow from one basin to another (interbasin flow) has been compiled by Harrill and others (1988) based on the series of reconnaissance reports done under the U.S. Geological Survey and the State of Nevada cooperative groundwater program.

Surface Water

In the study area, perennial streamflow is sparse, with the exception of the Colorado River drainage. Most surface water in the region is either runoff or spring flow discharge. Precipitation falling on the slopes of the mountains forms small, intermittent streams that quickly disappear and infiltrate as groundwater recharge. In addition, several streams originate from snowmelt in the high altitudes of the Spring Mountains. Both of these types of streams have highly variable base flows and in dry years have almost imperceptible discharges. Springs maintain perennial flow for short distances in some of the drainages.

Fluvial Systems

In most of Nevada, nearly all the streams that originate in the mountains are ephemeral and lose flow to alluvial aquifers as the streams emerge onto the valley floors. In southern Nevada, there are three main fluvial systems: The Colorado River (Lakes Mead and Mohave), the Virgin and Muddy Rivers, and the Las Vegas Wash (fig. 3.3). The Colorado River is supplied primarily by runoff from the Rocky Mountains. The Virgin and Muddy Rivers and the Las Vegas Wash are all tributaries to the Colorado River. The Muddy River begins as a series of regional springs in Moapa Valley and drains into the northern arm of Lake Mead (Colorado River). The Virgin River originates in Navajo Reservoir in southwestern Utah and enters Lake Mead from the north (forming the northern arm of the lake). Prior to the construction of the Hoover Dam, the Muddy River joined the Virgin River. The Las Vegas Wash drains Las Vegas Valley and largely contains urban runoff, shallow groundwater, reclaimed water, and storm water runoff. The Las Vegas Wash supports a large wetland. USGS measures discharge on all four of these rivers.

Flow in the Colorado River and its tributaries (Muddy and Virgin Rivers) is monitored by entitlement holders, the Bureau of Reclamation, and the USGS. The flow is monitored to assess the amount of Colorado River that is diverted, returned, and consumptively used to determine whether individual users have exceeded their entitlement of water (Matuska 2011). The Southern Nevada Water Authority and the USGS have measured water quality on the Muddy River at various times as part of tributary inflow to Lake Mead. The USGS has monitored water quality (temperature, specific conductance, sediment concentration, and chemical analyses) on the Virgin River since 1948 to assess salt-loading problems by establishing baseline loading conditions over a variety of hydrologic conditions.

The Colorado River drainage is the main source of water for southern Nevada. Approximately 90 percent of southern Nevada's water resources are obtained from the Colorado River and its tributaries (Southern Nevada Water Authority 2011, http://www.snwa.com/html/wr_index.html, last accessed May 26, 2011). The state of Nevada is permitted, by the Colorado River Compact of 1922 and the Boulder Canyon Project Act of 1928, an allotment of 300,000 acre-feet per year from the Colorado River and its tributaries.

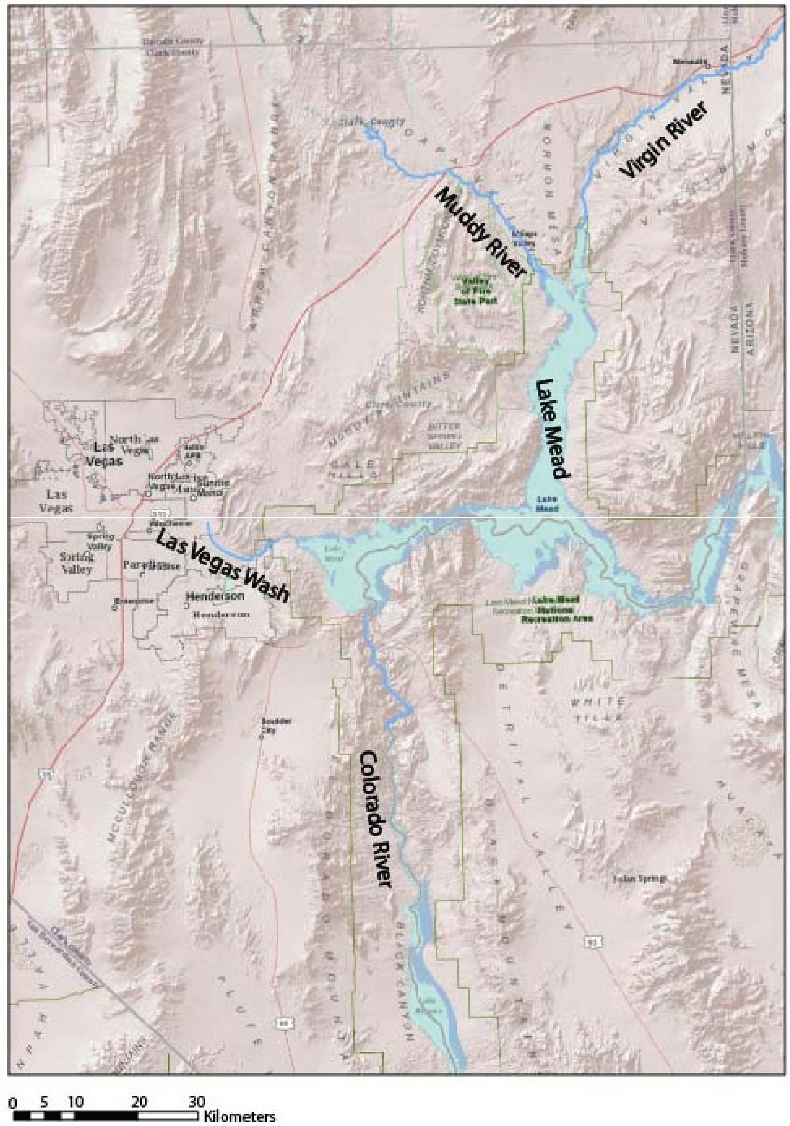

Figure 3.3—Perennial fluvial system in southern Nevada.

Springs

A spring is where groundwater flows to the land surface. Spring discharge can form pools or creeks and can provide water to plants and animals. Most of the groundwater discharged naturally in southern Nevada flows from springs and seeps. Springs also are an important and complex component of the groundwater budget. Spring discharge can originate from a local or regional source, or a mixture of more than one source. Geography, geology, and precipitation control spring discharge. Discharge from springs can flow along the land surface, infiltrate back into the groundwater system, evaporate, be transpired, or undergo a combination of these processes. Measurable properties of spring discharge reflect these sources, controls, and processes, and therefore can be used to estimate local or regional components of the study area groundwater budget.

In southern Nevada, springs are an important water resource. Historically, Native Americans, early pioneers, miners and settlers, and modern residents (including farmers and ranchers) have used spring water for drinking, bathing, agriculture, mining, and recreational purposes. Many of the settlements and towns in the study area are located near larger springs that have been a source of water for humans since Native Americans began utilizing them thousands of years ago. Springs in southern Nevada support a large amount of the aquatic and riparian species in arid regions (Fisher and others 1972; Gubanich and Panik 1986; Myers and Resh 1999; Williams and Koenig 1980).

Because springs are sourced ultimately in groundwater, increased groundwater pumping from existing wells and new points of diversion, could impact nearby water-dependent ecosystems by reducing the amount of groundwater discharge and decreasing shallow water tables. Increased pumping could result from increasing water supplies for population growth and from the development of solar power plants. Springs emanating from perched aquifer systems in the higher mountain ranges in the study area are threatened by climate change.

Springs help sustain unique aquatic, riparian, and phreatophytic ecosystems, some of which support threatened or endangered species endemic to the region. Some of the more recognizable threatened or endangered species include the Devils Hole pupfish (*Cyprinodon diabolis*), the Ash Meadows Amargosa pupfish (*Cyprinodon nevadensis mionectes*), and the Moapa dace (*Moapa coriacea*) (http://www.fws.gov/endangered/, last accessed Sept. 1, 2011).

Groundwater discharges at the Ash Meadows National Wildlife Refuge, Pahranagat National Wildlife Refuge, the Moapa Valley, at numerous springs and seeps in the mountainous areas, and along parts of the Amargosa River. Additionally, groundwater is intersected at Devils Hole, a fissure in the regional carbonate-rock aquifer in the Ash Meadows area. Several hundred springs are scattered throughout Clark County and basic environmental and biological characteristics of the larger discharge springs have been inventoried (Sada 2000; Sada and Nachlinger 1996, 1998). The MSHCP reported 506 springs in Clark County, although most of these springs dry frequently and fewer than 200 springs occur persistently in Clark County (Sada, 2000; Sada and Nachlinger 1996, 1998). Most springs can be classified as local (low discharge and cool temperatures) or regional (high discharge and warmer temperatures).

Local Springs—Local springs are generally low volume, low temperature springs that mostly discharge from areas within the mountain ranges of southern Nevada. These local springs are believed to be derived from local recharge from precipitation. Local springs occur both at higher altitudes in mountainous areas and at lower altitudes adjacent to mountain fronts. The higher altitude springs are less susceptible to impacts from pumping than their lower altitude counterparts. Because these local springs are dependent on local recharge from precipitation, changes in precipitation patterns as a result of climate change could impact their discharge. In most cases, only the locations of the springs (derived from the USGS National Hydrologic Dataset) are available. Discharge and water quality information is not routinely collected for most local springs by the USGS or any other Federal, state, or local agency. The Nevada Natural Heritage Program classifies one wetland in the extreme southern part of the study area as a “priority wetland” for conservation: Mojave riparian wetlands along the Colorado River below Davis Dam (Skudlarek 2008).

In the Spring Mountains, water moving laterally from bedrock and alluvial aquifers to the surface form the over 100 surveyed springs (Hershey 1989; Purser 2002; Sada and Nachlinger 1998). Spring discharge varies from year to year with some springs drying up annually, some drying only after extended droughts, and others flowing continuously

(Sada and others 2005). A few perennial streams (such as Carpenter Canyon, Clark Canyon, Cold Creek, Deer, McFarland, Santa Cruz, Sawmill, and Willow) are associated with large springs and/or spring complexes (Hughes 1966; Maxey and Jameson 1948; Nachlinger and Reese 1996).

Regional Springs—Regional high-volume springs having flows greater than 1,500 cubic meters per day (m^3/d) discharge in Ash Meadows (60,000 m^3/d), Manse Spring in Pahrump Valley (5000 m^3/d), Pahranagat Valley (60,000 m^3/d from Hiko, Ash, and Crystal Springs), the Muddy River springs area in Moapa Valley (10,500 m^3/d), and Rogers and Blue Point Springs along Lake Mead in the Muddy Mountains (4,200 m^3/d and 1,400 m^3/d, respectively) (fig. 3.4). Typically, these regional springs discharge water with temperatures greater than 30 degrees Celsius (°C) directly from the rocks that make up the regional carbonate-rock aquifer (Harrill and Prudic 1998; San Juan and others 2010). Discharge from these large springs is typically taken up by evapotranspiration. The exception to this is Muddy Springs in Moapa Valley, which discharge into the Muddy River (Harrill and Prudic 1998). Discharge from these regional springs is measured by the USGS and cooperating agencies and entered into NWIS.

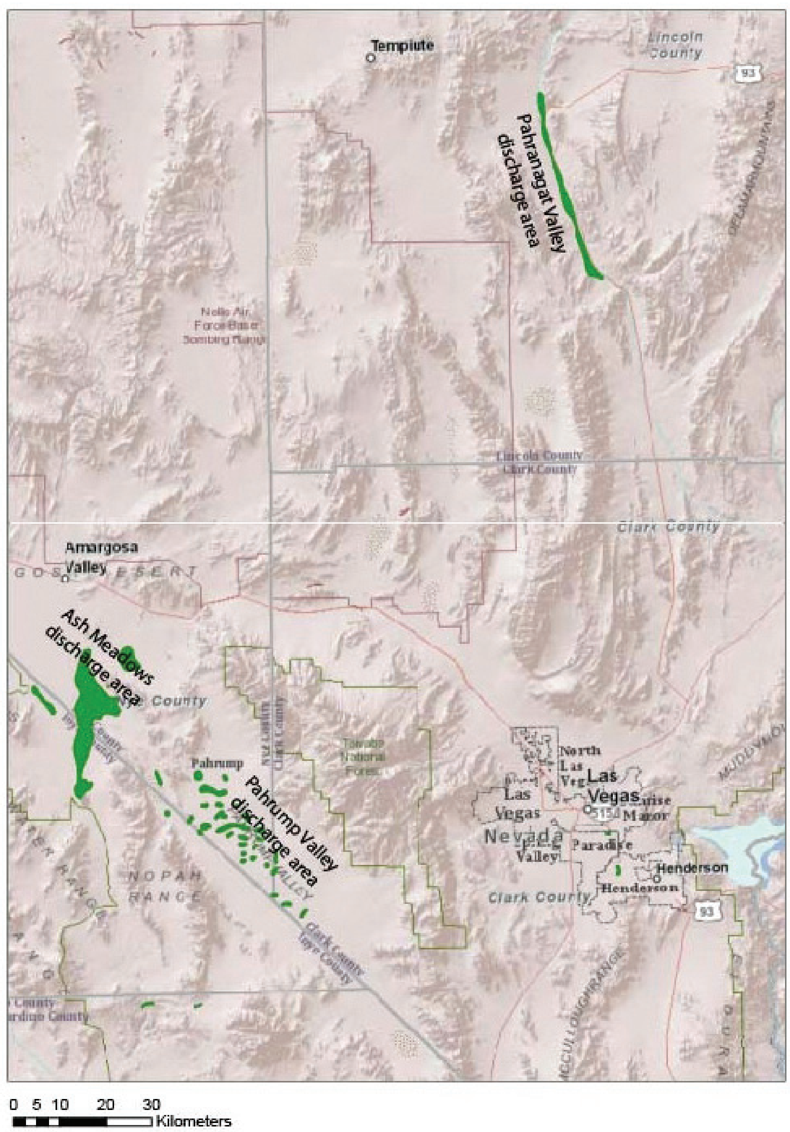

Figure 3.4—Regional spring discharge areas in southern Nevada (Harrill and others 1988).

In some areas in southern Nevada (Ash Meadows in the Death Valley regional system and the Virgin River in the Colorado River system), diffuse discharge has been estimated by using micrometerological stations and remote sensing to estimate the amount of regional evapotranspiration from some major discharge areas in southern Nevada (DeMeo and others 2008; Laczniak and others 2001).

Water Chemistry

Water chemistry issues within the Lake Mead National Recreation Area (LAME) probably have the greatest visibility in Southern Nevada. Lake Mead is the largest and one of the most intensely used reservoirs in the western United States. Many human activities can affect the chemistry of water in Lake Mead such as boating and fishing, runoff from agricultural lands, inflows of treated wastewater, and urban runoff. Many of the water chemistry issues that affect LAKE have been summarized in a U.S. Geological Survey (USGS) Circular titled Lake Mead National Recreation Area Aquatic Ecosystem (Rosen and others 2012).

Perchlorate and mercury are two contaminants that have been found in LAME that have anthropogenic sources (Shimshack and others 2007; USEPA 2001). Studies suggest that perchlorate and mercury may have health effects on fish populations in LAME (Cizdziel and others 2003; Crouch 2003; Kramer 2009; Snyder and others 2002). Concentrations of organic contaminants have been high enough in Lake Mead to cause toxicity or endocrine disruption to aquatic organisms (Advanced Concepts and Technologies International 2010). Better understanding of the sources, transport, and fate of contaminants is important to understanding their effects on aquatic organisms and the overall aquatic ecosystem of LAME.

Water chemistry has been studied in several rivers in the southern Nevada, most notably the Muddy and Virgin Rivers. The USGS has analyzed a variety of chemical constituents in samples from these rivers including major ions, nutrients, and pesticides. Although these data have not been analyzed, the results suggest that anthropogenic activities influence the chemistry of water in these rivers. In desert landscapes common in Southern Nevada, springs provide the only reliable source of water and support unique ecosystems. The chemistry of water from springs is critical to the abundance and diversity of species found at springs (Sada and others 2005). For example, spring snails are restricted to portions of springs that provide suitable physical and chemical conditions (Sada 2008). In general, human disturbances of the natural ecosystems at springs have been limited to livestock trampling and recreation and have not resulted in significant changes in the water chemistry of springs.

The USGS has conducted several intensive studies of the water chemistry of springs in several areas of Southern Nevada region. Samples from 28 springs throughout Clark County were collected from July 2008 to September 2010 and analyzed for a variety of chemical constituents. Results indicate that the groundwater from these springs is derived from various aquifers in the region. In Black Canyon south of Hoover Dam, springs support unique riparian ecosystems. Using geologic and geochemical methods, it was determined that the source of water to springs in Black Canyon is locally derived groundwater most likely driven by the hydrostatic pressure of Lake Mead (Justet and others, in preparation).

Hydrologic and Water Quality Data Collection

The USGS investigates the occurrence, quantity, quality, distribution, and movement of surface and groundwater and disseminates the data to the public: Tribal, state, and local governments; public and private utilities; and other Federal agencies involved with managing Nevada's water resources. In 1889, the U.S. Geological Survey established its first gaging station in Nevada that provides data to the public about Nevada's water resources.

The USGS has a distributed water database that is locally managed within the Nevada Water Science Center. Surface water, groundwater, and water quality data are compiled from these local, distributed databases into a national information system. Data collected on behalf of or by cooperating agencies is compiled, quality-assured, and entered into the database. Information from these sites is served on the Internet through NWISWeb, the National Water Information System Web Interface. NWISWeb provides all USGS water data that are approved for public release.

The USGS also collects and analyzes chemical, physical, and biological properties of water, sediment, and tissue samples. The NWISWeb discrete sample database is a compilation of over 4.4 million historical water quality analyses in the USGS district databases through September 2005. The discrete sample data is a large and complex set of data that has been collected by a variety of projects ranging from national programs to studies in small watersheds. At selected surface-water and groundwater sites, the USGS maintains instruments that continuously record physical and chemical characteristics of the water including pH, specific conductance, temperature, dissolved oxygen, and percent dissolved-oxygen saturation. Supporting data such as air temperature and barometric pressure are also available at some sites. Published and provisional hydrologic and water quality data collected or compiled by the USGS are available online: http://waterdata.usgs.gov/nv/nwis/nwis.

The USGS and various DOE contractors routinely collect groundwater levels at the NNSS to aid in the development of the groundwater models. USGS collected data is entered into NWIS, but much of the information collected by DOE contractors is not. Data from the USGS NNSS programs, in addition to being available in NWIS, are available at: http://nevada.usgs.gov/doe_nv/. While budget constraints at the DOE for monitoring has resulted in a reduced monitoring network, many Federal agencies still see value in continuing to collect this information. Many wells from the old Yucca Mountain monitoring network have been picked up for continued water-level data collection by Interior agencies (USGS, BLM, and FWS) and Nye County.

To assist with these efforts to better understand the dynamics of Lake Mead, the USGS, in cooperation with the National Park Service, Southern Nevada Water Authority, and Clark County Water Reclamation, collects water-quality, water-velocity, and meteorological data as part of its Lake Mead Monitoring Network. Studies are currently underway to determine temporal changes and spatial distributions of natural and anthropogenic chemical compounds in Lake Mead. The USGS currently maintains one monitoring station on the lake in Boulder Basin south of Sentinel Island. The Sentinel Island station records depth-dependent measurements of water temperature and specific conductance and hourly averaged meteorological data (air temperature, relative humidity, solar and net radiation, and wind speed and direction). The Black Canyon station records depth-dependent measurements of water temperature, specific conductance, dissolved oxygen, pH, and turbidity. The water-quality data are collected every 6 hours beginning each day just after midnight. Both stations are equipped to record hourly water-velocity data.

The Southern Nevada Water Authority (SNWA) collects water-quality data from source water as well as finished drinking water as part of providing a safe drinking water supply to the Las Vegas metropolitan area. This includes collecting water-quality data from Lake Mead, the largest source of drinking water for Las Vegas. The USGS cooperates with SNWA to collect water-quality data from Lake Mead as well as other areas of southern Nevada including the Virgin River and Colorado River below Hoover Dam. Other Federal, state, and local agencies collect water-quality data in southern Nevada including the U.S. Bureau of Reclamation (BOR), the U.S. Environmental Protection Agency (EPA), the Clark County Water Reclamation District (CCWRD), the City of Las Vegas, and the City of Henderson. The BOR collects water-quality data from Lake Mead while the EPA collects water-quality data below Hoover Dam. The CCWRD, City of Las Vegas, and City of Henderson cooperate to collect water-quality data at a number of sites in the Las Vegas Wash and from Lake Mead.

Knowledge Gaps and Management Implications

As climate change and increasing populations potentially reduce available water supplies for both human and biologic communities, the collection and interpretation of information to define and assess local and regional hydrologic conditions becomes vital. Assessing the information that is regularly collected by Federal agencies in southern Nevada has indicated that there are several gaps in data collection. Since there tends to be a project by project approach to data collection, at times there is no long term program(s) to collect data. Data are collected for the goals of a certain project and once the project is completed, data collection ends. There is very little long-term continuity or planning on basic data collection that could be used to assess the hydrologic and biologic health of the study area.

Base Conditions of Springs and Rivers

Base conditions of springs and rivers just prior to settlement of southern Nevada are largely unknown. A qualitative assessment of these conditions could be accomplished by examining historical records (such as early settler diaries and journals, military exploration reports, and 19th century scientific reports) and compiling observations of streamflow and springs conditions.

Water Levels

Water levels are currently collected by a variety of agencies over the SNAP area for a variety of purposes. This work is primarily project based. Collection of water-level data is concentrated in few areas (for example, Las Vegas Valley, Pahrump Valley, Amargosa Desert, and the Nevada National Security Site). For some hydrographic areas there is very little or no water-level data. The water level data is essential to establishing baseline conditions of and estimating amounts of regional groundwater flow. Work could be done to establish areas where a paucity of data exist and then canvass these areas for existing wells that could be used to collect water levels. In areas where no wells exist, it may be necessary to drill wells to be able to obtain water-level information.

Pumping Inventories

Currently, the pumping inventories in the study area are estimated by Nevada Division of Water Resources (NDWR) in irrigated valleys, along with some project specific work (such as the Death Valley regional flow system). A systematic method of estimating pumping using the existing inventories, along with remote sensing for the entire

SNAP study area on an annual basis would aid in estimating water budgets. Updating the water use data base would involve:

1. Acquisition and processing of Thematic Mapper imagery to estimate irrigated acreage;
2. Compiling State Pumpage Inventories;
3. Estimating, by user and location, annual groundwater pumpage; and
4. Entering annual pumpage estimates into a database.

Evapotranspiration Estimates

Estimates of evapotranspiration (ET) are performed by government and (or) scientific organizations on a project-by-project basis and rarely as a comprehensive program. Estimates of ET could be performed to assess the amount of water discharging from the regional groundwater system over the entire study area. These estimates could be repeated every few years to assess potential impacts of changing recharge due to climate change. High-resolution multi-spectral imagery will be used to delineate the extent, density, and diversity of riparian vegetation within groundwater discharge areas. Discharge area mapping techniques would be based on land-cover classification methods and defined vegetation index threshold values. The accuracy of these mapped discharge areas will be assessed with field-based ground-truth observations. Atmospheric and water-level data would be measured with micrometeorological stations consisting of eddy-covariance and energy-balance sensors. Each ET site will also be equipped with rain gages to measure precipitation, and a monitoring well equipped with a pressure transducer to monitor daily and seasonal groundwater-level fluctuations. Periodic collection of samples and additional field measurements will be needed to partition between phreatophytic consumptive use of groundwater, precipitation, and periodic surface water flow. At each ET site, precipitation, plant-stem water, soil water, groundwater, and surface water flow, if available, could be sampled quarterly and analyzed for stable hydrogen- and oxygen-isotope concentrations. The isotope data will be used as a tracer to evaluate the relative proportion of source waters (precipitation, groundwater, and possibly surface water) contributing to the measured ET. Soil-water content could be measured quarterly using a neutron-moisture probe to document seasonal changes in soil-water storage (upper 1 m) that occur in response to precipitation, surface water flow, and ET.

Recharge Estimates

Knowing the amount of recharge in the mountainous areas is an important component of a water budget. In the past, recharge amounts have been estimated using a variety of methods, with generally more sophisticated methods utilized as the processes involved in recharge became better known. Recently, more sophisticated methods of estimating the amount of recharge to the groundwater system have been developed. These newer methods should be used to get more accurate estimates of recharge for water budgets. Net infiltration has been used as a proxy for groundwater recharge from infiltration (San Juan and others 2010). Net infiltration for the DVRFS was estimated using a distributed-parameter method, INFILv3, described by Hevesi and others (2003). As an extension and improvement of this method, these existing estimates were refined and updated using the more recent Basin Characterization Model (BCM) that has been used in the Great Basin (Flint and others 2011). Direct measurement or improved estimates of precipitation could be helpful in refining these estimates of recharge. Additionally, both INFILv3 and BCM use streamflow estimates as calibration points; collection of more streamflow discharge could help to constrain the model.

Interbasin Flow

Knowing the amount of recharge from underflow from adjacent basins would help to refine water budgets and assess natural resource damage in a hydrographic basin from activities in adjacent basins. Currently there are rough estimates from the NDWR Reconnaissance Reports and from several regional groundwater models constructed for various uses in southern Nevada. A review of the existing hydrologic and geologic data and results from numerical models for both the Death Valley and Colorado flow systems could help to refine the amount of interbasin flow in the study area.

Spring Discharges

Establishing baseline conditions for spring discharge and water quality would be useful for restoration work, management guidelines and to better understand effects of climate change and other anthropogenic impacts to these ecosystems. Currently, several springs in the study area are monitored by various Federal agencies using full continuous stage/discharge streamgages or biennial or quarterly direct discharge measurements. These springs are mostly regional springs emanating from the carbonate-rock aquifer. While the regional springs play a significant role in evaluating overall water resource viability in the study area, more data are needed on important local springs in mountainous areas. These data would be useful for assessing water budgets and the potential for climate change associated with lessening recharge.

The collection of continuous stage/discharge data is required for calculating spring output and assessing seasonal and overall trends. For instance, a drop in stage and discharge at a given spring could indicate potential drawdown from pumping nearby. Not every local spring is large enough to support a full streamgage; field reconnaissance to assess target springs must be completed.

On those springs that support sensitive species of fish and other animals, water quality data are needed to establish baselines and direct conservation efforts. At the very least, simple water temperature probes can be installed for monitoring continuous water temperature data. For a more robust solution, continuous water quality probes that collect many different chemical parameters (i.e. temperature, conductance, pH, and turbidity) can also be considered. Historical baseline conditions of springs could be obtained by searching historical records from the 19th and early 20th centuries. Mendenhall (1909) has descriptions of springs in the Mojave Desert from the late 19th and early 20th centuries.

Streamgaging

Direct measurement of peak flows in natural streams presents a unique challenge in the desert environment. During summer monsoons, rain can be localized and peak flows on streams can last 30 minutes or less. A worker must essentially be on-site when the rain begins in order to measure summer peak flows. During winter rains, peak flows can last from several hours to several days but often contain very high sediment and debris loads, which make direct measurements extremely difficult and unsafe to attain. Acoustic Doppler profiling technology is favored for quickly measuring highly unstable elevated flows as measurements can be obtained in as little as 12 minutes. Recent advances in Doppler technology have made it more useful for measuring discharges with high sediment loads. Conventional current meter methods can also be used to measure discharge in those streams where Doppler would be impractical. Direct measurement of peak flows coupled with long term flow monitoring would greatly aid in assessing a more accurate total water budget for surface water. Although less preferable than long-term flow monitoring, short-term studies focusing on synoptic streamgaging (i.e. performing multiple discharge measurements on the same stream at the same time to provide a "snapshot" of conditions) would help improve understanding of where the streams lose or gain flow from the groundwater system.

Measurements of peak flows can be made either from a bridge or cableway or by wading. Wading is typically very unsafe in desert washes where the water can rise from a trickle flow to several feet deep in a short period of time. However, many streamgaging sites are located in areas where a bridge or cableway does not exist. In cases where a worker cannot enter the water to directly measure, an indirect measurement of discharge must be done after the water has receded. High water marks such as debris piles, mud lines, and cut marks are flagged and surveyed and an approximate discharge for the flood is computed. Indirect methods can be accurate to within 5 percent of true peak discharge, but often are only within 20 percent of the peak. More cableways must be funded and installed in areas where bridges do not exist.

While channel-mounted up-looking acoustic devices can work well for directly measuring discharge in unwadeable stable channels (for instance, concrete-lined irrigation ditches), they do not work well for most natural channels in southern Nevada due to scour and fill processes occurring in the channel during flow. Instrumentation installed in concrete-lined urban channels in the Las Vegas Valley have issues with vandalism, theft, and the potential for urban debris striking and damaging or destroying expensive equipment during periods of flow. Additionally, these urban channels undergo annual or semi-annual cleaning during which debris is scraped from the channel using heavy machinery. Any instrumentation placed in the channel has the potential to be damaged during these operations.

Should cableway installation be impractical and direct measurement of discharge impossible, a series of crest stage gages (CSGs) could be installed in selected indirect measurement reaches. A CSG is a piece of pipe with caps on the top and bottom vertically anchored next to a stream. There are a series of holes in the sides of the caps, a wooden stick inside the pipe, and powdered cork in a reservoir in the bottom cap. During high flows, water enters the bottom of the pipe through the holes in the cap and carries the powdered cork up as it rises inside the pipe. As the water recedes a cork line is left on the stick, which provides a very reliable high water mark from the flood. High water marks in CSGs are more accurate than those determined by debris piles, mud lines, or cut marks and help reduce the uncertainty in indirect discharge measurement computations. If several CSGs are installed in a given gaged reach, an accurate high water mark profile and slope can be determined. These, in turn, would be used to determine the amount of stream discharge that could be used to improve long-term monitoring efforts.

Water Chemistry and Quality

Numerous gaps in water-quality information exist in Southern Nevada and the data needed are dependent on the area of interest and the scientific question to be answered. An example of a data gap is the lack of information on stable isotopes of hydrogen and oxygen in precipitation water. Understanding the modern signature of stable isotopes in precipitation relative to groundwater is important in delineating modern from ancient recharge and enhances understanding of the sources and flow paths of groundwater and the sustainability of groundwater resources.

Data Repositories

While the USGS maintains a large database on hydrologic information (NWIS), there are hydrologic data collected by various governmental and scientific organizations that are not contained within these national databases and thus cannot be used for answering questions concerning management of the natural and cultural resources of the study area. Some effort needs to be put forth to capture these data and enter them into NWIS for use by scientists working in southern Nevada, as well as the general public.

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Chapter 4

Invasive Species in Southern Nevada

Matthew Brooks, Steven Ostoja, and Jeanne Chambers

Introduction

Southern Nevada contains a wide range of topographies, elevations, and climatic zones emblematic of its position at the ecotone between the Mojave Desert, Great Basin, and Colorado Plateau ecoregions. These varied environmental conditions support a high degree of biological diversity (Chapter 1), but they also provide opportunities for a wide range of invasive species. In addition, the population center of the Las Vegas valley, and the agricultural areas scattered throughout Clark, Lincoln, and Nye counties, all connected by a network of roads and highways, plus ephemeral and perennial watercourses, provide abundant opportunities for new invaders to be transported into and within southern Nevada (Brooks 2009; Brooks and Lair 2009).

Invasive species are a concern for land managers because they can compete directly with native species (Brooks 2000; Chambers and others 2007; DeFalco and others 2003, 2007; Mazzola and others 2010), change habitat conditions (Brooks and Esque 2002; Esque and others 2010; Miller and others 2011), and alter ecosystem properties (Brooks and Matchett 2006; Brooks and Pyke 2001; Evans and others 2001). Many invasive species have already established and spread to the point that they are now considered to pose significant problems in southern Nevada. However, there are likely many more that have either not been transported to or colonized the region, or have established but for various reasons not spread or increased in abundance to the point where they have a significant impact. Land managers must understand both current and potential future problems posed by invasive species to appropriately prioritize management actions.

This chapter addresses Sub-goal 1.2 in the SNAP Science Research Strategy (table 1.3; Turner and others 2009), which is to protect southern Nevada's ecosystems from the adverse impacts of invasive species. It provides a brief overview of the key concepts associated with the ecology and management of invasive species, and includes information relevant to all five strategic goals identified by the National Invasive Species Council: prevention, early detection and rapid response, control and management, restoration, and organizational collaboration (National Invasive Species Council 2001, 2008). Restoration also is discussed in a broader context in Chapters 5 and 7. This chapter does not present a comprehensive review of all invasive species or associated land management issues in southern Nevada, but rather uses key species of concern to illustrate invasion ecology concepts and management strategies. It is focused on terrestrial and aquatic plants and animals, and does not address potential invasive taxa from the other Kingdoms. The information presented herein is intended to provide a foundation upon which land management plans can be developed and project-level decisions can be made relative to the management of invasive species in southern Nevada.

Overview of Invasive Species Management

Executive Order 13112 issued by President Clinton in 1999 called for the establishment of the inter-departmental National Invasive Species Council (NISC) and directed its members to create a national plan to serve as a comprehensive blueprint for Federal action on invasive species. This plan was published in 2001 (National Invasive Species Council 2001) and was updated in 2008 (National Invasive Species Council 2008). It identifies five strategic goals: prevention, early detection and rapid response, control and management, restoration, and organizational collaboration. It also includes priority strategic action plans with objectives and implementation tasks for 2008 through 2012. These documents provide the guiding principles and priorities for invasive species management on Federal lands, including those in southern Nevada.

Invasive species are defined as "a species that is 1) non-native (or alien) to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health" (National Invasive Species Council 2001). Many non-native species do not cause harm, and are actually beneficial to humans (e.g., crop species). Others are clearly invasive and harmful outside of their native range (e.g., European starling). Still other non-native species are considered invasive by some, but beneficial or otherwise desirable by others (e.g., some ornamental plants, wild and free roaming horses and burros). Land managers, policy makers, and society in general must determine which non-native species are invasive and pose the greatest threats, and which are the most important to actively manage.

Species invasions proceed through the general phases of transport (long distance dispersal), colonization, establishment, and spread (Booth and others 2010). Each stage presents unique challenges and opportunities for management actions to control invasive species. As a general rule, preventing transport and colonization of potential invaders is the most effective approach to invasive species management. This is accomplished by state and Federal noxious species lists and associated quarantine and inspection processes preventing the import and sale of these species as a first and most effective line of defense.

There is also a need for early detection, prioritization, and rapid response to manage invading species that slip through the inspection and prevention cracks. Because there are more species than can be managed, a prioritization process is key to refining early detection plans and to improving the detectability of the highest priority species. Depending on the types of existing information and resources available to process the information, a generalized, prioritized, or optimized monitoring plan can be developed to improve the efficacy of monitoring efforts (Brooks and Klinger 2009; fig. 4.1). These same concepts can be used to prioritize sites and species for control efforts. Species invasions often stall at the establishment phase when spread of local populations may be constrained by dispersal and/or environmental barriers (Richardson and others 2000). This lag in spread may persist for decades, offering the best opportunity to prioritize and control locally established populations.

Understanding the mechanisms of propagule pressure and resource availability can facilitate both detection and control efforts (Brooks 2009; Mazzola and others 2010; fig. 4.2). Propagule pressure is related to the number or density of seeds and other plant parts capable of dispersing and establishing. Resource availability refers to amount of resources necessary for plant growth. A generalized monitoring plan can be developed with a basic understanding of where propagule pressure is likely to be highest (e.g., along roadsides, near urban or agricultural centers) and where resource availability is highest (e.g. riparian areas, mid elevation ecosystems, intermittent washes, roadsides) (Brooks 2009). In addition, depending on the relative significance of propagule pressure or resource availability, management actions can either focus on reducing numbers of plants and propagules (e.g., herbicides, mechanical thinning) or reducing resource availability (e.g., increasing nutrient uptake by soil microbes or promoting the growth of competitive plants).

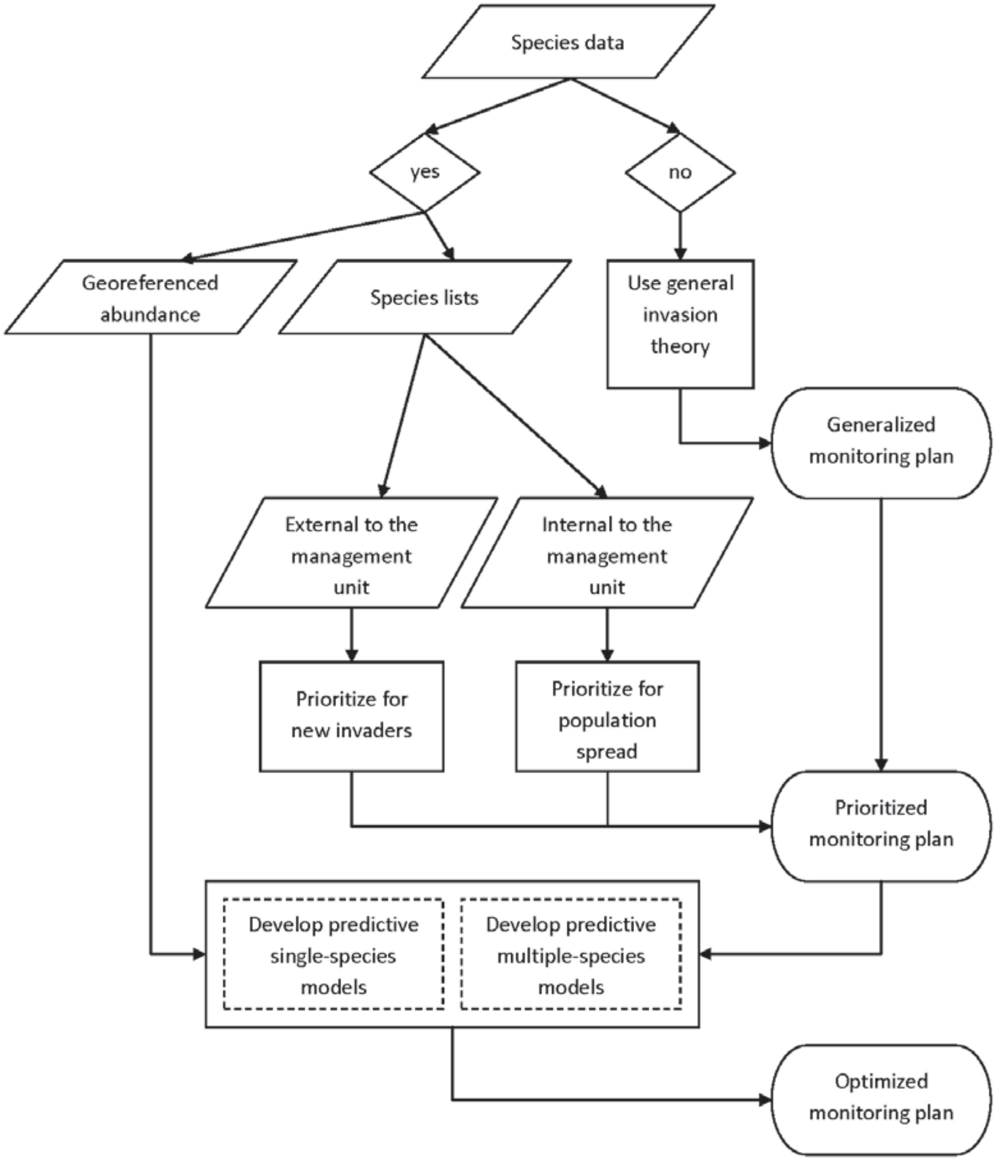

Figure 4.1—Steps for developing early detection monitoring plans (reprinted with permission from Brooks and Klinger 2009).

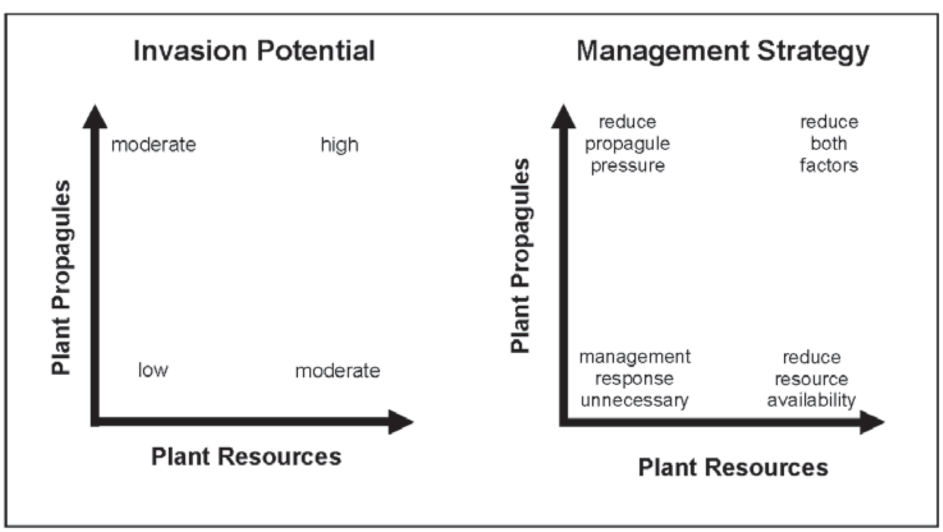

Figure 4.2—Main factors affecting plant invasions and management responses (modified with permission from Brooks and Lusk 2008).

The Interagency Weed Sentry Project in Clark County, Nevada, was a significant early detection effort that began in 2004 with protocol development and lasted through 2009. It was focused on surveying roadsides, trails, and shorelines (Lake Mead and Lake Mojave) to detect and record the location of new plant invaders (Abella and others 2009). These survey areas represent centers of propagule dispersal and locally high resource availability, and corridors of movement of species among regions (Brooks and Lair 2009). However, other recognized pathways of invasion in the Mojave Desert occur along riparian and dry wash corridors (Abella and others 2009; Brooks 2009), and it is possible that many species are missed by not surveying these areas. The Weed Sentry Program also focused search efforts on a subset of likely invaders with the most potential to cause the greatest management problems. Although this approach ignored established species, some of which cause the greatest management problems (e.g., *Bromus* spp. that alter fire regimes) (Brooks and Esque 2002; Brooks and Pyke 2001), it provided for a more efficient survey approach for newly invading species (Abella and others 2009; Brooks and Klinger 2009). This early detection program was discontinued in 2010, but agencies have continued to inventory invasive species on their own lands through various methods including aerial surveys and incidental observations associated with other field efforts.

Once new populations of invading species are identified, they need to be prioritized for control efforts. Species prioritization is typically based on relative threats posed, dispersal and spread potential, current range and extent patterns, and in some cases feasibility of control (Warner and others 2003). Site prioritization considers the conservation value of the site, the location relative to other nascent populations (especially if it is on the leading edge of the invasion front), and feasibility of control at the site. Control efforts may include chemical, mechanical, or cultural treatments, alone or in combination with each other. Follow-up control treatments are often required to improve efficacy.

Although much of invasive species management is focused on detection, prioritization, and control efforts, the most efficient and effective way to manage these species is to restore or maintain resistance of southern Nevada ecosystems to invasion. For example, functional diversity of plants is positively correlated with resistance to invasion (Brooks and Chambers 2011), so managing ecosystems to restore or maintain a wide array of plant life forms can hinder plant invasions. More detailed discussion of this topic is presented in Chapters 1 and 7.

Invasive Plants

Uplands

What are upland invasive plants and how did they get here?—The majority of invasive plant species that dominate upland areas in southern Nevada are annual life forms (Brooks and Esque 2002). Annuals complete their entire lifecycle in 1 year, germinating, growing, reproducing, and dying, typically within the winter to spring time period. They are ideally suited to avoid the inhospitable arid conditions that characterize most of the year by remaining dormant as seeds in the seedbank. Seeds also provide an ideal mechanism for dispersal, allowing annual species to spread both within and among areas (Brooks 2009).

Invasive annual grasses are significant components of all southern Nevada ecosystem types except for the alpine and bristlecone pine ecosystem types. Cheatgrass (*Bromus tectorum*) is found mostly in the mixed conifer, piñon-juniper, sagebrush, and blackbrush/shadscale types. Within the Mojave Desert scrub ecosystem, red brome (*Bromus rubens*) dominates the upper elevations, and Mediterranean split-grass (*Schismus barbatus*, *Schismus arabicus*) the lower elevations. The most widespread invasive forb is red-stemmed filaree (*Erodium cicutarium*), which occurs in significant numbers from the piñon-juniper, ecosystem all the way down to the lower elevations of Mojave Desert scrub. Other species of note include various mustard species (*Brassica tournefortii, Hirshfeldia incana, Sisymbrium irio, Sisymbrium altissimum*, *Malcomia africana*), which occur mostly within the Mojave Desert scrub type. Burr buttercup (*Ceratocephala testiculata*), prickly Russian thistle (*Salsola tragus*), and Russian knapweed (*Acroptilon repens*) are common invaders in sagebrush, piñon-juniper, and mixed-conifer ecosystems. The invasive perennial green fountaingrass (*Pennisetum setaceum*) also is escaping ornamental plantings and spreading by windblown and sheet flooded seed along dry washes much as it has done in the southern Mojave Desert and Sonoran Desert (Matthew Brooks, personal observation while living and working in the Las Vegas Valley during the 2000s). Specific locations of spread in southern Nevada are from ornamental planting in the Las Vegas valley and Laughlin areas into upland springs in the Newberry Mountains and along the shorelines of Lake Mohave and Lake Mead (C. Deuser, personal communication).

What are effects of upland invasive plants?—The greatest and most well documented threat that annual invasive plants pose to upland areas of southern Nevada is the alteration of fire regimes (Chapter 5). Most of southern Nevada is characterized by Mojave Desert scrub, which, because of its relatively low native plant cover, has experienced little historic fire. Accordingly, species that inhabit this ecosystem type have generally not evolved tolerance to fire (Brooks and Minnich 2006). Cheatgrass and red brome colonized North America during the late 1800s, have spread into southern Nevada, and since at least the 1930s have filled the interspaces between native perennial plants and persisted as standing fuels creating a continuous fuelbed that can carry fire. These same invasive grasses typically increase in dominance following fire and promote a shortened fire return interval that facilitates type-conversion of native shrublands into non-native invasive grasslands. Fire is considered one of the primary threats to the recovery of the desert tortoise (*Gopherus agassizii*), a Federally threatened species (USFWS 1994). Fire in Mojave Desert scrub also may have negative effects on forage production, aesthetic and recreational resources of value, and soil stabilization (Chapter 5).

Invasive plants also can outcompete individual native plants for limiting resources, especially in the seedling stage (e.g., Defalco and others 2003, 2007), although it is unknown what the net effects of competition are on native populations and communities. In addition, the seeds of some invasive plants (e.g., red brome, red-stemmed filaree) are eaten and also dispersed by native granivores, although these seeds may have differing nutritional quality compared to native species (Kelnick and MacMahon 1985). The desert tortoise will consume standing crops of red brome if there is little else to eat (Esque 1994), and this may cause physiological problems associated with potassium levels (Nagy and others 1998).

How can upland invasive plants be managed?—Annual plants are notoriously difficult to manage. Their seeds are easily dispersed and often remain viable for many years. Preventing their transport into new areas of southern Nevada is the best first line of defense, followed by eradication or containment of nascent populations (Brooks 2009). Washing of equipment and removal of propagules from shoes and clothing before leaving infested areas also can help reduce dispersal rates (Brooks and Lusk 2008). Repeated treatment over a period of years, typically with herbicides, is generally required until the soil seedbank becomes exhausted. Supplemental watering to stimulate seeds to germination may help expedite multi-year control efforts. However, repeated control treatments of the same type, especially herbicide treatments, may lead to selection for resistant invasive plant genotypes and thus complicate future control efforts (Radosevich and others 1997).

Management aimed at increasing the ecological condition of degraded ecosystems and restoring disturbed ecosystems also are viable strategies for managing invasive plant species (Chapters 5 and 7). Resistance to annual bromes is significantly increased by native perennial species, especially grasses and forbs, which are their strongest competitors (Allen and others 2002; Booth and others 2003; Chambers and others 2007). Because sagebrush, piñon-juniper, and mixed conifer ecosystems evolved with fire and periodic disturbance, vegetation management treatments that reinitiate succession and maintain high structural and functional diversity can increase resistance to invasion and prevent conversion to invasive species dominance following disturbances like fire or drought. Wildland use fire, prescribed fire, and mechanical treatments can be used to decrease woody species dominance, prevent high severity fire, and increase the competitive abilities of native grasses and forbs (Brown and others 2000; Pyke 2011). Due to inherently low resistance of Mojave Desert scrub ecosystems to invaders, management must focus on protection and eliminating or reducing stressors such as fire, dispersed recreational activities, ORV use, and overgrazing by wild horses, burros, and cattle.

Riparian/Aquatic and Springs

What are riparian/aquatic invasive plants and how did they get here?—Riparian and spring ecosystems are characterized by both annual and perennial invasive plant species but the most apparent are often perennials (Dudley 2009). Perennial species that have clonal or rhizomatous life forms or that are capable of root sprouting are ideally suited to survive the scouring floods and sediment deposition that often typify arid riparian ecosystems. These species also are often highly competitive with native riparian species. The most infamous perennial invader in southern Nevada is tamarisk or saltcedar (primarily *Tamarix ramossisima, T. aphylla*), which occurs in both riparian and spring ecosystems. This species was introduced to North America as an ornamental in the 1800s, and has subsequently spread throughout the continent (Dudley 2009). Most invasive species in these ecosystems are facultative or obligate riparian species that require elevated water tables for their establishment and persistence (USDA Plants Database 2012). Facultative or obligate riparian species in southern Nevada include the perennials, giant reed (*Arundo donax*), Russian olive (*Elaeagnus angustifolia*), camelthorn (*Alhagi pseudalhagi*), and perennial pepperweed (*Lepidium latifolium*), and the annual rabbitsfoot grass (*Polypogon monspeliensis*). Upland species that utilize seasonal increases in water availability or that occur at the periphery of these ecosystems include Russian knapweed (*Acroptilon repens*), invasive annual grasses such as ripgut brome (*Bromus diandrus*), red brome, and cheatgrass, and invasive mustards.

There are few aquatic plant invaders in southern Nevada, and those that are currently present do not pose serious threats. However, there are a few poised to invade that do pose real threats. Eurasian water-milfoil (*Myriophyllum spicatum*) has been reported along the Colorado River in the vicinity of Parker Arizona (Jacono and Richarson 2011) and giant salvinia (*Salvinia molesta*) has been reported farther downstream at the Imperial National Wildlife Refuge (Howard 2011).

What are the effects of riparian/aquatic invasive plants?—Because of their growth over many years, perennial species can attain large size, displace native vegetation, and significantly affect the physiographic structure of vegetation stands (Dudley 2009).

For example, conversion of native riparian vegetation to tamarisk stands can affect wildlife habitat quality and ecosystem properties associated with fire and hydrologic regimes (Dudley 2009). However, this ecosystem continues to support a diversity of species including two birds of conservation concern—the yellow-billed cuckoo (*Coccyzus americanus*) and the southwestern willow flycatcher (*Empidonax traillii extimus*)—that utilize tamarisk stands to forage and even nest in when native vegetation is unavailable (Bateman and Ostoja 2012). Giant reed, Russian olive, perennial pepperweed, Russian knapweed, and camelthorn can also significantly alter the structure of riparian communities, but are currently confined to a few localized populations in southern Nevada.

Eurasian water-milfoil and giant salvinia have the potential to choke out waterways, increase eutrophication, disrupt food webs, and otherwise significantly alter aquatic habitats of southern Nevada (Howard 2011; Jacono and Richarson 2011). These changes could threaten everything from endemic animals such as pupfish and spring snails, to game species such as sunfish, bass, and trout.

How can riparian/aquatic invasive plants be managed?—Challenges associated with controlling and managing riparian invasive plants differ from those of uplands. Many perennial species have persistent below-ground roots and rhizomes that make eradicating populations difficult (e.g., giant reed, perennial pepperweed). Also, seeds and other propagules are readily transported in flowing water and by the animals that utilized these ecosystems. Mechanical or prescribed fire treatments are often used initially to reduce aboveground biomass and stimulate resource re-allocation from belowground to aboveground tissue. Then, after regrowth has occurred, chemical treatments are used as a follow up to kill the plants. Treatment of resprouts may be necessary during subsequent years. Recently a biocontrol leaf eating beetle introduced to control tamarisk has spread into southern Nevada along the Virgin River corridor and is in the process of killing or at least reducing the vigor of tamarisk plants in that region (Bateman and others 2010). Long-term success of control treatments often requires restoration with native species and continued monitoring to detect reoccurring or new invasions.

Options for controlling aquatic plants are limited once the species have established local populations. Educational programs promoting watercraft washing and periodic inspections at entry points are potentially the most effective way to prevent transport and colonization of new waterways.

Invasive Animals

Terrestrial

What are terrestrial invasive animals and how did they get here?—While perhaps less conspicuous and less abundant than invasive plants, invasive animals can have significant ecological and economic consequences in southern Nevada. Small cryptic species like Argentine ants (*Linepithema humile*) and imported red fire ants (*Solenopsis* spp.) are difficult to detect and can be challenging to identify. Red imported fire ants, native to South America, were originally introduced to the southern United States between 1918 and 1930. While the ecological effects of this introduction are not fully known, existing data suggest cause for concern (Dowell and others 1997; Porter and others 1988). Native to Brazil and Argentina, Argentine ants are thought to have been originally introduced by coffee ships in the southern United States and have slowly moved west in landscape material and potted plants (Suarez and others 2001).

Africanized honey bees have also recently invaded southern Nevada from initial introductions in South America. Other non-native species like the heavily managed wild horses (*Equus ferus*) and burros (*Equus asinus*) represent a historical place holder for the American West and are thought by many to be a national cultural treasure, emblematic of the pioneer spirit of the West. In fact, the 1971 Wild Free-Roaming Horse and Burro Act (Public Law 92-195) specifically states, that "It is the policy of Congress that wild free-roaming horses and burros shall be protected from capture, branding, harassment, or death; and to accomplish this they are to be considered in the area where presently found, as an integral part of the natural system of the public lands…" Nonetheless, wild horses and burros come with an ecological cost (Abella 2008; Beever and Brussard 2004), and could potentially be categorized as invasive species as defined by the National Invasive Species Council (National Invasive Species Council 2001) if not for their specific exclusion from such distinction. Burros specifically were heavily used in the 1800s to assist with mining operations but were released or escaped and became wild as operations declined (Abella 2008). Effects of wild or otherwise free roaming cattle are also of concern especially near watering sites, and feral dogs (*Canis familiaris*) and cats (*Felis catus*) can pose significant threats to native animals near urbanized areas.

What are the effects of terrestrial invasive animals?—Argentine ants are successful and voracious predators in part because they will combine territories and attack other insects including native ant colonies, lizards, snakes, and small mammals (Grover and others 2008). Red imported fire ants compete with native fire ants, prey on invertebrates and vertebrates, and may affect plant assemblages by selective seed removal. In addition, red imported fire ants prey on solitary bees that pollinate native plant species (Vinson 1997). Because these ant species prefer relatively moist areas, their impacts will most likely be near urbanized areas and springs, seeps, and riparian areas.

Even though wild horses and burros maintain that iconic image of the American West and are protected on public lands under the 1971 Wild Free-Roaming Horse and Burro Act, some studies suggest they can cause significant ecological effects (Abella 2008; Beever and Brussard 2004). Heavy use by horses and burros can result in reduced plant cover and diversity and increased soil disturbance and potential erosion. Abella (2008) found that wild burros prefer grasses and forbs and are more likely to consume native Indian ricegrass (*Achnatherum hymenoides*) than would be expected by chance. Wild horses can cause damage by trampling vegetation, soil compaction, and overgrazing (Ostermann-Kelm and others 2008). Bighorn sheep (*Ovis canadensis nelson*) are reported to avoid water sources when wild horses are present and their densities are reduced by 75% where horses are present (Ostermann-Kelm and others 2008).

The full impact of feral cats and dogs is not well known for southern Nevada, but due to extensive urban development there is a continuous supply of feral pets that have the potential to directly and indirectly impact native wildlife groups (Denny 1974; Lowry 1978). It is known that feral cats and dogs are among the main predators of the Federally protected desert tortoise (Bergman and others 2009) in addition to birds and other wildlife. Dogs hybridize with native canids (coyotes, *Canis latrans*, in the case for Southern Nevada) and the highest ratio of dog-coyote hybrids is near large human population centers (Mahan and others 1978). Packs of feral dogs also pose a direct threat to humans and could negatively affect recreational use of public lands in southern Nevada.

How can terrestrial invasive animals be managed?—Control of invasive ants can be difficult. Aside from baiting and chemical control, few options exist and even these may have some residual impact to non-target groups. Because wild horses and burros are Federally protected on public lands under the Wild Horse and Burro Act, local resource managers need to review options and assess impacts against desired conditions when it comes to their control and management. Removals are conducted, but require continued monitoring and follow-up control efforts. Local exclosures can be used to protect critical habitat features and resources, and fertility control is a recent option that requires additional study. Feral cat and dog control can also be very tricky. Trapping is considered an effective control strategy for feral cats and dogs, but requires close coordination with adoption groups and is usually coupled with fertility control. (Barnett 1986). However these methods are difficult to implement due to negative public responses associated with animal rights concerns as well as complexity and costs.

Aquatic

What are aquatic invasive animals and how did they get here?—Several notable aquatic invasive species exist in southern Nevada including the quagga mussel (*Dreissena rostriformis*), bullfrogs (*Rana catesbeiana*), red swamp crayfish (*Procambarus clarkii*), and various species of fishes (Bradley and Deacon 1967). Quagga mussels are freshwater mollusks and are perhaps the most notorious aquatic invasive species in the region. This small zebra-shell-patterned mussel has spread across the western United States as larva in boat livewells and bilges and as adults when attached to boat hulls, engines, aquatic weeds, or other surfaces. Quagga mussels are present in Lake Mead and Lake Mojave and may have spread to various upland freshwater sources. The American bullfrog was introduced to southern Nevada in the 1920s (Jennings and Hayes 1994) and is now widespread in wetlands in Las Vegas Valley, Indian Springs Valley, and the Muddy and Virgin River valleys and in several upland springs in the region. The red swamp crayfish is native to the southeastern United States, is commonly used as bait by fishermen, and has become established in southern Nevada. Various species of fishes, including the mosquitofish (*Gambusia* spp.), red shiner (*Notropis leutrensis*), shortfin molly (*Poecilia mexicana*), cichlids (*Oreochromis* spp.), and tilapia (*Tilapia* spp.) have been introduced to southern Nevada. The mosquitofish was intentionally introduced to the region for control of mosquitos in ponds and other abandoned water sources (Bence 1988). Cichlids were introduced in various fresh water sites around Lake Mead NRA. Red shiners are thought to have been introduced through the emptying of bait buckets, but it is also a common aquarium fish (Nico and Fuller 2010; Nico and others 2011).

What are the effects of aquatic invasive animals?—Quagga mussels directly threatened water supplies and associated water diversion and management operations since they can clog pipes and compromise water intake systems. In addition, they can clog engines and encrust boats, docks, and associated facilities, alter the aquatic food web, impact sport fishing, and litter beaches with their small sharp shells. The economic cost associated with quaggas can easily reach millions of dollars.

Bullfrogs are aggressive and voracious predators of native toads and frogs, reptiles, small mammals, and birds; some of which are listed under the Endangered Species Act. Along the Muddy River, bullfrogs and red swamp crawfish are thought to be responsible for the elimination of the relict leopard frog (Bradford and others 2004) and have preyed on other amphibians in other regions (Gramradt and Kats 1996).

The mosquitofish, red shiner, and cichlids have adversely affected native invertebrates, amphibians, and fishes (USFWS 1995). Mosquitofish have been known to harm, kill, and outcompete other small fishes, including natives (Haynes and Cashner 1995; Hubbs and Deacon 1964) and prey on native treefrog (*Hyla regilla*) tadpoles (Goodsell and Kats 1999). In addition, mosquitofish have been shown to contribute to algal blooms by directly preying on zooplankton grazers (Nico and others 2011), suggesting impacts on aquatic food webs. Shortfin mollies prey on larval fish including the Federally endangered Moapa dace (*Moapa coriacea*) and Moapa White River springfish (*Crenichthys baileyi moapae*) (Scoppettonne 1993). Information from the 1980s indicates that relict leopard frogs and cichlid fish coexisted in Blue Point and Rogers Springs (Courtenay and Deacon 1983), and although recent surveys indicate that relict leopard frogs still occur at these sites (collection sites 17 and 18; Bradford and others 2004) there is evidence of substantial predation by cichlids and other non-native fishes on larval frogs and eggs (J. Jaeger, personal communication).

How can aquatic invasive animals be managed?—Prevention is the key to quagga mussel control because even if adults are killed the larvae have the ability to evade control measure, spread great distances, and later recolonize. It is important that all mud, plants, and aquatic organisms are cleaned and removed before vehicles or equipment are transported. Gear, equipment, and vehicles that come in contact with water should be drained, dried, and cleaned before moving (boat washing locations can be found on the internet). Bullfrog control can be difficult, but gigging has proven effective in some sites. Physical methods for control of bullfrogs and crayfish include de-watering and temporary habitat removal, but this can also affect native species. Because crayfish, and to some degree bullfrogs, are able to travel long distances over ground, physical methods have limited utility. However, an exclusion fence installed by the U.S. Bureau of Land Management around Perkins Pond in the Warm Springs area, following dewatering to remove bullfrogs, has been able to keep this frog from recolonizing. Crayfish moving up the Muddy River will likely threaten the pond in the future, but the hope is that the fence will also limit colonization by this species (J. Jaeger, personal communication). Chemical control methods include biocides, piscicides (e.g. rotenone), and pheromones, but the effective dosage required often kills other non-target organisms (McClay 2000; Oberg 1967).

Knowledge Gaps

Most invasive plant research from southern Nevada and the greater Mojave Desert has focused primarily on a few species, most notably red brome and cheatgrass in upland areas, tamarisk in riparian areas, and animal invaders in aquatic habitats. Even with this information, many key questions still remain relative to these well-studied species: (1) what are their net effects on native plants and animals; (2) what are the best combinations of control and restoration strategies to eradicate them and prevent their re-establishment, or at least minimize their dominance and negative effects; and (3) how will their abundance and effects change in the future? Very little is known about the potential effects of the vast majority of invasive plants, making it difficult to prioritize among them for early detection and rapid response control efforts. This information is especially urgent for some notable species, such as green fountaingrass, giant salvinia, and Eurasian water-milfoil, that are poised to colonize or spread from localized populations in southern Nevada.

Even less research has focused on the effects of invasive and non-native animals within the Mojave Desert; most information must be inferred from studies done in other regions, which can pose extrapolation problems. For example, ecological effects of non-native wild horses, burros, and cattle may differ in the more arid Mojave Desert from elsewhere in the Intermountain West where most of the studies on these species have occurred. In contrast, some species that are generalist predators likely have similar effects wherever they occur. Species such as feral dogs may pose obvious threats to prey species such as individual desert tortoises, but it is much more difficult to estimate their effects on desert tortoise populations. In general, the net effects of invasive animals on natural resources of value are of ultimate concern, yet there is very little information available to make these predictions.

Among the five strategic goals for invasive species management identified by the National Invasive Species Council (2008), there is probably the least urgent need for new information regarding prevention and organizational collaboration. There is somewhat of a need for information on control and management, although numerous control studies from both within and beyond southern Nevada provide decent information on how to control some of the most problematic perennial invasive species (e.g., tamarisk). Effective control strategies for annual invasive species remain limited by soil seedbanks that often elude control treatments and ongoing stressors that promote the spread and persistence of these species. The greatest need is for information to help inform early detection and rapid response and restoration efforts including minimizing or eliminating stressors. The former requires knowledge of the areas that are most susceptible to invasion and an understanding of the potential effects of newly invading species to prioritize efforts to monitor and control them. Unfortunately, published literature may not always be the best source of data because species that are documented to cause significant problems in other ecosystems may or may not do the same in southern Nevada. Local assessments are clearly needed. Restoration treatments could provide the ultimate defense against invasions because robust native communities are more resistant to invasion than are depleted communities. Unfortunately, restoration actions have a high degree of failure in the Mojave Desert without significant investments of time and funding, which is often a limiting factor. The specific aspects of native communities that confer the greatest resistance to invasion are just beginning to be understood (e.g. Abella and Newton 2009; Abella and others 2012). Thus, information is most needed to address prioritization and restoration actions tailored for southern Nevada, and to understand how various stressors described in Chapter 2 interact with and affect species invasions.

Management Implications

Prevention is clearly the first line of defense against invasive species. The most effectively managed invasive species are those that are kept from being transported to, and colonizing within, southern Nevada. Species can be transported accidentally by people and equipment, and this mode of transport can be minimized by washing tools and vehicles, especially when leaving sites with known local infestations. Other species can be transported purposefully into a region, then spread on their own into wildland areas. These purposeful transportations can be discouraged by preventative regulations for state and Federal noxious species. Success may also be realized through public education and partnerships with the agricultural and ornamental horticultural community for other high priority species to help find less invasive alternative species.

Early detection and rapid response requires significant pre-planning to be effective. Prioritization is necessary to focus detection efforts on sites that are most invasible and species that are most likely to cause significant management problems if they are allowed to colonize, establish, and spread. Information provided in the introduction section explains how the effectiveness of early detection monitoring plans can be maximized.

Control and management also require prioritization to triage nascent populations for rapid response control actions. It is also important to continue monitoring and retreating these areas for a few years to ensure there are no surviving individuals. Ideally, monitoring should be designed to evaluate the efficacy of control treatments, and adjust them accordingly in the future. If the ultimate objectives of control treatments are to benefit other species (e.g. natives), biodiversity (e.g. native species diversity), or ecosystem properties (e.g. reduce fire spread potential), then those factors should also be targeted for monitoring to determine if objectives are met.

Restoration of robust native ecosystems can increase the resilience of degraded areas to subsequent biological invasions. Unfortunately, the specific factors that increase resistance to invasion are poorly understood, so restoration guidelines are generally focused on maximizing characteristics like abundance and diversity of native species, diversity of functional types, and groups of species important for critical aspects of ecosystem function (e.g. nutrient cycling). All restoration projects should be carefully monitored to both determine if their restoration targets are achieved and to evaluate their effects on invasion resistance.

Organizational collaboration is required to effectively manage invasive species because they truly know no political boundaries, and if neighboring land owners are not doing their part, then efforts to prevent invasions and the problems that follow will often be in vain. Sharing resources and expertise by Federal and local agencies through cooperative agreements and through the interagency Southern Nevada Restoration Team can assist with the process of collaboration. Cooperative Weed Management Areas (CWMA) are formal groups that can also facilitate this process, especially in ensuring that species priorities are consistent across land management units and that coordinated management plans are maintained over time.

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Chapter 5

Fire History, Effects, and Management in Southern Nevada

Matthew Brooks, Jeanne Chambers, and Randy McKinley

Introduction

Fire can be both an ecosystem stressor (Chapter 2) and a critical ecosystem process, depending on when, where, and under what conditions it occurs on the southern Nevada landscape. Fire can also pose hazards to human life and property, particularly in the wildland/urban interface (WUI). The challenge faced by land managers is to prevent fires from occurring where they are likely to threaten ecosystem integrity or human developments, while allowing fires to occur where they will provide ecosystem benefits. The Southern Nevada Agency Partnership (SNAP) Science and Research Strategy summarizes this desired outcome with Sub-goal 1.1, which is to manage wildland fire to sustain Southern Nevada's ecosystems (table 1.3; Chapter 1). This chapter provides information that will help land managers develop strategies to achieve this goal. It begins with a background section on fire history, spatial and temporal patterns of fire, and fire effects for the major ecosystem types of southern Nevada, (table 1.1; Chapter 1). Potential fire management actions are then discussed, the overall implications of the information to fire management are summarized, and the major knowledge gaps are described.

Fire History

Southern Nevada is situated within a broad ecotone between the Central Basin and Range of the Cold Desert ecoregion to the north and the Mojave Basin and Range of the Warm Desert ecoregion to the south, two regions more commonly recognized as the Great Basin and Mojave Desert (Chapter 1). The topography of this region is dominated by broad basins separated by isolated mountain ranges that contribute to local environmental gradients that translate into highly variable vegetation types and fire regimes. The predominant view of fire in this region is focused on the ecosystem types that dominate the majority of the landscape, namely Mojave Desert scrub and to a lesser extent blackbrush/shadscale (table 1.1; Chapter 1). This view is that fires were historically infrequent; all fires are detrimental because they have been historically infrequent and native species are not adapted to them, and significant management responses are often required to mitigate their negative effects on natural, cultural, and recreational resources. Although one or more of these assumptions is likely accurate across most of this region, there are some areas that likely do not align with this dogma because of their differing fire histories and recovery potential. The probability of fire in any ecosystem is a function of sufficient fuel, conducive weather conditions, and sources of ignition (van Wagtendonk 2006). These factors vary over the landscape in southern Nevada and back through history, so it is erroneous to think that the occurrence of fire has been relatively constant across space and time. Understanding the fire history of southern Nevada is essential for evaluating the causes of recent fire trends and placing them within the correct evolutionary context to better evaluate their effects, develop well justified fire management plans, and manage individual fires appropriately.

Prehistoric Fire Record

The deserts of North America were created during the early Pleistocene (approximately 2 million year ago) when uplifting mountain ranges established a rainshadow blocking storms moving eastward from the Pacific Ocean and northwestward from the Gulf of Mexico (Axelrod 1995). In the process, forests and woodlands retreated from lowlands and moved into higher elevation refugia. Since the last glacial period at the beginning of the Holocene approximately 10,000 years ago, the Mojave Desert and southern Great Basin Desert have continuously experienced arid to semi-arid conditions (Van Devender 1977; Van Devender and Spaulding 1979; Tausch and Nowak 2000; Tausch and others. 2004). Conditions since then have fluctuated, but generally trended toward increased aridity (Van Devender 1977; Van Devender and Spaulding 1979) that has likely caused an upslope shift in vegetation formations and their associated fire regimes (McKinley and others, in press; Tausch and Nowak 2000; Tausch and others 2004).

Indigenous humans also influenced fire regimes in pre-historic North America (Williams 2000), including Paiutes in southern Nevada and Shoshones in eastern Nevada (Stewart 1980). Fire was used for hunting game, clearing vegetation, growing food, opening pathways of travel, managing pest species, and facilitating the growth of vegetation with desirable properties (e.g. basket materials, tobacco, seeds for meal, game forage, fuel-breaks). The shift of vegetation formations upslope during the Holocene was likely mirrored by indigenous humans following natural resources necessary for survival in the Mojave and Great Basin deserts. In the Mixed Conifer, Piñon and Juniper, and Sagebrush Ecosystems of the Mt. Irish area of Lincoln County, fires were very frequent from 1550 to 1860 (mean fire return interval 4 years), but then declined precipitously between 1861 and 2006 (only two fires in 1883 and 1916) (Biondi and others 2011). This transition from frequent to infrequent fire was coincident with Euro-American settlement and the displacement of Native Americans in this region during the middle 1800s. Accordingly, fire most likely occurred primarily at higher elevations and in more mesic riparian areas, both because fuels were more conducive to fire spread and ignitions from Native Amreicans were likely more frequent in those areas. In addition, current lightning occurrence in southern Nevada is positively correlated with elevation due to the orographic effects of terrain on climate (Randerson and others 2004), a physical phenomenon that has likely occurred as long as the mountain ranges of southern Nevada have been in existence back through the Holocene and beyond.

With increased aridity, decreased productivity, and decreased human presence over prehistoric time, the spatial extent of fire across southern Nevada undoubtedly declined and became increasingly isolated within disjunct high elevation areas. A dominance shift from perennial grasses to woody non-sprouting shrubs (Spaulding 1990) suggests a change in fuelbed characteristics from one that is conducive to fire spread and adapted to periodic fire, to one which is less conducive and less resilient to fire (McKinley and others, in press; Miller and Wigand 1994). In addition, the change from perennial grasses to shrubs suggests a shift of summer rains of the North American monsoon away from southern Nevada, and with that shift a decline in the incidence of lightning from summer thunderstorms.

Historic Fire Record

The first accounting of extensive historic fire in southern Nevada was reported by Croft (1950) who estimated that 20 percent of the 161,875 ha (400,000 acres) of blackbrush (*Coloegyne ramossissima*) that occurred in the region burned during the late 1930s and early 1940s. This time period coincided with a 4-year period of high rainfall and strong El Nino-Southern Oscillation (ENSO) signature from 1938-1941, which was one of the highest rainfall years on record, eclipsed only by rainfall totals during 1983 and 2005 (Hereford and others 2006; National Climate Data Center, www.ncdc.noaa.gov). It appears that high rainfall temporarily increased fuel loading and continuity and facilitated fire spread. During the mid-century drought from 1942 to 1975 there were relatively few fires documented in southern Nevada, followed by a significant increase in fires when precipitation began to increase in 1976 (Brooks and others 2007; McKinley and others, in press). This has been attributed to low fuel loads and fuelbed continuity and infrequent lightning from summer monsoons during the middle decades of the 1900s, followed by increases in precipitation and lightning during the latter decades (McKinley and others, in press).

Ranchers and U.S. Bureau of Land Management (BLM) staff implemented a program of prescribed burning in the late 1930s and into the 1940s to increase forage production for livestock in blackbrush stands of southern Nevada (Croft 1950). Additional blackbrush burning likely occurred at least through the 1960s, because a policy review during that time by the Range and Forestry Office of BLM in Nevada recommended that blackbrush burning continue to increase forage production (Dimock 1960). However, it is unlikely that most of these mid-century fires spread extensively considering the low productivity of these systems and drought conditions during the middle 1900s.

Current Fire Record

Fire records for recent decades have been derived using point occurrence databases publically available for Federal lands in the Mojave Desert (Brooks and Esque 2002; Brooks and Matchett 2006; Brooks and Minnich 2006) and other desert regions in North America (e.g. Collins and others 2006; Knapp 1997; Schmid and Rogers 1988and others). Although these point occurrence databases include all reported fires, they can also contain a high degree of error, up to 30 percent for DOI lands (Brown and others 2002) and can therefore be highly misleading. There are also regional sources of fire perimeter data that can provide more precise information than that associated with point occurrences (McKinley and others, in press). However, these fire perimeter databases can also misrepresent area burned by as much as 18 percent (Kolden and Weisberg 2007) and are typically only available for short time intervals within specific geographic areas. In contrast, the current fire record results summarized below in this chapter were derived using Landsat satellite imagery to precisely document area burned by large fires (≥1,000 acres) between 1972 and 2007 in Lincoln and Clark Counties (McKinley and others, in press). Although these large fires only represent 1-2 percent of the total number of fires that occurred during that time interval in southern Nevada, they comprise 93 percent of the total area burned.

Approximately one million acres burned in Lincoln and Clark counties as a result of 116 large fires that occurred during a 36-year period from 1972 through 2007 (McKinley and others, in press). A chronology of these fires is graphically portrayed in figure 5.1 where shades from cool to warm colors represent the chronology of fire occurrence beginning with the oldest fires (blue) and ending with the recent fires (red). This figure shows that most of the older fires (pre-2005) occurred in Lincoln County, aside from a cluster of fires during the 1980s in the Spring Mountains of western Clark County.

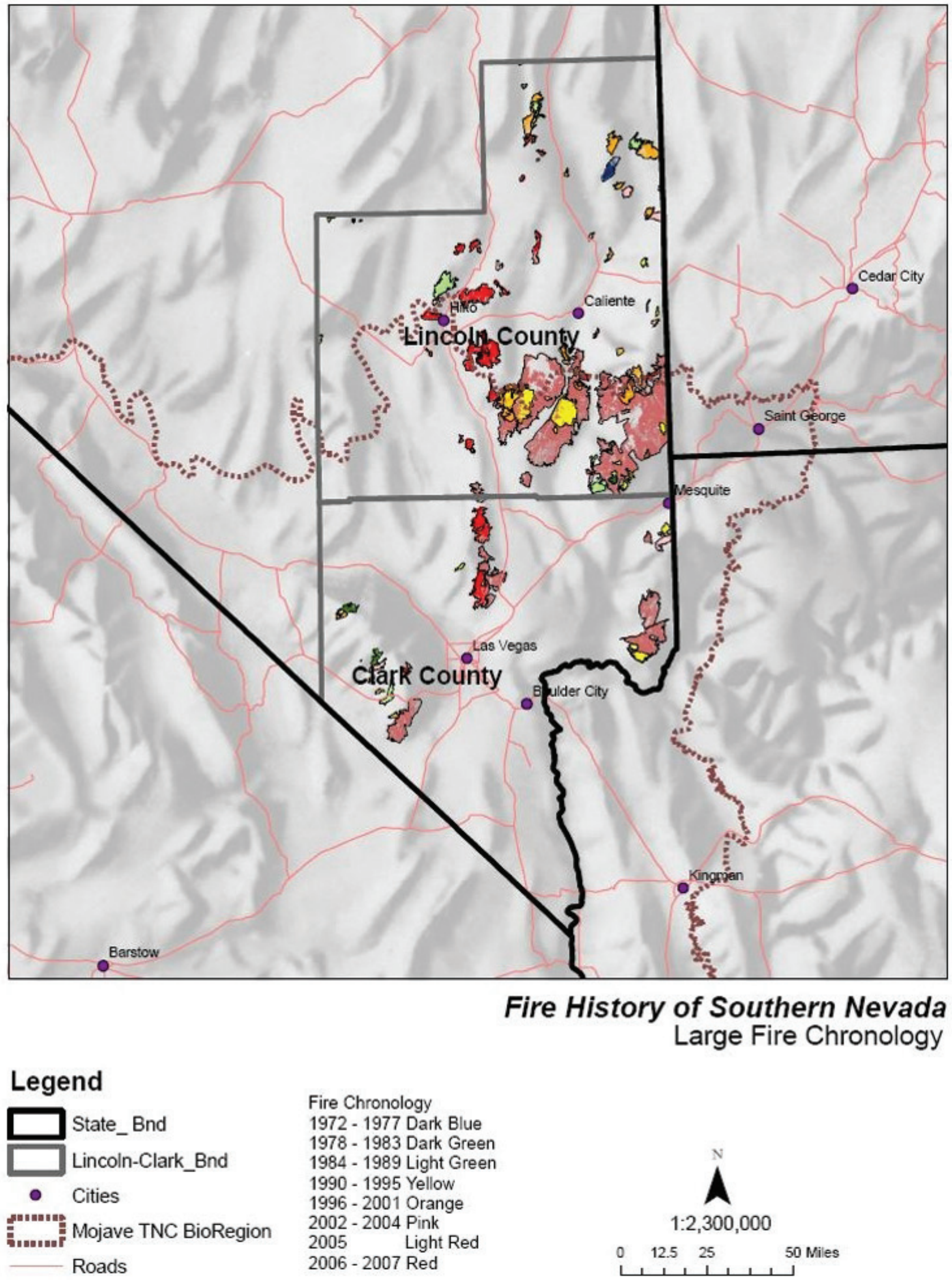

Figure 5.1—Large fire chronology 1972 through 2007 inclusive (≥1,000 acres). Shades from cool to warm colors represent the chronology of fire occurrence beginning with the oldest fires (blue) and ending with the recent fires (red) (reprinted with permission from McKinley and others, in press).

Figure 5.2 illustrates that most of the burned acreage (90%) occurred in areas that had not previously burned during the 36-year study period, 8 percent occurred in areas that had burned once before, and 2 percent occurred in areas that had burned two or three times before during this time period.

The number of fires and area burned from 1972 through 2007 may have been unprecedented in the historic record extending back to the late 1800s (McKinley and others, in press). In particular, the 2005 and 2006 fire seasons were extreme events that had

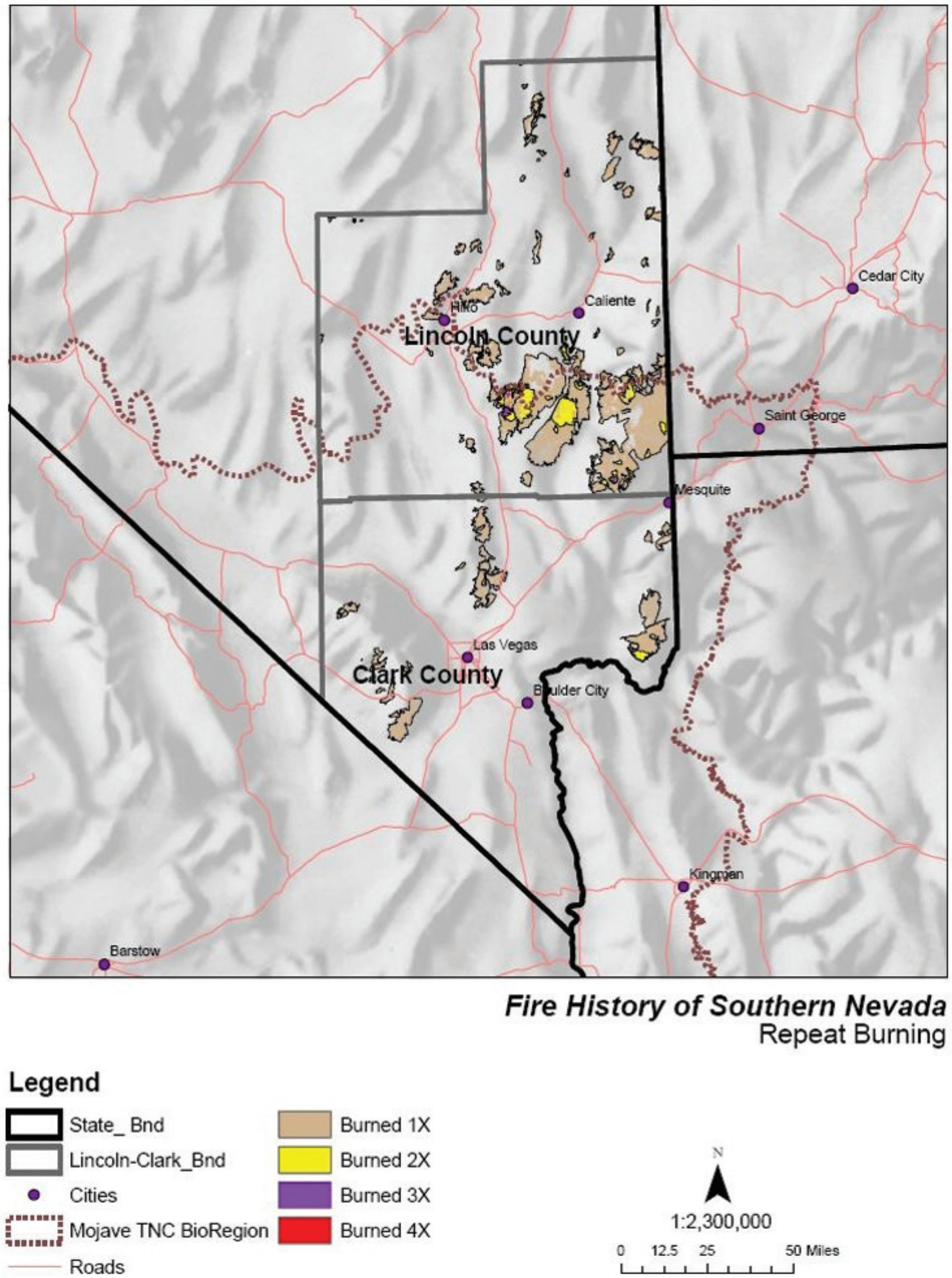

Figure 5.2—Fire frequency of large fires 1972 through 2007 inclusive (≥1,000 acres) (reprinted with permission from McKinley and others, in press).

a major influence on the fire statistics for both number of fires and total area burned. The number of fires and area burned in those 2 years were so statistically anomalous that it is appropriate to evaluate trends with and without them included in the analyses. When 2005 and 2006 were excluded from the analyses, the number of fires and total area burned from 1972 through 2007 actually showed an increase up to the mid-1990s followed by a downward trend (fig. 5.3), a pattern that has persisted through 2012 (Matthew Brooks, personal observation of fire frequency while conducting studies in the Mojave Desert). Although the conditions that led to the fires in 2005 and 2006 may only occur every century or more (see below), this does not mean large areas will not burn in the future.

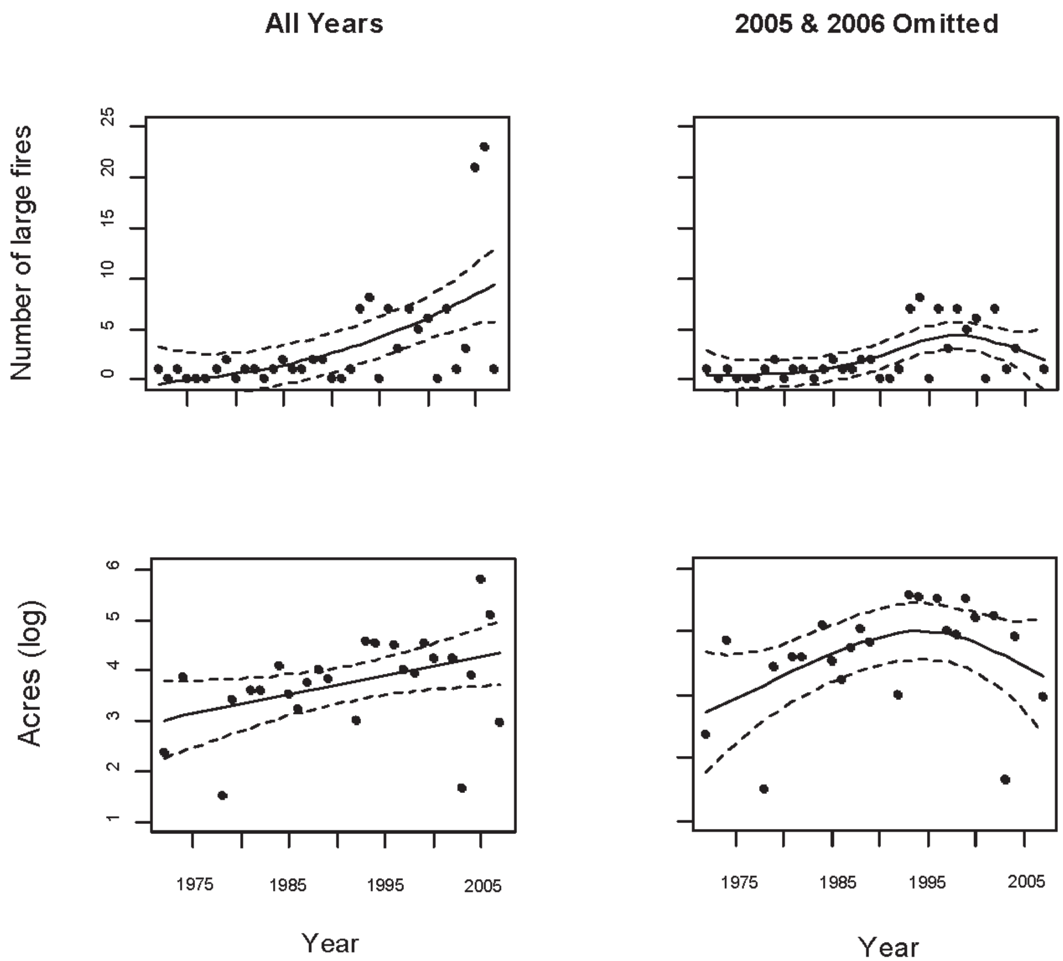

Figure 5.3—Patterns over time (1972-2007) for the number of large fires (≥1,000 acres), total area burned ($\log_{10}$ acres), mean fire size ($\log_{10}$ acres), and the proportion of burned area classified as high severity in Clark and Lincoln counties, Nevada. The shape of the relationship was derived from generalized additive models. Dotted lines are 95% confidence bands (modified with permission from McKinley and others, in press).

These trends must also be considered within the context of the 36-year sampling period (1972-2007). Previous studies from the Mojave Desert have reported both increasing numbers of fires (1980-1995, Brooks and Esque 2002) and no change in number of fires (1980-2004, Brooks and Matchett 2006). The differing conclusions of these two previous studies were entirely due to the different timespans of the datasets they used. As an extreme example, the conclusions published in Brooks and Matchett (2006) may have been very different if the data set included just 1 or 2 additional years (2005 and 2006). Thus, fire trends derived from only a few decades of data must be evaluated very cautiously, especially in a place like the Mojave Desert where fire occurrence is so episodic.

Temporal and Spatial Patterns of Burning

Evidence presented above from the historic and current fire record suggests that fire activity in southern Nevada is primarily associated with the warm (positive) phase of the multi-decadal Pacific Decadal Oscillation (PDO) cycle during which perennial fuels increase, and secondarily with the El Niño phase of the interannual El Niño-Southern

Oscillation (ENSO) cycle during which fine ephemeral fuels increase. It appears that the ENSO effect may not be sufficient alone to promote large fires, and may only kick in during the latter part of or soon after a multi-decadal period of high rainfall associated with the PDO (e.g. after 1993, and especially during 2005 and 2006). Although intentional burning by humans has at times added significantly to acres burned, these fires likely remain small when climatic conditions cause fuelbeds to be sparse.

Non-native annual grasses alter fire regimes worldwide through a process known as the grass/fire cycle (D'Antonio and Vitousek 1992; Brooks and others 2004). Species in the genera *Bromus* are specifically associated with changes in the temporal and spatial patterns of burning in upland areas of Mojave and Great Basin Deserts (Brooks 1999; Brooks and Matchett 2006; Brooks and Pyke 2001; Link and others 2006; Whisenant 1990). Although these species can undoubtedly alter fire regimes of southern Nevada, their influence is ultimately tied to the longer-term PDO and shorter-term ENSO cycles. Warm PDO phases are associated with exponential population growth of non-native annual grasses, such as that documented for *Bromus rubens* from the late 1970s through 1990 in southern Nevada (Hunter 1991). Increasing populations lead to high propagule production and dispersal into new areas (Brooks 2009), potentially increasing the regional scope of the grass/fire cycle. The El Niño ENSO phase is associated with years of extremely high rainfall that lead to episodic spikes in fuel loads created by invasive annual grasses and heightened fire hazards, especially in lower and middle elevation shrublands (Brooks and Matchett 2006). The hallmark of the grass/fire cycle is a landscape dominated by non-native annual plants, with low abundance of native woody species, and short fire return intervals. In southern Nevada, such landscapes are currently most common in Lincoln County (fig. 5.2), and fig. 5.4 illustrates how many of these landscapes look when burned.

Figure 5.4—A section of the 2005 Southern Nevada Fire Complex in the Tule Desert region of Lincoln County, Nevada. This is an area that had burned within the past few decades and was dominated by standing dead *Bromus* spp. biomass at the time of the fire (photo credit, Bureau of Land Management, Ely Field Office files).

One major factor that could decouple fire regimes from the PDO/ENSO cycles is related to the potential for the monsoon track to shift farther north and west from its current position at the southwest margin of the region (Hereford and others 2006). The vast majority of fires that occurred during the past few decades in the Mojave Desert have been associated with areas experiencing both high winter rainfall and high summer monsoonal rainfall and lightning, the former boosting fine fuel loads and the latter providing ignition sources and extreme wind conditions (J. Tagestad and others, in preparation). If the monsoonal track moves further into the Mojave Desert, then fires may follow, and if these fires move into areas where fire was historically infrequent and conditions are conducive to growth of non-native annual grasses, then a grass/fire cycle may emerge in those areas as well. In contrast, if the monsoon moves south and eastward, then fires may become less prevalent and the grass/fire cycle may wane as a significant land management threat.

Another factor that could affect future fire occurrence is increasing human population. More people likely mean more human ignitions. More people also mean more fossil fuel combustion that leads to increased rates of regional nitrogen deposition (see Chapter 2). Plant productivity, and therefore fuel production, especially non-native herbaceous fuels, are primarily influenced by precipitation and soil nitrogen levels (Brooks 2003; Rao and Allen 2010). Because elevated CO_2 increases water use efficiency of *Bromus* species, it has the potential to exacerbate the problem (Smith and others 2009; Chapter 2).

Alpine and Bristlecone Pine Ecosystems—These ecosystem types are located above 2,600 m in the Spring Mountains and the Sheep Range. Although lightning is relatively frequent in these ecosystems, fuels are sparse and continuity is low and most fires do not spread beyond single bristlecone pine (*Pinus longaeva*) or limber pine (*Pinus flexilus*) trees (Fryer 2004; Johnson 2001).

Mixed Conifer, Piñon and Juniper, and Sagebrush Ecosystems—These ecosystem types are predominantly located in the Spring and Sheep mountain ranges at elevations between 1,200 and 3,200 m. Lightning occurs frequently in these ecosystem types. These shrublands, woodlands, and forest stands are dominated by sagebrush (*Artemisia* spp.), chaparral shrubs, juniper (*Juniperus* spp.), piñon pine, and small stands of ponderosa pine, and have fire patterns that are driven mostly by long-term, decadal to century-scale PDO patterns of rainfall and perennial fuel accumulation (Brooks and Matchett 2006; Littell and others 2009). Continuity and amounts of native perennial fuels alone can be sufficient to carry fire under extreme fire weather conditions (i.e. high temperatures and wind, and low relatively humidity), and fire is a part of the natural disturbance regime. Years of high rainfall can produce additional herbaceous fuels that enhance fuelbeds and potentially further facilitate fire spread, but they also can increase live perennial fuel moisture levels that can decrease spread rate. Thus, the net effect of high rainfall on fire behavior at high elevations can be hard to predict.

Blackbrush/Shadscale and Mojave Desert Scrub Ecosystems—Fire patterns in these low and middle elevation shrublands, dominated by saltbush (*Atriplex* spp.), creosotebush (*Larrea tridentata*), and blackbrush, are affected most by short-term, interannual patterns of rainfall and ephemeral herbaceous fuels associated with the ENSO cycle (Brooks and Matchett 2006). Fire frequency is higher at the interface with higher elevation ecosystem types where fires often start and spread. Continuity and amounts of perennial fuels are insufficient alone to carry fire; pulses of herbaceous fuels following periods of high rainfall are necessary to fill the interspaces between perennials and allow fire to spread, and fire is not a major part of the natural disturbance regime. Fuels created by non-native annual grasses are more persistent than those from native forbs, and as such contribute more to fire spread potential (Brooks 1999). Altered fire regimes from invasive annual grasses (i.e. the grass/fire cycle) are most prevalent in these ecosystem types (Brooks and Matchett 2006).

Riparian and Spring Ecosystems—Fire patterns in riparian zones depend on where they occur on the southern Nevada landscape. The major riparian corridors that occur along the rivers of southern Nevada are situated at lower elevations within upland areas dominated by Mojave Desert scrub. Pre-historic Holocene and historic conditions of perennial grasses and shrubs as an understory beneath canopies of towering cottonwoods supported periodic low to moderate intensity surface fire that spread very rarely into the sparse surrounding uplands (Dwire and Kauffman 2003). Thus, fire is part of the natural disturbance regime, although at moderately long-return intervals (Petit and Naiman 2007). Indigenous humans also used fire during the Holocene to clear riparian terraces for agricultural purposes and to promote growth of basketry materials (e.g. rushes, reeds, and milkweed). The spread of fires was likely limited by barriers of vegetation gaps, standing water, and narrow bottleneck points along the floodplain where gaps occurred in the more consistently dry upland benches. Following the invasion of saltcedar (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*), ladder fuels and overall fuel loads increased, resulting in a more frequent and high intensity crown fire regime (Busch and Smith 1993; Lovich and others 1998; Busch 1995). In addition, the invasion of non-native annual grasses in both the riparian and surrounding uplands provides more continuous fuelbeds that likely allow fires to reach greater size now than in the past. In contrast, fire patterns in higher elevation riparian zones embedded within blackbrush, sagebrush, and mixed conifer uplands are affected more by the fire regimes of the surrounding ecosystem types than by the riparian fuels themselves. Similarly, patterns of natural fires at isolated springs are controlled by the fire regime of the surrounding vegetation. There is also evidence that indigenous humans, and then later Anglo settlers, used fire to reduce vegetation cover to facilitate hunting opportunities and enhance water flow rates.

Fire Effects

Fire and Fire Regime Characteristics

Although land management actions focus on individual fires, the ultimate influence of fires across landscapes and over time is attributed to fire regimes. The type (ground, surface, or crown fire), frequency (i.e., return interval), intensity (heat released), severity (ecological response), size, spatial complexity, and seasonality of fire define the fire regime within a given geographic area or vegetation type. Over very long time periods, the prevailing fire regime conditions can have a strong influence on the evolution of species. When fire regimes are altered (e.g. by plant invasions or land management practices) the recovery of the resident species following fire can be compromised and landscapes can be converted to new vegetation types that are better adapted to the new fire regime (Brooks 2008). Thus, the management of individual fires must be placed within the broader context of how they will affect the management of fire regimes.

It must also be understood that all fires are not the same. Unfortunately, the vast majority of published studies on fire effects report the effects of “fire” as if it is a univariate factor. Multiple aspects of fire behavior, seasonality, and spatial pattern can influence the effects of fire. Fire behavior can vary widely based on fuel, weather, and ignition characteristic (van Wagtendonk 2006). In addition, rate of spread, residence time, flaming zone depth, fuel energy content, fire type (ground, surface, crown), and other factors can influence fire intensity (energy released), which is a primary factor associated with fire severity (effects on the environment). The season during which a fire occurs can also significantly influence the survivorship of individuals and the responses of populations and communities (Fites-Kaufman and others 2006). Fires that occur when plants and animals are reproducing are often most damaging because they can potentially eliminate recruitment for the year (Fites-Kaufman and others 2006; Shaffer and others 2006and others). Survivorship of perennial plants is also lower when they are actively growing because below-ground carbohydrate reserves are depleted, whereas survivorship is higher when they are dormant because below-ground reserves are at their peak (Pyke and others 2010). Survivorship of animals may also be higher when they are hibernating or otherwise located below-ground and away from intense heating (Shaffer and others 2006). Fires also differ based on their spatial patterns of burning. Heterogeneous burns with unburned islands and abundant areas of low fire severity provide sources of propagules to recolonize burned areas, thus decreasing recovery time to pre-burn conditions. Homogenous complete burns with few unburned islands and uniformly moderate to high fire severity are often slower to recover to pre-burn conditions unless the resident species are fire adapted. Thus, one should never assume similar ecological responses to fire per se, but instead should expect similar responses among fires of similar characteristics considering the factors discussed above plus additional site and ecosystem type factors discussed below.

Site Characteristics

The predominant life forms of plants and animals at a site can influence their overall responses to fire. Plant life forms with meristem (perennating) tissue located aboveground tend to have the highest mortality rates because that life sustaining tissue occurs close to the flames and smoldering fuels and is exposed to the highest temperatures during fires (Pyke and others 2010). The general exception is when meristems are located far aboveground and away from flames with limited ladder fuels to carry fire up into their vicinity (e.g. some palm trees). In contrast, plant life forms with meristem tissue or dormant seeds located at or below the surface of the mineral soil tend to have the lowest mortality rates because they occur where temperatures are lowest during fires (Brooks 2002). Animal taxa that are more vagile or arboreal can avoid fire-induced mortality better that than those that are more sedentary (Shaffer and others 2006). However, susceptibility to mortality among the very young is more a factor of where their nests or dens are located, than the vagility of their species. For example, birds that are extremely vagile are more adept at avoiding extreme temperatures from fire, but nestlings have high mortality rates because they are typically situated within flammable nests located in the heart of the fuelbed and combustion zone. Thus, effects of fire on plants and animals can vary depending on the types of species. However, the longer term effects of fire on subsequent growing conditions or habitat characteristics are generally thought to have even greater effects on populations and communities.

The effects of fire can vary greatly depending on the elapsed time since the previous fire. Excessively short fire return intervals that do not allow time for individual plants to recover or new individuals to establish and reach reproductive maturity can reduce the abundance of maladapted species at a site. This is a significant mechanism by which vegetation type conversions occur as part of the grass/fire cycle (Brooks 2008). Excessively long fire return intervals that allow the abnormal accumulation of surface and ladder fuels can alter fire behavior and similarly reduce the abundance of maladapted species.

Relative concern about fire effects within a given area often hinges on the current or potential future dominance by invasive non-native plants. These species alone are often undesirable from a natural resource management perspective, but when their effects on fuelbeds and fire regimes are considered they often become significant fire management concerns as well (Brooks 2008).

Other factors such as historical and current land uses and weather patterns (especially precipitation) can influence the effects of fire at a particular site. Historically intense land use disturbance such as livestock grazing can produce similar effects as antecedent fire, including reduced perennial cover, reduced species diversity, and increased dominance by invasive plants. Thus, the landscape response to fire in these areas may be similar to that associated with short fire return intervals. Similarly, periods of drought before burning may reduce a species' abundance and resource reserves, and drought following burning may hinder its post-fire survival and/or establishment rates, in both cases rendering the species less tolerant.

Ecosystem-Specific Effects

Alpine and Bristlecone Pine Ecosystems—Bristlecone pine and limber pine trees are thin barked and lack adaptations to fire. These tree species can only survive low intensity surface fire or lightning strikes that do not result in complete girdling of the cambial tissue (Brooks and Minnich 2006; Fryer 2004; Johnson 2001). Many of these long lived trees have multiple scars indicating survival following lightning strikes that occurred repeatedly over their 1,000+ year lifespan, but apparently these ignitions did not spread to engulf trees and probably did not spread beyond the trees struck. Sparse surface fuels result in small fires and low fire intensities that likely had limited effects on small woody shrubs and herbaceous species in the understory. As a consequence of a warming climate, invasive annual grasses may move upslope and present fine fuel management problems in the future, and fire may facilitate this process (table 5.1).

Mixed Conifer Ecosystem—Interior ponderosa pine (*Pinus ponderosa* var. *scopulorum*) is one of the most fire-adapted conifer species in North America. Its adaptations include open crowns, self-pruning branches, thick bark, thick bud scales, tight needle bunches protecting meristems, high foliar moisture, and a deep rooting habit (Howard 2003). Widely spaced older trees display higher fire survival rates than more densely packed and younger trees. White fir (*Abies concolor*) is a thin barked tree species with branches and foliage from top to bottom that make it highly vulnerable to mortality from fire. Mountain mahogany (*Cercocarpus* spp.), Gambel oak (*Quercus gambelii)*, manzanita (*Arctostaphylos* spp.), and snowberry (*Symphoricarpos albus*) are all elements of the interior chaparral vegetation type often found in the understory of mixed conifer sites. All but mountain mahogany are extremely tolerant of fire (Brooks and others 2007).

Long intervals without fire allow the accumulation of understory and ladder fuels that generally result in higher severity crown fires that can threaten the persistence of isolated mixed conifer stands in southern Nevada (table 5.1). High severity events are often followed by initial dominance by understory chaparral species that may persist as an alternative vegetation type if conditions are no longer conducive to pine establishment. A warming climate may exacerbate this process.

Table 5.1—Typical fire management concerns associated with site and fire characteristics and guidelines for appropriate fuels management, fires suppression, and Emergency Stabilization and Rehabilitation (ES&R) actions in the major ecosystem types of southern Nevada.

Ecosystem type burned	Typical fire management concerns	Guidelines for appropriate management actions
Alpine and Bristlecone pine	*Fire* – Fires that burn more than a few acres and/or completely consume multiple trees. *Site* – Tree mortality and increased down woody fuels. Low tree recruitment post-burn and increased dominance of *Bromus* spp. could alter fire regime.	*Fuels* – Rarely warranted *Suppression* – Rarely warranted except to protect small and/or isolated stands if excessive fire spread is likely. *ES&R* – Rarely warranted unless perhaps to control invasive plants or following excessively large and severe fires.
Mixed conifer	*Fire* – High severity crown fire. Long fire return interval that allow excessive fuel accumulation. *Site* – Heavy surface and ladder fuel loads could lead to high severity crown fire. Wildland/urban interface (WUI) limits its fire management options.	*Fuels* – Periodically warranted in the WUI, egress routes, and where surface and ladder fuels have accumulated increasing the risk of large fires. Mechanical treatments may be initially needed, but subsequent treatments should utilize low severity, surface prescribed fire. Follow-up control of invasive plants may be needed during the first few post-treatment years. *Suppression* – Rarely warranted except in the WUI, egress routes, and where surface and ladder fuels have accumulated increasing the risk of large fires. Low severity surface fire with minimal crowning should be allowed as a natural fire regime component for vegetation management benefits. Follow-up control of invasive plants may be needed during the first few post-fire years. *ES&R* – May be warranted to stabilize slopes near the WUI or following excessively large and severe fires.
Piñon and Juniper	*Fire* – High severity crown fire. Short fire return interval that does not allow re-establishment of shrub understory or trees. *Site* – Dominant invasive annuals. Short fire return intervals (≤60 years).	*Fuels* – Rarely warranted except in the WUI and egress routes and in shrub-dominated areas exhibiting tree expansion. Prescribed fire may be the more cost-effective over large areas. Follow-up control of invasive plants may be needed during the first few post-fire years. *Suppression* – Warranted in the WUI, and to prevent large, high severity crown fires, but low severity surface fire in areas of undesirable tree expansion may be allowed as a natural fire regime component for vegetation management benefits. Follow-up control of invasive plants may be needed during the first few post-fire years. *ES&R* –Warranted to reestablish native plant community characteristics and to control invasive plants if inadequate perennial herbaceous species and shrubs exist for recovery. Herbicides may allow short-term control but long-term control requires a wider array of management actions, aerial seedings have low to moderate establishment rates.
	Fire – Large, homogenous fires *Site* – Dominant invasive annuals. Short fire return intervals (≤40 years).	*Fuels* – Rarely warranted, except in the WUI and egress routes and perhaps to increase the competitive ability of perennial herbaceous species and prevent invasive annual grass dominance. Prescribed fire rarely warranted except perhaps to create a stand-age mosaic in very old late-successional contiguous stands. Follow-up control of invasive plants may be needed during the first few post-treatment years. *Suppression* – Warranted in the WUI, and in areas with low abundance of perennial herbaceous species and high risk of conversion to annual invasive grasses. *ES&R* – May be warranted to reestablish the native community and to control invasive plants if inadequate perennial herbaceous species and shrubs exist for recovery. Herbicides may allow short-term control but long-term control requires a wider array of management actions, aerial seedings have low to moderate establishment rates.

(continued)

Table 5.1—(Continued).

Ecosystem type burned	Typical fire management concerns	Guidelines for appropriate management actions
Blackbrush/ shadscale	*Fire* – Large, homogenous fires. *Site* – Dominant invasive annuals. Short to moderate fire return intervals (≤100 years).	*Fuels* – May be warranted to reduce non-native annual grass fuels, perhaps centered on roads, to facilitate fire suppression. Follow-up treatments may be needed on an annual basis. *Suppression* – Warranted under most circumstances. Prescribed fire is never warranted except perhaps for experimental purposes. *ES&R* – May be warranted to reestablish the native community and to control invasive plants if inadequate perennial herbaceous species and shrubs exist for recovery. Herbicides may allow short-term control of non-native annual grasses, but long-term control requires a wider array of management actions including reestablishment of native perennial species. Aerial seedings have low establishment rates. Livestock closures are necessary post-fire to facilitate recovery of native perennial plants.
Mojave desert scrub	*Fire* – High severity, large, homogenous fires *Site* – dominant invasive annuals, short to moderate fire return intervals (≤100 years)	*Fuels* – May be warranted to reduce non-native annual grass fuels, perhaps centered on roads, to facilitate fire suppression. Follow-up treatments may be needed on an annual basis. *Suppression* – Warranted under most circumstances. Prescribed fire is never warranted except perhaps for experimental purposes. *ES&R* – May be warranted to reestablish the native community and to control invasive plants if inadequate perennial herbaceous species and shrubs exist for recovery. Herbicides may allow short-term control but long-term control requires a wider array of management actions including reestablishment of native perennial species. Aerial seedings have low establishment rates. Livestock closures are necessary post-fire to facilitate recovery of native perennial plants.
Riparian and Spring	*Fire* – High severity crown, large homogeneous fire. *Site* – Dominant invasive perennials. Heavy surface and ladder fuel loads could lead to high severity crown fire. Flood disturbance may have larger effects than fire especially in unregulated riverine systems (e.g. Virgin River)	*Fuels* – May be warranted to reduce non-native tamarisk and Russian olive fuels to reduce high severity fire. Prescribed fire may be the most cost-effective way to reduce invasive plan biomass over large areas, but follow-up control of surviving invasive plants will always be needed during the first few post-fire years, potentially followed by native plant revegetation. *Suppression* – May be warranted in the WUI or where tamarisk and native vegetation are intermixed, otherwise low to moderate severity fire may be allowed where native fuels predominate as a natural fire regime component for vegetation management benefits, or moderate severity fire may be allowed where tamarisk dominates to remove above-ground biomass as a prelude to other tamarisk control actions such as herbicide treatments followed by native plant revegetation. *ES&R* – May be warranted to control tamarisk, herbicides may allow short-term control but long-term control requires a wider array of management actions including native plant revegetation which may be accomplished by seedings or outplantings.

Piñon and Juniper Ecosystems—Single-leaf piñon (*P. monophylla*), Utah juniper (*Juniperus osteosperma*), Rocky Mountain juniper (*Juniperus scopulorum*), and western juniper (*Juniperus occidentalis*) are relatively thin barked and contain ladder fuels that facilitate consumption of their entire canopies, so they have low tolerance of fire (Brooks and Minnich 2006). However, stands can re-establish within about a century. Understory vegetation, such as interior chaparral, at higher elevations is very tolerant of fire that occurs at moderate return intervals. Sagebrush is intolerant of fire and rabbitbrush (*Chrysothamnus* spp.) is fire tolerant, but sagebrush communities can reestablish given longer fire return intervals (25-50 years) and relatively small fire size.

Excessively long intervals between fires may lead to canopy closure, seedbank depletion, fuel accumulation, and high fire severity, all of which reduce piñon-juniper resilience to fire (Allen and others 2008; Miller and others 2005, 2008) (table 5.1). If invasive annual grasses are present, they have the potential to dominate post-fire landscapes leading to short intervals (~2-5 years) between fires that do not allow time for trees to establish and grow to maturity.

Sagebrush Ecosystem—The sagebrush ecosystem is dominated by several different shrub species that are typically killed by fire, including big sagebrush (*Artemisia tridentata tridentata, A. tridentata wyomingensis* and *A. tridentata vaseyana*), low sagebrush (*A. arbuscula*), Bigelow sagebrush (*A. bigelovii*), and black sagebrush (*A. nova*). Other species such as rabbitbrush, snakeweed (*Gutierrezia sarothrae*), spiny hopsage (*Grayia spinosa)* and cliffrose (*Purshia neomexicana*) can resprout if only partially burned, and perennial grass species including wheatgrass (*Agropyron* spp.), bluegrass (*Poa* spp.), and needlegrass (*Achnatherum* spp.) usually survive topkilling.

High abundance of invasive annual grasses may lead to short fire return intervals that do not allow sufficient regeneration times for native sagebrush species to persist (table 5.1). These conditions also may lead to large homogenous fires that hinder seed dispersal of native perennial species back into burned areas and result in intense competition of the invaders with native seedlings for available resources.

Blackbrush/Shadscale Ecosystem—Blackbrush is the dominant shrub species in areas with shallow limestone-derived soils, and this species is easily killed and very slow to re-establish following fire (Brooks and others 2007). Shadscale (*Atriplex confertifolia*) and budsage (*Artemisia spinescens*) dominate on heavy, rocky soils and also are killed by fire. Other subdominant shrubs species include cliffrose, Mormon tea (*Ephedra* spp.), snakeweed, wolfberry (*Lycium* spp.), and spiny hopsage and all can resprout to varying degrees.

Similar to sagebrush ecosystems, high abundance of invasive annual grasses may lead to fire return intervals that that are shorter than the regeneration times of native blackbrush species (table 5.1). Invasive annual grass dominance may also lead to large homogenous fires that hinder seed dispersal of native perennial species back into burned areas and result in competition of the invaders with native seedlings for available resources. Although perennial plant cover may approach unburned conditions within the first four post-fire decades, species composition typically does not (Abella 2009; Brooks and others, in prep.; Engel and Abella 2011).

Mojave Desert Scrub Ecosystem—Creosotebush is the dominant species in upland areas and saltbush species are dominant in alkaline soils of lowland basin areas. Bajadas, the most common landform, are dominated by creosote bush and white bursage (*Ambrosia dumosa*); subdominants include desert thorn (*Lycium andersonii*), bladder sage (*Salazaria mexicana*), indigo bush (*Psorothamnus fremontii*), blackbrush, brittlebush (*Encelia farinosa*), and burro bush (*Hymenoclea salsola*). Most of these species have the capacity to survive fire if more than half of their aboveground biomass is left unburned (Brooks and Minnich 2006). Yucca species such as Joshua tree (*Yucca brevifolia*) and Mojave yucca (*Yucca schidigera*) often survive burning, but the Joshua tree often dies within the first few years after fire due to drought and herbivory stress on resprouts (DeFalco and others 2010).

Similar to sagebrush and blackbrush ecosystems, high abundance of invasive annual grasses may lead to excessively short fire return intervals that do not allow native Mojave desert scrub species to reestablish (Brooks 2011) (table 5.1). Although perennial plant cover may approach unburned conditions within the first four post-fire decades, species composition typically does not (Abella 2009; Brooks and others, in prep.; Engel and Abella 2011).

Riparian and Spring Ecosystems—Historical fire coupled with periodic flooding has resulted in riparian plant species adaptations that confer some degree of tolerance to fire. The invasion of saltcedar, Russian olive and invasive annuals have increased fuel loads, created ladder fuels where little previously existed, and resulted in the potential for larger, more intense, and more frequent fires than occurred historically (Dwire and Kaufman 2003) (table 5.1). Although some native riparian species may not survive this altered fire regime (e.g. cottonwood trees), others are clonal and are capable of surviving fire and resprouting (e.g., willows). However, the altered fire regime can also be accompanied by vigorous post-fire resprouting and seedling establishment of non-natives creating an intense competitive environment that can suppress native species (Dudley and Brooks 2006). Thus, the net effects on natives can be significant even though they may be generally tolerant of fire and other disturbances.

The degree to which fire may have affected the evolution of plant species in the vicinity of springs is related to the fire regime of the surrounding vegetation type. Current species assemblages may also have been affected by historical fire use by indigenous humans. In addition, some spring sites are dominated by non-native saltcedar, which can increase its dominance following fire if it is not actively managed.

Management Actions

Pre-Fire Fuels Management

Livestock grazing can reduce cover of perennial vegetation in the Mojave Desert (Brooks and Berry 2006), which may have led to reduced fuel continuity and landscape-scale flammability of fuelbeds in mid to upper elevation ecosystem types such as blackbrush/shadscale, sagebrush, and piñon and juniper after grazing began in the late 1800s (Brooks and Minnich 2006). Intensive grazing associated with livestock watering sites also can be associated with reduced cover of red brome (*Bromus rubens*) (Brooks and others 2006), which is the primary fine fuel that carries fire in the Mojave Desert (Brooks 1999; Brooks and Minnich 2006). Although livestock grazing has been shown to reduce flame lengths and fire spread rates in the Great Basin (Diamond and others 2009), it may only be a significant factor in early successional vegetation stands dominated by herbaceous species (Launchbaugh and others 2008). In addition, the intensity of grazing required to significantly alter fire behavior may actually facilitate the long-term dominance of non-native grasses that are often one of the most significant fuel management concern in the Mojave and Great Basin Deserts (Brooks and others 2007; Knick and Connelly 2011; Wisdom and others 2005). Moreover, extensive grazing over many decades on predominantly BLM lands in Lincoln County, Nevada, is coincident with the largest expanses of burned landscapes in the entire Mojave Desert (Brooks and Matchett 2006).

In contrast, nearby lands within the Desert National Wildlife Refuge to the west of these BLM lands have been protected from livestock grazing since the refuge was created in the 1930s and do not contain evidence of widespread fires (Brooks and others 2007).

Following the 2005 Mojave Desert fires, there was serious discussion about using herbicides to manage invasive annual fuels along the margins of dirt and paved roads to create fuelbreaks and reduce the window of opportunity for fires to spread and become large (e.g. Brooks and others 2005) (table 5.1), however it has rarely been implemented in part because its efficacy has yet to be evaluated in southern Nevada. Grass-specific herbicide used in small plot experiments has been effective at controlling the non-native Mediterranean split grass (*Schismus* spp.) promoting post-fire establishment of less flammable native forb species in the northwestern Sonoran Desert (Steers and Allen 2010). Even if herbicides are effective in the short-term, they would need to be applied at least every few years as a part of a regular maintenance program to maintain fuelbreaks. If this is done, then these corridors of managed fuels can be used to facilitate fire suppression efforts and potentially reduce the frequency of fire starts from vehicles travelling along roads that parallel treated areas. Mechanical thinning of fuels is a viable management option at very localized scales, due to relatively high cost and potential for undesirable side-effects. For example, narrow (e.g. <10 m wide) managed fuel zones along the margins of roads may be appropriate to minimize anthropogenic ignitions in sagebrush, blackbrush/shadscale, and Mojave Desert scrub ecosystems (table 5.1). Mechanical thinning of understory fuels in old mixed conifer stands may be necessary prior to the reintroduction of low to moderate intensity surface fires. This same approach of understory thinning followed by low to moderate intensity fire can be used in areas exhibiting piñon and juniper expansion into areas where the presence of these trees is not desirable. If fuel beds are already conducive to low to moderate intensity fire, then fire alone should be the preferred alternative.

It should be noted that fuelbreaks, thinnings, or any other type of fuels reduction project can also have negative effects, such as facilitating the spread of invasive plants (Merriam and others 2006). Accordingly, the cost and ecological effects associated with the creation and maintenance of managed fuel zones should always be weighed against their efficacy in slowing or stopping fires, the additional costs and efficacy of suppression efforts where fuelbreaks are not present, and the ecological effects of increased burned areas where fires attain larger size due to the absence of managed fuel zones.

Fire Suppression

Clearly, the most effective way to protect the majority of the low to mid elevation shrubland ecosystem types of southern Nevada from fire damage is to prevent fires from starting and/or spreading into large areas. This requires aggressive fire suppression efforts that may include aerial water and retardant drops and off-road travel by suppression equipment (e.g., engines, dozers). The use of these tactics should not be taken lightly, because phosphate-based retardants may promote dominance by invasive annual plants (Besaw and others 2011; Brooks and Lusk 2008) and off-road travel, especially the use of dozers, can damage both natural and cultural resources. Thus, the potential negative effects of aggressive fire suppression must be weighed against the potential negative effects of fires spreading to cover more area and the ability to mitigate negative suppression effects immediately following fires.

In contrast, wildland fire use may be the preferred alternative rather than fire suppression at higher elevation and tree dominated ecosystems in southern Nevada (table 5.1). Fire spread potential is minimal in the alpine and bristlecone pine ecosystem type, but if these conditions change in the future (e.g. due to climate change or plant invasions) then fire suppression may be necessary. Periodic low to moderate intensity fire is a desirable natural ecosystem process in the mixed confer ecosystem type, and to a lesser degree in the piñon and juniper and sagebrush ecosystem types. Fire suppression in these types should only be limited to what is required to protect the wildland-urban interface (WUI) and/or to limit the spread of fire into excessively large fires that could threaten the persistence of relatively small isolated vegetation stands.

Post-Fire Emergency Stabilization and Rehabilitation

Aerial seeding is often used to increase the recovery potential of native vegetation and decrease the dominance of invasive annual plants on post-fire landscapes in southern Nevada. Although very few studies exist from the Mojave Desert, numerous studies have been published regarding post-fire seeding in the Intermountain West. These studies indicate that establishment success of seeding projects depends on precipitation (Wirth and Pyke 2009) and that very high seeding rates may be required at the lower end of the precipitation spectrum (Thompson and others 2006). They also suggest that successful seeding can lead to lower invasive species abundance (Evans and Young 1978; Goodrich and Rooks 1999; Thompson and others 2006; Wirth and Pyke 2009), although unsuccessful seeding efforts may actually increase invasive plant abundance (Ratzlaff and Anderson 1995). Studies near completion from the Mojave Desert provide only scant evidence of establishment success following aerial seeding of post-fire landscapes in southern Nevada (Brooks and others. in prep.). These studies also indicate that, in general, perennial seedlings only appear in measureable numbers where both rainfall is high and density of invasive annual plants is low. Thus, seedings alone may not be the correct tool to control invasive annual plant populations in areas that they already dominate. Another study near completion reports that establishment of seeded species can be improved where mechanical pitting is done using hand tools and seeds are broadcast by personnel on the ground (DeFalco and others, in prep.). In general, aerial seedings have very low establishment rates in southern Nevada and Emergency Stabilization and Rehabilitation (ES&R) resources may be better applied in other ways (table 5.l).

Temporary closures for livestock grazing are also implemented to provide native perennial vegetation a chance to recover following fires. These closures typically last only a few years, and it is unclear if they are beneficial. They also appear difficult to enforce, as livestock are often observed within closure areas (Matthew Brooks, personal observation of post-fire landscapes during the winter following the 2005 fire season, Lincoln County, Nevada). Survival of residual native plants may be enhanced by protection from post-fire grazing, especially in blackbrush/shadscale and Mojave Desert scrub ecosystems where species generally have low capacity for post-fire recovery (table 5.1).

Knowledge Gaps

Understanding Fire Histories

A better understanding of fire histories of southern Nevada ecosystem types can be used to develop more effective management plans for these areas. Specific studies targeting key ecosystem types and locations are needed to test current hypotheses regarding assumed historic fire frequencies. These include dendrochronology studies of the mixed conifer zone in the Spring Mountains, and soil stratigraphy studies using charcoal lenses as proxies for fire events within watersheds dominated by single ecosystem types.

Climate and Fire Size and Frequency

Routine evaluations of the relationship of climate to fire size and frequency and how this relationship might change with climate warming are needed to develop effective fire management strategies. Precise descriptions of spatial and temporal patterns of burning only span a few decades of comprehensive records (e.g., agency reports and satellite imagery). Conclusions about fire trends can vary widely depending upon which time interval one evaluates within the current record. Re-evaluation of these data should be done at regular intervals (e.g., 5 year) to test the robustness of the current hypotheses regarding short-term ENSO and longer-term PDO effects on fire regimes.

Fire Effects on Plant Species and Vegetation Types

The effects of fire on plant species and vegetation types must be more thoroughly understood before predictive models can be useful to management. Within each ecosystem type the various effects of fire, fire regime, and local site characteristics need to be investigated further. This will require intensive data from numerous fires, and possibly the use of experimental fires. Even less information is available regarding the effects of fire on animals, but because so many sensitive species are associated with particular ecosystem types, a full understanding of fire effects on animals can only be realized after a more complete understanding of vegetation responses.

Post-Fire Management

Additional information is needed regarding appropriate management actions after fire. It is well established that aerial seedings of post-fire landscapes have very low establishment rates. However, much less is understood about other management actions designed to reestablish native vegetation. Also, little is known about the effects of post-fire grazing. For example, how does the duration and intensity of post-fire grazing by livestock affect vegetation resilience to fire and expansion of invasive annual grasses? How effective is livestock grazing at managing fuels created by invasive annual plants?

Fire Suppression Impacts

Considering that fire suppression may be the most effective fire management tool in low to mid elevation ecosystem types, there is a need to better understand the relative impact, both negative and positive, of aggressive fire suppression tactics (e.g. retardant drops and off-road travel) versus allowing fires to spread and burn more areas.

Semi-Arid Ecosystem Response to Wildfire

Because tree infilling and growth are ongoing processes in higher elevation conifer and piñon and juniper ecosystems, information is needed on the response of these semi-arid ecosystems to wildfire and fire and fuels treatments. Information also is needed on how fire and fuels treatments can be used for restoring and maintaining landscape heterogeneity of these diverse ecosystems.

Management Implications

Important take-home messages for land managers are that (1) the effect of an individual fire event should be evaluated within the context of the ecosystem type in which it occurs, the characteristics of the fire, and characteristics of the site; (2) fire suppression is the most cost effective way to manage fires across most of southern

Nevada, except in a few ecosystem types where fire is part of the natural disturbance regime and wildland fire use should be an option to achieve management objectives; and (3) the current range of post-fire mitigation tools used are either ineffective or their effectiveness is poorly documented. Like all aspects of land management, fire management must ultimately be placed in the broader context of all the other factors associated with managing landscapes in southern Nevada. In some cases decisions may need to be made regarding where to allocate limited resources, and in other cases conflicting objectives may need to be resolved between fire management and those focused on other management topics (especially natural and cultural resources). The information contained in this chapter should help all parties better understand issues associated with fire management.

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Chapter 6

Species of Conservation Concern and Environmental Stressors: Local, Regional, and Global Effects

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Introduction

Species conservation has traditionally been based on individual species within the context of their requisite habitat, which is generally defined as the communities and ecosystems deemed necessary for their persistence. Conservation decisions are hampered by the fact that environmental stressors that potentially threaten the persistence of species can operate at organizational levels larger than the habitat or home range of a focal species. Resource managers must therefore simultaneously consider local, regional, and/or global scale stressors for effective conservation and management of species of concern.

The wide ranging effects associated with global stressors such as climate change may exceed or exacerbate the effects of local or regional stressors. Although resource managers may only be able to directly affect local and regional stressors, they still need to understand the direct and interactive effects of global stressors and ultimately how they affect the lands they manage. Conservation of species in southern Nevada is further complicated by the fact that the region includes one of the largest and fastest growing urban centers in North America. To accomplish the goal of species conservation, resource managers must identify actionable management options that mitigate the effects of local and regional stressors in the context of the effects of global stressors that are beyond their control.

Species conservation is typically focused on a subset of species often referred to as species of conservation concern that have either demonstrated considerable decline or are naturally rare or have limited distributions. Stressors can directly and indirectly impact species in a variety of ways and through a diversity of mechanisms. Some stressors have been more intense in the past (e.g., livestock grazing) whereas others are only now emerging as new stressors (e.g., solar energy development, climate change). The primary stressors affecting southern Nevada ecosystems are listed in table 2.1 and reviewed in detail in Chapter 2. This chapter addresses Sub-goal 1.4 in the SNAP Science Research Strategy which is to sustain and enhance southern Nevada's biotic communities to preserve biodiversity and maintain viable populations (table 1.3; Turner and others 2009). We provide numerous examples of how stressors affect the range and/or habitat of select species of conservation concern. It is important to note that the species or groups of species discussed in this chapter by no means represent a comprehensive treatment of all species of conservation concern listed in table 1.2 (Chapter 1). Rather, several species where chosen as examples for each southern Nevada ecosystem type to illustrate how stressors and linkages among them can affect species of conservation concern, keeping in mind that many of the species considered here are found in more than one ecosystem type. In addition, the stressors that may impact a species in one ecosystem may not be those that affect it in another ecosystem and different species in the same ecosystem may not be affected by the same suite of stressors. Finally, at the start of each ecosystem section we summarize key resource concerns, species used as examples, key stressors, and potential synergistic effects of those stressors relative to the species examples.

Alpine and Bristlecone Pine Ecosystems

Key resource concerns	General lack of understanding of basic ecology of species, need for assisted migration
Species examples	Rare, covered (i.e., under regional resource management plans) and/or endemic plants
Local and regional stressors	Recreation, invasive species, nitrogen deposition, habitat modification, disease, altered fire regime
Global stressors	Climate change
Synergistic effects	Climatic induced susceptibility to nitrogen deposition, stochastic disturbance/recreation and invasive species, climate change altering local feedback systems (pollinators, herbivory, fire regimes)

The alpine ecosystem occurs at sites generally above 3,500 m in the Spring Mountains where alpine fell-fields and exposed dry rocky soils occur. Alpine meadows can also be found in swales where soil moisture accumulates in fine textured soils. We also include in this section the bristlecone pine ecosystem, which occurs on dry rocky slopes above the mixed conifer (2,600 m) and below the alpine ecosystems in the Spring and Sheep Mountain ranges. At its upper ecotone, bristlecone pine occurs as open woodlands transitioning into alpine fell-fields, whereas at its lower ecotones bristlecone pine is intermixed with other tree species as it transitions into the mixed conifer ecosystem. These alpine and bristlecone pine ecosystems occur as sky islands, where species occupy sites that occur in relative isolation amidst the vast lower elevation desert landscape. The geographic isolation among sites and the unique biophysical setting and environmental extremes of these ecosystems have led to the evolution of unique plant and animal assemblages and numerous endemic species, as is evident in the Spring Mountains (Clokey 1951). Several species of covered, rare, and/or endemics plant species occur within the alpine and bristlecone pine ecosystems of southern Nevada.

Alpine and bristlecone pine ecosystems are susceptible to various stressors and disturbances because of their relative isolation and extreme elevation. Species inhabiting these ecosystems have few options to negotiate associated stressors, especially those that operate at global and regional scales (e.g., climate change and atmospheric nitrogen deposition). Locally, recreation (e.g., snow skiing developments, rock climbing), invasive species (e.g., dandelion), associated stochastic disturbance events (e.g., avalanches), and altered fire regimes can affect the species that occur here. The limited amount of available habitat in these ecosystems limits the degree to which species, especially plants, can respond to disturbance or stressors.

The effects of climate change and associated global stressors on alpine ecosystems in particular have been associated with increased species richness at mountain peaks as populations of lower elevation species move upslope (Pauli and others 1996). Subsequent increases in the numbers of potentially competing species may threaten resident alpine species. Climate change can lead to changes in snow duration, depth, and extent, which may differentially produce substantial changes in the carbon and nitrogen soil dynamics of alpine ecosystems (Williams and others 1998). Climate change can further affect the type, timing, and amount of precipitation, which is especially detrimental to species living in alpine and other ecosystems (Chapter 2). Warming climate conditions leading to longer growing seasons may also result in the upslope migration of mixed conifer species; the associated increase in understory fuels may alter fire regimes and threaten the persistence of bristlecone pines and other white pine species (Chapter 5).

Alpine and bristlecone pine ecosystems are also very susceptible to atmospheric nitrogen deposition, which is a broad scale regional disturbance that can alter naturally low rates of primary productivity and soil microbial activity (Chapter 2). Although nitrogen is a key nutrient for plants, high rates of nitrogen deposition from atmospheric pollutants have been linked to ecosystem stresses in plants including increased rates of herbivory, pathogen susceptibility, and reduced frost and drought tolerance (Bowman and Steltzer 1998). Nitrogen deposition has also been shown to promote dominance of invasive annual plants in the Mojave Desert (Brooks 2003), which could promote the establishment of altered fire regimes (Brooks and Pyke 2001). Nitrogen deposition is a consequence of urbanization and industrialization and, given the proximity of the alpine ecosystems to the greater Las Vegas area, its potential ecological effects are significant.

Because of difficulty in access and the relative isolation of the sky-island ecosystem, direct disturbance from human activity is rare. However, recreational use, including hiking, camping, and activities associated with rock climbing, can lead to soil disturbance and compaction and erosion, and these activities have increased during recent decades with human population increases in the greater Las Vegas region. In addition, recreational activities may facilitate the introduction of non-native plant species (DRI 2008) by both facilitating dispersal and causing disturbances that can facilitate weed establishment rates. Invasive annual grasses moving upslope could pose a particular threat to bristlecone pines from altered fire regimes (Chapter 5).

Alpine and bristlecone pine ecosystems are essentially high elevation deserts, with limited water availability and extremely short growing seasons. Collectively, the stressors that act on this ecosystem can have dire effects on species of conservation concern, potentially affecting key habitat requirements for naturally rare and/or endemic species. Few management options exist for regional managers to negotiate reductions to global climate change, or similar widespread regional stressors such as nitrogen deposition. However, actions focused on minimizing impacts from recreation and/or invasive species and altered fire regimes can be important for species of conservation concern that inhabit these ecosystems.

Mixed Conifer Ecosystem

Key resource concerns	General lack of understanding of basic ecology of species, increased fire and invasive species risk
Species examples	Endemic butterflies
Local and regional stressors	Fire suppression, habitat modification/fragmentation, invasive species, vegetation management, recreation and unregulated grazers
Global stressors	Climate change
Synergistic effects	Fuels thinning operations and invasive species

The mixed conifer ecosystem occurs in the Spring and Sheep Mountains from 1,200 m to 3,200 m in southern Nevada. This ecosystem consists of three unique types: (1) white fir forests, (2) ponderosa pine forests, and (3) ponderosa pine/mountain shrub community (see Chapter 7). Unlike adjacent ecosystems at lower elevations, mixed conifer forests receive more precipitation, have longer growing seasons, and experience milder summertime temperatures, all of which provide the necessary conditions to support diverse groups of plants and animals.

The mixed conifer system is affected by a suite of local and regional stressors including fire and fuels management activities, recreation, and urban and water development. Historical fire suppression has promoted fuel accumulation, which can lead to high intensity fires that burn large areas and compromise habitat integrity (Battaglia and Shepperd 2007). These stressors have individually and synergistically compromised the stability and persistence of species of conservation concern in the region, and this is especially evident in the Spring Mountains. The effect of climate change on episodic and stochastic weather events coupled with long-term effects associated with years of fire suppression, and more recently invasive species and recreation, combine to impact the persistence of butterflies endemic to the Spring Mountains (USFWS 2011a).

Eight species of endemic butterflies occur in the Spring Mountains and are managed by the United States Forest Service (USFS) in cooperation with the United States Fish and Wildlife Service (USFWS) under a Conservation Agreement between the two agencies. Four of the eight species have been identified as conservation priorities including the Mt. Charleston blue butterfly (*Plebejus shasta charlestonensis*), Morand's checkerspot (*Euphydryas anicia morandi*), Spring Mountains acastus checkerspot (*Chlosyne acastus robusta*), and Spring Mountains dark blue butterfly (*Euphilotes ancilla purpura*). These four species were identified as a priority in the Conservation Agreement because of the limited number of locations where the species are currently known to occur. In 2006, these species were added to the Forest Service Regional (R4) Forester's Sensitive Species List, and they are currently among the species of conservation concern in southern Nevada (table 1.2; Chapter 1).

The Mt. Charleston blue butterfly, one of seven unique subspecies of the wider ranging Shasta blue butterfly (*Plebejus shasta*), was petitioned for listing as an endangered species in 2005. The habitat for the Mt. Charleston blue butterfly is characterized as flat ridgelines above 2,500 m occupied by its host plant species. Primary among these host plants is Torrey's milkvetch (*Astragalus calycosus* var. *calycosus*), a small, low-growing perennial and herbaceous legume that grows in open areas between 1,500 and 3,300 m in subalpine, bristlecone, and mixed-conifer communities in the Spring Mountains

(Weiss and others 1997). On March 8, 2011, the USFWS announced that listing the species is warranted, but precluded by higher priority actions; therefore they added it to the list of candidate species. If it rises higher on the priority list, the USFWS will develop a proposed rule to list this subspecies and make any determination on critical habitat during development of the proposed listing rule (USFWS 2011a).

Climate change is among the factors hypothesized to be responsible for the decline of the Mt. Charleston blue butterfly. Extreme climate events potentially linked to climate change can adversely affect butterflies with small restricted populations (Gilpin and Soulé 1986; Shaffer and others 2001). The Mt. Charleston blue is thought to be susceptible to random environmental and climatic events, specifically, extreme precipitation and drought events (Murphy and others 1990). The timing and number of emergent individuals that reproduce depend on a combination of environmental conditions; the result can mean the difference between a successful and an unsuccessful year for the species in question. Madsen and Figdor (2007) reported a nearly 30 percent increase in storm frequency associated with extreme precipitation in the past 6 decades in Nevada. Such extreme weather events directly impact the life cycle of the subspecies, and also indirectly impact the subspecies as mediated through host plant dynamics. The IPCC (2001) predicts that altered regional patterns of temperature and precipitation as a result of global climate change will continue. These altered climate patterns could increase the potential for extreme precipitation events and drought throughout the range of the Mt. Charleston blue, which may intensify the threats this species may be experiencing.

Various forms of habitat modification, including years of fire suppression, and introductions of non-native invasive species, are linked to the declines in species of conservation concern in the mixed conifer ecosystem (Weiss and others 1988). Historically, low-severity fires typically burned through Ponderosa pine stands within the range of the Mt Charleston blue and may have allowed for a more open mixed conifer forest characterized by a more abundant and diverse understory. Fire suppression has led to altered community successional patterns, which has altered host plant dynamics, altered butterfly movement patterns and reduced solar insolation (Wiess and others 1997). Additionally, the closing of the forest canopy may have compromised the metapopulation processes including colonization and recolonization dynamics. Shrub and forb in-filling as well as increased dominance of invasive grasses may out-compete and potentially decrease the abundance and quality of host plant resources for this butterfly species.

The mixed conifer ecosystem may also be affected by various forms of recreational use, including hiking, rock climbing, and skiing. The Spring Mountains are home to the Las Vegas Ski and Snowboard Resort (LVSSR) that operates under a USFS special use permit. It is difficult to assess the degree to which the resort affects the endemic butterflies within the Spring Mountains. It is also possible that the active management for ski runs and potential expansion, including thinning of trees and shrubs and seeding of non-native species for erosion control, may indirectly impact the butterfly by preventing host plants from reestablishing in disturbed areas. Such disturbances are different from naturally created forest gaps and may not promote host plant establishment. In summary the effects of such disturbance features and events on host plant establishment are unknown and require further investigation.

In 2009, the USFS initiated the Spring Mountains National Recreation Area Hazardous Fuels Reduction Project to reduce accumulated forest fuel and lower fire risk by providing fuel breaks along human-use corridors, on the edges of private property, and at other human use areas such as campgrounds. Treatments varied widely depending on specific site conditions, but generally included use of heavy equipment and mastication treatments. These operations require investigation because they may directly impact butterfly population dynamics and habitat if individuals or host plant patches are killed or destroyed.

The mixed conifer ecosystem is the focus of a diverse and varied set of management programs including vegetation and fuels management, rare species conservation, non-native species management, endemic butterfly research, and more. Increased pressure from urbanization and recreation will continue to challenge resource managers with balancing permitted human activities with protecting ecosystem integrity.

Piñon and Juniper Ecosystem

Key resource concerns	Range expansion and stand in-fill, larger and higher severity fires, non-native species, disease
Species examples	Piñon jay, gray vireo, gray flycatcher, desert bighorn sheep
Local and regional stressors	Fire, invasive species, nitrogen deposition, vegetation management and unregulated grazers
Global stressors	Climate change (e.g., extended drought, longer fire seasons and periods of severe fire weather), carbon dioxide enrichment
Synergistic effects	Conversion to annual grasses and complete loss of habitat, extended drought and insect outbreaks, grazing and brown headed cowbird parasitism, woodland expansion and increased bighorn sheep predation rates

The piñon-juniper woodlands occur between 1,500 and 2,500 m, below the mixed conifer ecosystem, and are often intermixed or adjacent to the sagebrush ecosystem. At the upper elevation ecotones the dominate species include single-leaf piñon (*Pinus monophylla*), Gambel oak (*Quercus gambelii*), mountain mahogany (*Cercocarpus* spp.) and sagebrush (*Artemisia* spp.), whereas at lower ecotones important species include Utah juniper (*Juniperus osteospera*), Rocky Mountain juniper (*J. scopulorum*), western Juniper (*J. occidentalis*), rabbitbrush (*Chrysothamnus*) and sagebrush. While this ecosystem type makes up about 12 percent of the state, it is less well represented in southern Nevada.

The expansion of piñon-juniper woodlands has been widely documented across the southwestern United States (Miller and others 2008), and this is thought to be largely due to reduced frequency of fire (Bauer and Weisberg 2009). Reports indicate that over the past 150 years piñon-juniper woodlands have expanded into other ecosystem types (e.g., sagebrush) and have also experienced increased plant density (i.e., in-filling), which has resulted in reduced dominance or the complete loss of understory plant species (Bauer and Weisberg 2009; Miller and others 2008). Miller and others (2008) found that at sites in the Great Basin, the area occupied by piñon and or juniper has increased 125 to 625 percent since 1860. The woodland expansion is greater at mesic sites and in-filling rates are greater at lower elevations (Weisberg and others 2007). The landscape scale shifts are primarily thought to be due to climate change, altered fire regimes, and livestock grazing (Romme and others 2009a,b). These dynamics may promote insect pressure leading to mortality, fire risk, and non-native plant invasions. Conversion to piñon-juniper woodland from other critical ecosystem types (e.g., sagebrush) promotes an increased risk of large-scale and higher severity fires, which impact wildlife within the piñon-juniper ecosystem. At lower elevations, fire may ultimately result in invasive annual grass dominance.

More recently, massive piñon pine die-offs have been documented across the West. Breshears and others (2005) found that from 40 to 80 percent of piñon (*Pinus edulis*) trees died between 2002 and 2003 at sites in Arizona, Colorado, New Mexico, and Utah, which may be related to climatic shifts and interactions with forest pathogens (Breshears and others 2009). Periodic droughts have promoted reductions in canopy cover, thereby resetting the successional clock in these systems (see Clifford 2011). Extended drought is a significant factor in insect outbreaks that can kill large stands of trees (Breshears and others 2005).

Within the piñon-juniper woodland, species including the piñon jay (*Gymnorhinus cyanocephalus*), gray vireo (*Vireo vicinior*), and gray flycatcher (*Empidonax wrightii*) are experiencing notable population reductions (Sauer and others 2008). Stand in-filling and piñon pine die-off have translated to decreased bird species' abundances in this ecosystem (Sauer and others 2008). The piñon jay caches piñon seeds, on which it relies throughout the year, in more open transitional stands near sagebrush and other more open habitat. However, shifts in community composition and die-off have resulted in lower piñon seed crops. The large expanses of closed-canopy stands without a satisfactory understory component are not suitable for piñon jays. According to ongoing telemetry studies being conducted by the Great Basin Bird Observatory, piñon jays prefer mixed age, early to mid-successional stands with a structurally diverse ecotone.

Gray vireos use mature or mixed-age piñon-juniper woodlands with scattered trees and open canopies, especially where juniper is more abundant (Goguen and others 2005). The gray vireo may be negatively impacted by stand in-fill due to altered fire regimes, reduction of shrub cover due to livestock grazing, increased abundance of invasive plants, and brown-headed cowbird (*Molothrus ater*) parasitism (Goguen and Mathews 2001). For example, Goguen and Mathews (1998) found that livestock grazing can indirectly affect the nesting success of some songbird species by increasing cow bird abundance, although data specific to southern Nevada is lacking. The gray flycatcher uses a diversity of habitats in Southern Nevada but has a preference for the piñon-juniper ecosystem in the Mojave portion of its distribution (Sterling 1999). Gray flycatchers use moderately open piñon-juniper/sagebrush transitional habitats and therefore have the potential to be negatively impacted by stand in-fill.

The desert bighorn sheep (*Ovis canadensis nelsoni*) occurs on sparsely vegetated steep slopes, canyons, and washes within multiple ecosystem types in southern Nevada, including piñon and juniper woodlands. Especially important habitat includes treeless or rocky areas that provide escape routes from predators. Desert bighorn sheep and other subspecies have experienced major population declines from the 1850s to the early 20th century (Buechner 1960). The desert bighorn is less studied than other subspecies, but reports suggest that numerous factors have contributed to population declines including disease, low reproductive output, habitat loss/fragmentation and degradation and predation (Buechner 1960; Gutiérrez-Espeleta and others 2000).

Disease is among the most important factors that has led to the decline of the desert bighorn sheep (USFWS 2000a), especially diseases contracted from domesticated cattle and sheep (Gildart 1999; Jessup 1985). Increased human effects, including habitat loss and degradation, have also impacted the desert bighorn sheep (DeForge 1981; Hick and Elder 1979). Such impacts include increased noise, lighting, and increased human and pet presence in sheep habitat. The increased presence of humans and pets promotes an increase in some predators including coyotes, especially along the wilderness/urban interface (Ditchkoff and others 2006). Desert bighorn have also been shown to avoid areas where feral horses are present, potentially altering their foraging and watering preferences (Ostermann-Kelm and others 2008). Climate variability can also lead to poor diet quality for desert bighorn sheep, a pattern especially important at lower elevations such as occur in Mojave Desert scrub (Epps 2004).

Increased woodland expansion, especially increased cover near watering sites, may also be facilitating increased predation rates by mountain lions (*Puma concolor*) on desert bighorn sheep. This same phenomenon is thought to be occurring with the Sierra Nevada Bighorn (*Ovis canadensis sierra*) populations (R. Klinger, personal communication). Predation by other species, including coyotes (*Canis latrans*) and bobcats (*lynx rufus*), may also reduce lamb recruitment, although the effects of these predators are not well known (Wehausen 2005).

Resource managers should consider using fire, vegetation management actions (thinning techniques), invasive species management, and restrictions on recreation activities when managing this ecosystem (see Crow and van Riper 2010). Dynamics brought upon by a changing climate, including drought and associated interactions with insects or other pathogens, will continue to challenge local resource managers.

Sagebrush Ecosystem

Key resource concerns	General habitat loss and degradation, grass-fire cycle, woodland encroachment
Species examples	Sage thrasher, sage sparrow, burrowing owl
Local and regional stressors	Fire, invasive species, nitrogen enrichment, OHV use, energy development
Global stressors	Climate change (i.e., extended drought), carbon dioxide enrichment
Synergistic effects	Grazing, annual grass invasion and fire regime shifts; climate change and woodland encroachment

Sagebrush ecosystems are less well represented in southern Nevada compared to the rest of the state. In southern Nevada the sagebrush ecosystem can be found in the Spring, Sheep, and Virgin Mountains at elevations between 1,500 to 2,800 m (RECON 2000). The loosely applied term sagebrush ecosystem is used to describe ecological systems where members of the genus Artemisia are the dominant species. In southern Nevada this includes big sagebrush (*A. tridentata*), low sagebrush (*A. arbuscula*), Bigelow sagebrush (*A. bigelovii*), silver sagebrush (*A. cana*), and black sagebrush (*A. nova*). The specific species association depends on elevation, topography, soil type, and degree of aridity.

Sagebrush ecosystems represent a contentious place marker among ranchers and conservationists across the Intermountain West. It has been argued that decades of improper land management have led to deterioration of this ecosystem type. It is thought that overgrazing, among other causes, has contributed to the reduction of associated species thereby promoting the invasion and dominance of invasive annual grasses, including cheatgrass (*Bromus tectorum*) and red brome (*B. madritensis*) (DiTomaso 2000). With the expanding dominance of invasive annuals grasses, fine fuels have become ubiquitous, and the potential for fire to ignite and rapidly spread is increased. Once burned, the area can become dominated by invasive grasses that effectively out-compete native species. This then allows for a reduction in the fire return interval from about 50 to 200 years to only several years. This is a well-established dynamic called the grass-fire cycle, which has rapidly transformed countless hectares of landscape to invasive annual grass dominance (Brooks and others 2004; D'Antonio and Vitousek 1992). Sagebrush is not well adapted to fire and is only able to regenerate from seed post fire, which may take years to decades. With the onset of the grass-fire cycle, natural regeneration of the native dominated communities is nearly impossible and active restoration efforts are not widely successful. Mojave scrub and blackbrush communities, other ecosystems described in this chapter, are also degraded by this grass-fire cycle dynamic.

To further complicate matters, climate change from carbon dioxide enrichment has been shown to increase productivity and biomass accumulation as well as alter the carbon to nitrogen ratio and digestibility of *Bromus* spp., potentially enhancing the competitive abilities of these non-native invaders (Smith and others 1987) and increasing the fuel loads (Ziska and others 2005). Sagebrush communities are also under threat from piñon-juniper expansion. Moreover, energy development, urban development and off-highway vehicle (OHV) recreation also place pressure on this ecosystem, which may be further exacerbated by future changes in climate (change in precipitation timing and type, melt off, and temperature shifts).

The ecological impacts associated with sagebrush habitat deterioration, or loss to annual grassland type conversion, have been widely documented in the Intermountain West. The deterioration alters soil morphology (Norton 2004), soil biota (Belnap and others 2005), native plant biodiversity (Humphrey and Schupp 2001), as well as diversity of invertebrates (Ostoja and others 2009), small mammals (Ostoja and Schupp 2009), reptiles (Newbold 2005), and birds (Knick and others 2003; Knick and Rotenberry 2002; Paige and Ritter 1999). However, the evaluation of specific mechanisms for shifts of wildlife species or communities have received less attention (but see Rieder and others 2010).

At the same time, the upper elevation sagebrush ecotones are experiencing increased juniper dominance, which may also compromise the integrity of the ecosystem for specific wildlife populations or guilds (see piñon-juniper section above). In fact, much of what is mapped by the USFS as the sagebrush ecosystem in the Spring Mountains National Recreation Area has a substantial component of juniper trees (Steven Ostoja, personal observation of plant community composition in the Spring Mountains, June, 2009).

In southern Nevada, bird species of conservation concern in sagebrush habitat include the sage thrasher (*Oreoscoptes montanus*), sage sparrow (*Amphispiza belli*), burrowing owl (*Athene cunicularia*), and others (see www.gbbo.org). Each of these species is negatively affected by habitat degradation and loss caused by urban, agricultural, energy, or other development. Sage thrashers use sagebrush habitat in southern Nevada during winter and migration periods; they prefer large expanses of sagebrush or shrub habitat, avoiding areas with junipers even when at low densities (Noson and others 2006). The burrowing owl is declining throughout much of its former range and is recognized as a National Bird of Conservation Concern by the U.S. Fish and Wildlife Service (Klute and others 2003). The owl is a yearlong resident throughout most of Clark County, but is only a summer and spring resident in adjacent southern Nevada counties. Increased development and associated effects (e.g., roads) promotes human disturbance to breeding colonies of owls (Poulin and others 1993). Moreover, because they are a ground nesting owl, domestic and feral dogs also have the potential to do great harm to their populations. The sage sparrow relies on large expanses of southern Nevada sagebrush and shrubland habitat during winter and migration periods. The sage sparrow is reported to be sensitive to cheatgrass invasion because of the reduction of shrub cover and loss of sparsely vegetated inter-shrub area that it requires for foraging. Research investigating the effects of grazing on sagebrush birds has shown mixed results (Page and others 1978; Saab and others 1995).

Invasive brome grasses, woodland expansion, and human activities will likely continue to threaten the sagebrush ecosystem in southern Nevada. Without question, these dynamics are closely linked to global stressors like climate change and pose a significant management challenge to land managers. The degree to which increased brome grass invasion is due to local disturbance versus increasing concentrations of carbon dioxide, nitrogen deposition, and climate mediated events is unclear. Climate models with projections of species range expansion may aid managers when considering management actions for species of conservation concern in this ecosystem type. At the same time, because so little of the sagebrush ecosystem naturally occurs in the region, conservation of what remains is important in the development of land management plans.

Blackbrush and Shadscale Ecosystems

Key resource concerns	General habitat loss and degradation, grass-fire cycle
Species examples	Blackbrush
Local and regional stressors	Fire, invasive species, nitrogen enrichment, OHV use, energy development
Global stressors	Climate change (precipitation patterns), carbon dioxide enrichment
Synergistic effects	Unknown

Blackbrush ecosystems are woody evergreen shrublands dominated by blackbrush (*Coleogyne ramosissima*) and are primarily found on thermic and shallow limestone-derived soils between 1,200 and 1,800 m in elevation (Pendleton and others 1995). Some blackbrush stands also occur on more mesic, deeper, and sandier soils, although that is not the norm in the Mojave Desert (Brooks and Matchett 2003; Matthew Brooks, personal observation of blackbrush community substrates throughout the Mojave Desert during the 1990s and 2000s). Shadscale (*Atriplex confertifolia*) can be dominant within the same elevation range on heavy, rocky soils (Brooks and others 2007). Associated species include Mormon tea (*Ephedra* spp.), wolfberry (*Lycium* spp.), hopsage (*Grayia spinosa*), and various species of grasses (Brooks and others 2007). The distribution of the ecosystem type is influenced by moisture, temperature, and soil types within the elevation range. Recent genetic analyses suggest that blackbrush is divided into two unique metapopulations, one centered in the Mojave Desert and the second on the Colorado Plateau (Richardson and Meyer 2012). Although we include both the blackbrush and the shadscale ecosystems in this section due to their similar ecological ranges, we focus on the dynamics and species composition associated with blackbrush due to the limited information available on shadscale.

Blackbrush/shadescale ecosystems are used as winter forage by deer and bighorn sheep (Bowns and West 1976) and habitat for numerous species of birds and small mammals (Brown and Smith 2000). In addition, there are 11 covered species that occur in the blackbrush ecosystem of Clark County, eight of which are reptiles and three of which are vascular plants. Here, we limit our discussion to blackbrush because it has been reduced to remnant patches or is in a highly degraded state throughout southern Nevada. The blackbrush ecosystem is one of the most flammable ecosystems in the Mojave Desert. Fires burn plants to ground level and destroy soil seedbanks (Brooks and Draper 2006; Brooks and others 2007). Because natural recruitment is low for all plants in this ecosystem, it may take centuries for natural recovery to occur following fire (Minnich 2003; Webb and others 1987). Disturbances, including grazing and recreation, allow the establishment of invasive species including *Bromus* spp. (see sagebrush section in this chapter). Once *Bromus* spp. is established, the grass-fire cycle is initiated and conversion of the area to non-native annual grasses is likely.

Fire, invasive species, grazing, development and recreation are among the greatest stressors to this ecosystem type. Grazing appears to have lasting effects on blackbrush shrub cover, soil crusts, and associated perennial plant cover (Jeffries and Klopatek 1987). Blackbrush ecosystems in healthy ecological condition were likely more extensive prior to European contact (see Brooks and others 2007). Large areas of blackbrush were burned into the mid-1900s to increase livestock forage production and are currently dominated by early seral species. Only sporadic re-colonization by blackbrush has occurred, and that has been focused on the more mesic end of this species' ecological range (M. Brooks, unpublished data). Recreational use, including foot, bike, horseback riding, and OHV use, can cause soil compaction and limit plant recruitment, which may facilitate habitat fragmentation. Habitat fragmentation may be especially problematic near rural and urban development.

Other potential stressors that threaten blackbrush and the integrity of the ecosystem include the application of pesticides, climate change, increased carbon dioxide in the atmosphere, and fire ants (*Solenopsis* spp.). It is possible that the use of pesticides near rural areas may harm burrowing insects (e.g., ants) and small vertebrates (e.g., lizards and small mammals), thereby affecting patterns of plant recruitment and growth. Additionally, climate change may affect soil moisture and associated warming temperatures may affect associated species of conservation concern in this ecosystem. Rising carbon dioxide concentrations in the air have been linked to increased productivity of non-native annual grasses (Ziska and others 2005). Native ant species burrowing activities are important to this ecosystem, and, may be negatively affected by non-native fire ants. Fire ants may also reduce survivorship of native mammals and ground-nesting birds (Lessard and others 2009; Smith and others 2004).

As suggested for the sagebrush ecosystem, focusing on protecting the remaining remnant patches of the blackbrush/shadscale ecosystem would be of greatest benefit. Because natural regeneration is so limited, especially for blackbrush, it is feared that this ecosystem could disappear without intense restoration management efforts (Jones 2011). Restoration efforts to reestablish blackbrush in the Mojave Desert have had limited success due to seed and seedling predation and low germination rates under hot and dry conditions.

Mojave Desert Scrub Ecosystem

Key resource concerns	General habitat loss, fragmentation and degradation
Species examples	Bajadas: desert tortoise; Sand dunes: three-corner milkvetch and white marginated penstemon; Gypsum soils: sticky ringstem, Las Vegas bearpoppy, and Las Vegas buckwheat
Local and regional stressors	Fire, invasive species, nitrogen enrichment, OHV use, energy development, habitat loss/fragmentation, feral dog/cat predation, grazing, mineral extraction and dumping
Global stressors	Climate change (precipitation patterns), carbon dioxide enrichment
Synergistic effects	Land development, recreation, and invasive species

The Mojave Desert scrub ecosystem is characterized by widely and regularly spaced shrubs up to 3 m tall, and occurs on well-drained soils on slopes, fans, and valley bottoms below 1,200 m (Shoenherr 1992). Several subtypes are considered within this ecosystem type, including bajadas (also called alluvial fans), sand dunes, and gypsum soil.

Bajadas

Bajadas are the most common landform in southern Nevada and are dominated by creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*), with other sub-dominant species including desert thorn (*Lycium andersonii*), bladder sage (*Salazaria mexicana*), indigo bush (*Psorothamnus fremontii*), blackbrush, brittlebush (*Encelia farinosa*), and burro bush (*Hymenoclea salsola*). This is the primary ecosystem type surrounding the major cities of southern Nevada and through which most of the major highways pass (fig. 1.2; Chapter 1), placing it within the wildland urban interface. Increased urbanization promotes human activities that have placed this ecosystem type and the iconic species it supports, including the desert tortoise (*Gopherus agassizii*) and the burrowing owl, at increased risk.

Federally listed as threatened under the Endangered Species Act, the Mojave population of the desert tortoise can be found in regions throughout the Mojave and Colorado Deserts north and west of the Colorado River in Utah, Arizona, southern Nevada, and California. The desert tortoise frequents creosote bush dominated Mojave Desert scrub vegetation, and other low elevation vegetation types, including saltbrush (*Atriplex* spp.), and to a lesser extent blackbrush ecosystems (Bury and others 1994). As of 2007, the estimated desert tortoise population density in the northeast Mojave Desert was 1.7 individuals/km^2, the lowest of all six recovery units (USFWS 2011b).

Recreational human activities such as target shooting and off road driving are known to directly kill or injure desert tortoises (Ladehoff and others 1990). For example, about 10 percent of shell remains from a tortoise study plot near Littlefield, Arizona, were found to have bullet holes (www.federalregister.gov). These occurrences are obviously more common at locations near urban areas where human activity is more frequent. People also collect tortoises for pets, food, and various commercial trades, which further compromises tortoise populations (Grover and DeFalco 1995).

Livestock grazing has been implicated in the decline of desert tortoise populations (Berry 1986). Avery and Neibergs (1997) noted that for most vegetation metrics considered, grazed sites were similar to ungrazed sites, although they did find that bulk density and penetration resistance of soils were greater at grazed sites. Cattle may compete with desert tortoises for forage, especially after winters of above average rainfall when abundant ephemeral resources are available (P. Medic, personal communication). Direct effects of cattle can include rubbing and nudging of tortoises; indirect effects include trampling of actively used burrows and destruction of shading vegetation around actively used burrows (Ladehoff and others 1990).

OHV use and livestock grazing have been implicated in concomitant reductions in native vegetation and increases in invasive species (Brooks and Pyke 2001; Lovich and Bainbridge 1999). Tortoise resource availability and quality may be locally compromised where invasive species densities have increased. Where vegetation cover has been reduced, tortoise habitat quality also is reduced, because fewer sites to shelter from the sun are available to them (USFWS 2008, 2011b).

Tortoises are also subject to diseases that affect populations. Upper respiratory tract disease (URTD) and a shell disease occur in the species. URTD occurs more commonly in wild populations near cities where captive animals may have infected those populations (USFWS 2008, 2011b). Habitat degradation, poor nutrition and drought are likely involved in increasing the susceptibility of individual animals to URTD (Jacobson and others 1991). The USFWS suggests that reducing the human-related spread of URTD and improving habitat conditions may be effective management tools for controlling URTD in wild populations (USFWS 2008, 2011b).

The common raven (*Corvus corax*) is a predator of the tortoise. The raven is associated with human subsidized food resources throughout the Mojave Desert (Kristan and Boarman 2007). Consequently, common ravens have been implicated as contributors to the decline of the desert tortoise (Kristan and others 2004) through direct predation on hatchlings and juveniles (USFWS 2011b). Predation pressure on tortoises can be especially important in drought years (Esque and others 2010).

Climate change may affect the desert tortoise through changes associated with animal metabolism and water relations that could shift population demography (see Henen and others 1998). Other effects of climate change may come indirectly, with changes in vegetation patterns or increased dominance of invasive species. These, too, may further compromise tortoise habitat. The USFWS (2011b) desert tortoise recovery plan estimates that $159 million, plus additional costs that cannot be estimated, is needed in order for the species to become self-sustaining into the future.

Sand Dunes

Sand dunes form with the combination of a sand source and windy conditions. In the Mojave Desert scrub ecosystem, sand dunes are common to playas, remnant lakes, and xeric bottomland basins. Sand dunes are home to highly specialized species that are adapted to living in harsh environmental conditions with limiting resources and water. The model animal of sand dunes may be the desert kangaroo rat (*Dipodomys deserti*), whose fossorial nocturnal nature and fine-tuned biology allows it to escape predators, survive without free water, and recover stored food caches when resources dwindle. Also present in dune systems are several plant species of conservation concern that are receiving some attention (are 'covered') under the Clark County Multiple Species Habitat Conservation Plan (MSHCP): three-corner milkvetch (*Astragalus geyeri* var. *triquetrus*) and white margined beardtongue (*Penstemon albomarginatus*). Three-corner milkvetch is a small ephemeral annual forb that occurs on open, deep sandy soil or dunes that are generally stabilized by vegetation or gravel veneer (Morefield 2001). Reports indicate that difficulty in managing the species comes from general lack of knowledge regarding the species ecology and population dynamics (RECON 2000). White-margined beardtongue is a small herbaceous perennial forb with a long taproot requiring fine, deep, alluvial sand within the Mojave Desert scrub ecosystem. This species prefers sand dunes at the base of hills and mountains in wind-blown sand dune areas but is also found in deep loose sand in washes (Button 1991; Scogin 1989).

Significant threats to the aforementioned species are posed by human activities, including the use of OHVs and multiple use trails that impact habitat and directly kill individual plants (RECON 2000). Energy development and associated urban expansion also threaten species directly and indirectly through habitat loss (Anderson 2001). Many trails and roads created for energy development directly affect individuals and populations. Once the trails or roads are on the landscape, they become available to the general public, support access to the desert landscape and allow increased, repeated use by various recreation groups. Established white-margined beardtongue individuals may survive isolated or infrequent OHV disturbance because the plant can re-sprout from the tap root if the above ground portions are damaged (Scogin 1989). However, sustained and repeated disturbance is much more likely to kill individual plants, and can have a significant impact on populations of both species. Domestic livestock grazing and activities associated with feral animals have the potential to result in significant habitat destruction as well (RECON 2000). Activities associated with water management, including diversion and ground water pumping, can make natural water unavailable and also potentially threaten the species.

Gypsum Soils

This ecosystem supports various gypsum soil community types. Gypsum is a soft sulfate mineral, and gypsum soils occur on more than 100 million ha on Earth (Verheye and Boyadgiev 1997). Gypsum soils are restricted to arid and semi-arid climates where low precipitation prevents gypsum from leaching (Parsons 1976). The physical and chemical properties common to gypsum soils are stressful to most plants. At the same time, these soils support a conspicuous and diverse set of endemic and rare plants in arid and semi-arid regions, and southern Nevada is no exception. The Las Vegas bearpoppy (*Arctomecon californica*) is endemic to gypsum soils in the eastern Mojave Desert and a MSHCP covered species. It has a patchy distribution across low "badland" hills, and is sometimes found on ridges and benches. Larger populations occur in Las Vegas Valley and on gypsum soils associated with the Colorado River drainage (RECON 2000). Another MSHCP covered species is sticky ringstem (*Anulocaulis leisolenus*), which also occurs on gypsum derived soils, primarily in the Frenchman Mountain area east of Las Vegas and further east to the Muddy Mountains and Gold Butte (RECON 2000). Sticky ringstem often co-occurs with the Las Vegas bearpoppy (RECON 2000). The Las Vegas buckwheat (*Eriogonum corymbosum* var. *nilesii*) is also restricted to gypsum-rich soils in Clark and Lincoln counties.

Once widespread and abundant, the Las Vegas bearpoppy has experienced population extirpations throughout southern Nevada (RECON 2000). The Las Vegas bearpoppy's decline is attributed to land development, general habitat degradation, highway construction and backcountry road development, and OHV use (ADGF 2000). Habitat loss and fragmentation due to urbanization are also cited as contributing to population losses and declines (RECON 2000). These direct effects on the populations have also translated to associated higher order effects, and reports indicate that pollinators have declined due to habitat fragmentation (NNHP 2001). Sticky ringstem habitat has been modified and degraded due to urbanization, development including mining, recreational activities, and trampling by ungulates (RECON 2000). Increased recreational use could result in mortality of individual plants as well as loss or disturbance to cryptogamic crusts (RECON 2000). Many of the historical populations of the Las Vegas buckwheat were lost to development as the greater Las Vegas area expanded. Extant populations are experiencing threats from habitat loss, invasive species, and climate change (USFWS 2010) and it is currently a candidate for Federal protection.

Mojave scrub is the most extensive habitat type in the region, and because of its prevalence at the wildland-urban interface it will be subject to increased local, regional, and global threats. Management efforts that concentrate on maintaining natural shrub densities, soil crusts, and healthy native vegetation where widespread intensive disturbance has been minimal would be most beneficial.

Desert (Mojave Lowland) Riparian Ecosystem

Key resource concerns	Tamarisk invasion, biological control beetle
Species examples	Yellow billed cuckoo, southwestern willow flycatcher
Local and regional stressors	Invasive species, fire, grazing, water diversion and extraction
Global stressors	Climate change (precipitation patterns and runoff)
Synergistic effects	Beetle induced vegetation/habitat changes and selective herbivory by unregulated grazers

In southern Nevada, this ecosystem occurs at elevations below 1,200 m and includes the Virgin, Muddy, and Colorado Rivers and Las Vegas Wash as well as adjacent systems (RECON 2000). Desert riparian and associated aquatic ecosystems are influenced by precipitation, topography, and geology (Poff and others 1997). Additionally, the intensity, timing, and frequency of flood events have an important role in shaping and maintaining this ecosystem type. Historically, Mojave riparian ecosystems were dominated by Fremont cottonwood (*Populus fremontii*), Goodding's willow (*Salix gooddingii*), and various species of shrub willows (*Salix* spp.). In higher elevations velvet ash (*Fraxinus velutina*) was an important species. Other riparian plants include honey mesquite (*Prosopis glandulosa*) and a variety of native herbaceous species. Mojave riparian ecosystems contribute disproportionally to local and regional species richness despite the relatively small area they occupy compared to other ecosystems in the region (Naiman and others 1993).

All rivers in the Mojave Desert in Nevada have been altered through surface water diversions, channelization, and dams, thereby resulting in compromised biological and hydrogeomorphic conditions and a loss of system structure and function. The biophysical characteristics (periodic scour, flooding, and sediment deposition) necessary to support riparian plant species and patterns of heterogeneity no longer exist for river systems in southern Nevada (Busch and Smith 1995). Consequently, much of the riparian vegetation is now dominated by invasive species, especially tamarisk, which is also called saltcedar (*Tamarix* spp.) (Shafroth and others 2005).

This ecosystem type is one of the most degraded and imperiled systems in the region. Stressors to this ecosystem include global effects of climate change; regional and local effects of fire, recreation, water manipulation projects; and the aforementioned effects of invasive species (e.g., Tamarisk, and aquatic – see Chapter 3). Climate change effects, especially resulting in changes in flow regimes linked to precipitation (timing and quantity), and increased evapotranspiration may further impact this ecosystem. It is expected that climate change will result in a warmer, drier climate, and reduced surface water across the range of species of conservation concern (i.e., yellow-billed cuckoo (*Coccyzus americanus*) and southwestern willow flycatcher (*Empidonax traillii* subsp. *extimus*)). However, various regional and local stressors individually and synergistically may prove to have a greater influence on species of conservation concern.

Tamarisk is highly competitive with native species and in most cases is the dominant species where it occurs. The effect of Tamarisk dominance on wildlife habitat has been considered most commonly for birds (van Riper and others 2008), and generally indicates that moderate levels of Tamarisk provide better habitat than sites that are Tamarisk monocultures. Although reports have stated that Tamarisk is the preferred habitat for flycatchers (Davis and others 2011) it should be cautioned that previously published reports on this subject (van Riper and others 2008) do not reach the same conclusion.

Efforts to control Tamarisk have been widely implemented and include the use of chemicals, mechanical methods, and fire. Most recently, land managers have released a biological control agent, the northern Tamarisk beetle (*Diorhabda carinulata*), which is native to Eurasia. In 2006, the northern Tamarisk beetle was released near St. George, Utah, and has subsequently expanded along reaches of the Virgin River. During the summer of 2011 the beetles became established within Tamarisk stands farther downstream along the Virgin River, and it may reach Lake Mead National Recreation Area (NRA) by 2012 or 2013. Based on patterns of defoliation along the Colorado River near Moab, Utah, the beetles will require multiple generations to cause substantial impact or even death to localized patches of Tamarisk stands at Lake Mead NRA However, the effect of the beetle on wildlife is unknown (Bateman and others 2010). Efforts are in place to evaluate the long-term effects of the northern Tamarisk beetle on wildlife and associated habitat quality (Bateman and others 2010; also see Bateman and Ostoja 2012).

Although, the effects of introduced biological control species on wildlife groups have received little consideration (but see Pearson and Callaway 2005, 2006, 2008), two potential outcomes seem plausible. First, the beetle may provide increased resources for insectivorous and omnivorous species, thereby conferring advantage for wildlife able to capitalize on these increased prey numbers (Pearson and Callaway 2005, 2006, 2008). However, beetle-caused defoliation and eventual death of Tamarisk trees may negatively affect birds by reducing breeding and nesting habitat. For example, defoliation may change the conditions surrounding a nest, which may lead to reductions in nest success due to loss of cover and increased predation associated with the microclimate of the nest. How the flycatcher and the cuckoo respond to this dynamic is unknown, but is of keen interest to ecologists and managers working in the area (see Bateman and others 2010).

Even with widespread type conversions, this ecosystem continues to support a diversity of organisms including fish, invertebrates, reptiles, amphibians, birds, and mammals (Bateman and Ostoja 2012). This ecosystem is also home to numerous species of conservation concern including the Federally endangered southwestern willow flycatcher and yellow-billed cuckoo. These are two species that are also covered in the Clark Country MSHCP (Clark County 2000).

The southwestern willow flycatcher is a small insect eating neotropical bird that uses riparian habitat for feeding, sheltering and cover while breeding, migrating, and dispersing (Paxton and others 2007). It was Federally listed in 1995 due to its small population size, historical and recent population declines, and habitat threats. The yellow-billed cuckoo is a medium sized bird that breeds in large blocks of riparian habitat (Johnson and others 2008). Nevada has listed the species as critically imperiled due to extreme rarity, imminent threats, and/or biological factors (Morefield 2011).

In Clark County, Nevada the yellow-billed cuckoo's decline has been linked to the reduction and degradation of riparian habitat, river channelization, livestock grazing, and use of pesticides, non-native species (Tamarisk), recreation, and brown-headed cowbird parasitism (Clark County 2000). Nevada has listed the species as a State Rank S1 Nevada State Protected, which means that the species is protected in Nevada and is considered critically imperiled due to extreme rarity, imminent threats, and/or biological factors.

Other local stressors that influence the habitat conditions for the flycatcher and cuckoo include grazing and recreation. Unregulated grazing along riparian systems can compromise ecological integrity where animals occur in sufficient numbers. Livestock that freely roam along arid riparian ecosystems can introduce a great deal of disturbance including reductions in stream bank stability and erosion. Loss of stream bank quality can lead to increased bank deterioration and reductions in habitat for wildlife. In addition, livestock can shift the competitive balance among co-occurring plant species via selective herbivory. Grazing animals can selectively remove desirable plants such as germinating cottonwood (*Populus* sp.) and willows, thereby decreasing native plant regeneration, and thereby indirectly facilitating co-occurring less palatable weedy plants. The effort to remove Tamarisk will be undermined if unregulated grazers selectively remove regenerating native vegetation, thereby facilitating increases in secondary weed populations. These types of synergistic effects are certainly difficult to predict but merit consideration and attention.

Best management practices for conservation of this ecosystem include protecting and potentially enhancing large to medium patches of habitat for species of conservation concern, with the goal of maintaining a heterogeneous habitat complex of open, mixed species and with a varied age canopy, shrub thickets, flowering shrubs, and forbs with ample floodplain and wetland sites intermixed. Protection of old growth trees and sites that have minimal invasive species dominance could also be given priority. Conservation would be enhanced if grazing and OHV use could be kept at levels whereby sites are not permanently impacted and bare soil is not exposed in large patches. Restoration of sites where Tamarisk has been controlled or burned could also be a priority, especially where these sites are adjacent to nearby native patches and where the effect of grazing or OHV use is absent to minimal. Evaluation of biocontrol effects on vegetation trajectories and wildlife habitat would be useful to support future land management decisions.

Spring Ecosystems

Key resource concerns	Habitat loss/deterioration, unregulated grazers
Species examples	Relict leopard frog
Local and regional stressors	Diversion/ground water pumping, land/water development, unregulated grazers, non-native aquatic species, recreation, disease (Chytrid fungus)
Global stressors	Climate change (precipitation patterns)
Synergistic effects	Water/urban/agricultural development & habitat isolation; small population size/isolation and disease susceptibility

Aquatic springs are biophysically diverse ecosystems due to differences in water chemistry, slope, substrate type, persistence, morphology, and size. Springs are most influenced by the type of aquifer, flow rate, landscape position, and local biology. There are two main types of springs, perennial and intermittent. Perennial springs are typically found at sites where deep aquifer ground water reaches the surface. Intermittent springs are typically fed by shallow ground water from localized precipitation. Most springs in Clark County are intermittent and less than 200 are persistent (Sada 2000). They vary in size, are biophysically diverse, and can be found from 250 m to 3300 m elevation in all landscape settings. The basic environmental and biological characteristics of several hundred larger springs within Clark County have been inventoried (Sada 2000; Sada and Nachlinger 1996, 1998).

Springs are inhabited by many spring-obligate species including invertebrates and vertebrates, some of which may be found only in one spring with highly limited distributions (see LaRivers 1949, 1950, 1962). This ecosystem type also provides habitat for 14 MHSCP-covered species including the relict leopard frog (*Rana onca*), which is a candidate for Federal listing under the protection of the Endangered Species Act. The relict leopard frog is a small sized spotted frog with an adult body length of 1 ¾ to 3 ¼ inches (Jennings 1988, 1993). Typical habitat includes permanent small streams, springs, and spring-fed wetlands (Jennings 1988). The species prefers relatively open shorelines where dense vegetation does not dominate. Once thought to be extinct, the relict leopard frog is known to occur at fewer than 10 unique sites (Jaeger and others 2001). The loss of relict leopard frog populations occurred concurrently with the loss or alteration of aquatic habitat due to spring drainage and water development for agricultural and urban applications (Jennings and Hayes 1994). Other notable high-profile species endemic to this ecosystem type not considered here include various species of desert fishes, for example dace (*Rhinichthys* spp.) and pupfishes (*Cyprinodontidae* spp.).

Spring ecosystems are highly sensitive to environmental disturbances. Because water resources are especially prized in arid ecosystems, natural spring systems are used for livestock, recreation, agriculture, and various domestic purposes (Sada and Vinyard 2002). Springs also are indirectly impacted by regional groundwater withdrawal pumping and water diversions. Most springs have been invaded by non-native aquatic and terrestrial species that can affect ecosystem properties (Chapter 3). Invasive species include invertebrates, bullfrogs (*Rana catesbeiana*), crayfish, turtles (e.g., red-eared slider (*Trachemys scripta* ssp. *elegans*)), introduced aquarium species (e.g., mosquito fish (*Gambusia* sp.)), cichlids and other predatory fishes, as well as plants (e.g., Tamarisk species, fan palms). Introduced cichlids are voracious predators and may consume eggs and tadpoles (Romin 1997). Introduced bullfrogs, another fierce predator, are known to eliminate native leopard frogs in the western United States through competition and predation (Hayes and Jennings 1986).

Non-native and unregulated ungulates have been shown to negatively affect spring and associated aquatic habitat by trampling vegetation and soils, and concomitantly causing water quality impacts. Cattle using water sources can draw down smaller water bodies, leaving amphibian egg masses exposed. This leads to desiccation of the eggs, which can increase fungal infections (USFWS 2000b). Cattle can also directly kill egg masses and maturing and adult animals (USFWS 2000b). Loss of streamside vegetation due to cattle grazing can reduce habitat for insects and small mammals (USFWS 2001), which are important dietary components for aquatic species (Cordone and Kelley 1961), including the relict leopard frog. Feral burros also have been implicated in the reduction of frog population numbers due to overgrazing of shoreline vegetation, trampling, and urination and defecation in the water (CBD 2002; Jaeger and Barnes 2001). It should be noted, however, that frogs benefit from open water habitat, which may be increased by cattle or other ungulate grazing. Three recent population extinctions occurred when emergent vegetation encroached into pools following the removal of livestock (RLFWG 2001). At still another two sites, after livestock grazing stopped frog populations were reported to stabilize (CBD 2002; Jaeger and Barnes 2010). Management actions require a detailed understanding of the interactions of the variety of influences on habitat condition. Monitoring is also important, so that managers know if the actions taken are leading to the desired conservation outcome. It is important to note that burros and horses rely on predictable water sources when present within any ecosystem type and sustained trampling and grazing at the water sources can have a variety of negative effects.

Chytridiomycosis is an infectious disease of amphibians caused by the fungus *Batrachochytrium dendrobatidis* ("Bd" or chytrid fungus; Berger and others 1998). The extraordinary virulence of chytrid fungus has caused the decline or extinction of hundreds of amphibian species around the world during the last several decades (Skerratt and others 2007) and hundreds more are considered at risk as chytrid fungus spreads into new areas. Chytrid fungus damages the mouthparts of tadpoles, then damages keratin in the skin of metamorphosed frogs, eventually killing them. Spores of chytrid fungus are ubiquitous in soil, but the aquatic spores infecting frogs is relatively new to science (Berger and others 1998). In 1998, chytrid fungus was found in numerous Arizona amphibians (RLFWG 2001). Reports suggest that chytrid fungus is most virulent at temperatures ≤23 °C and its pathogenicity and virulence decline significantly at ≥27 °C (Piotrowski and others 2004). It appears that thermal springs provide important habitat where frogs can persist despite the presence of chytrid fungus. Luckily, the relict leopard frog only occurs naturally in thermal springs that all have source temperatures >30 °C (Jaeger and Haley 2011).

While attention was given to a single species in this section, other notable species exist in this and associated riparian ecosystems. These include various species of pupfishes and daces as well as invertebrates and plants. The habitats that support these species are highly imperiled due to direct effects of historical and ongoing manipulation or destruction, and their conservation will be an ongoing challenge to resource managers. While not discussed in this section, the effects of climate change are likely to intensify the local and regional stressors. Management of the springs ecosystem is particularly difficult because of its critical dependence on already limited water availability.

Knowledge Gaps and Research Guidance

The overview of research on species of conservation concern provided in this chapter is not a complete review of all species and research topics, but it is a good representation of the nature of single species research in southern Nevada. One of the hallmarks of this body of research is that very little is known about the relative threats posed to, or the mitigation actions needed to protect virtually all species of concern except perhaps the desert tortoise. Too often research jumps immediately to mitigation strategies, without first determining what specific factors pose the greatest threats and are the most important to mitigate. In addition, the evaluation of potential threats typically focuses on the usual anthropogenic suspects (e.g., OHVs, livestock grazing, invasive species, and climate change) without first carefully considering which factors are most likely to pose the greatest threats. Finally, fundamental science associated with the life history characteristics and habitat requirements of species typically receives the least attention, even though these topics are where research programs could most benefit conservation programs. In the section below, we provide a case study that illustrates how a research program was organized in a hierarchical and thoughtful way, in order to provide maximum cost-efficiency and ultimate utility in the management of species of conservation concern.

Research Strategy Case Study: Endemic Butterflies of the Spring Mountains

The Spring Mountains are home to numerous endemic species, including eight butterfly taxa, as discussed previously. Four of these species have very limited distributions and there is concern that their populations may be declining. One of these species, the Mt. Charleston blue butterfly, is currently a Candidate species for listing by the USFWS. Very little is known about the autecology and habitat requirements of these eight butterfly species. Conservation of these species can be based on a comprehensive research framework such as the one proposed below. Although this framework is specific to the endemic butterflies of the Spring Mountains, it provides a good example of what is required to fully inform land managers about species of conservation concern.

Initially, it is critical to understand the life cycles and the key habitat, threats, and restoration factors associated with each life history stage for each butterfly species. Detailed information is needed regarding overwintering stages, larval development, pupation, and adult behavior including oviposition, roosting, basking, and mating. For all of these stages, habitat preferences and related phenologies (the specific seasonal timing of life history events) must be understood, as well as potential threats and mitigating restoration factors (fig. 6.1). This kind of natural history information has been critical in other studies of the population persistence of butterflies (e.g., New and others 1995; Weiss and others 1988).

The next step is to describe the species' population structure and dynamics, including identification of the highest priority populations that are critical to the persistence of each butterfly. Butterflies occur in relatively discrete patches or populations across the landscape (fig. 6.2). The degree to which patches of occupied habitat are or are not connected by dispersal is of primary importance for the management of rare species (Hanski and Thomas 1994). From a conservation perspective, it is also important to know if all patches have equal probabilities of going extinct or being recolonized following extinction (as is assumed in a classic metapopulation). In reality, all patches do not have equal probabilities of persistence through time; instead, some locations act as demographic sources (providing migrants that move to other locations) while others act as sinks (receiving immigrants that act to maintain local populations that would otherwise not persist) (Boughton 1999).

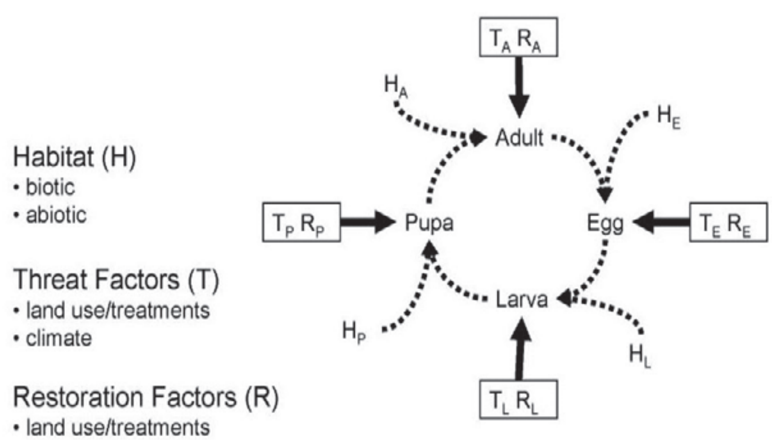

Figure 6.1—Conceptual model illustrating how habitat factors (H), threats (T), and/or restoration activities (R) could impact a butterfly or invertebrate species, and their relationships with critical habitat factors at the adult (A), egg (E), larval (L), and pupa (P) life history stages at the within-patch scale.

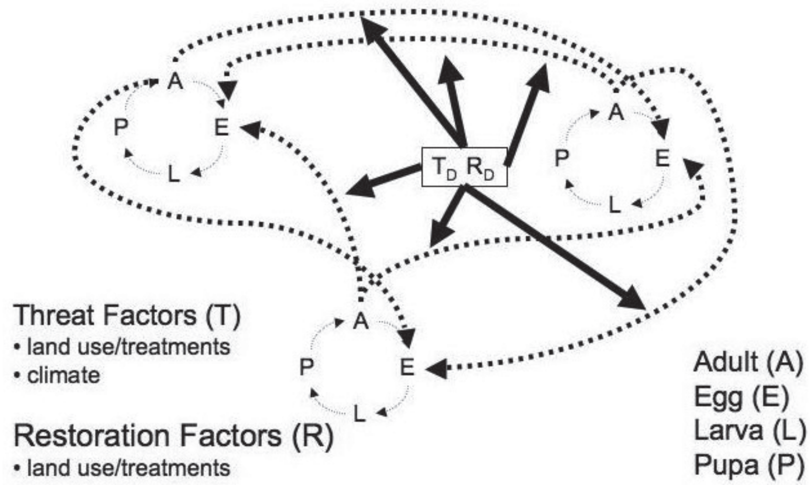

Figure 6.2—A conceptual model showing how threats and restoration can affect among (habitat) patch dispersal. Patches are represented by life cycle diagrams for adults (A), eggs (E), larva (L) and pupa (P), and dispersal among patches is shown as dotted lines being potentially impacted by both threats (T_D) and restoration (R_D).

The third step is to describe the structural and floristic composition of the habitat for each species, including habitat used during each season as well as for dispersal. Attempts to characterize habitat for butterflies and other species can often be hampered by pre-existing biases regarding “suitable conditions” for a particular species. For butterflies, presence of larval host plants and nectar resources is often assumed to be sufficient to define requisite habitat, but that assumption can be erroneous. There is a pressing need to understand the net habitat requirements (across life history stages) for focal butterfly species, and in particular how to distinguish between suitable and unsuitable habitat (fig 6.3). Specifically, there is a need to characterize suitable habitat (both within and among patches) associated with population persistence. In some cases natural enemies may be an important habitat consideration, because mortality from natural enemies can

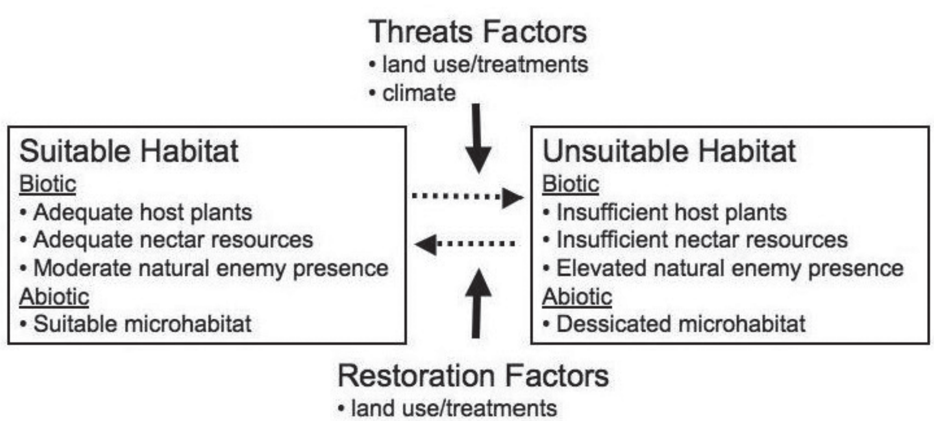

Figure 6.3—A habitat dynamics model illustrating the transition of habitat from suitable to unsuitable (or vice versa) depending on the influence of threats and/or restoration factors (the list of habitat characteristics here is illustrative, not exhaustive).

be a significant factor that is frequently ignored in butterfly conservation plans (Bergman 1999). Precise knowledge of habitat requirements is needed to inform a range of management decisions including where and how to initiate restoration efforts, where to allocate resources when it comes to mitigating certain threats, and where to attempt reintroductions of butterflies should that become necessary. Knowledge of habitat requirements can also direct management efforts by identifying species most at risk through habitat destruction or degradation. This is especially important in the Spring Mountains where vegetation management activities (i.e. fuels reduction/thinning operations) could have an impact/threat on the habitat condition of these species and could easily be modified.

As only a final step, habitat restoration and mitigation actions should be evaluated. Ecological restoration is accomplished by the redirection of natural populations, communities, wildlife habitat, or other ecosystem processes toward trajectories deemed more desirable (Jordan and others 1987). These trajectories can be defined in many ways, but are often focused on promoting specific habitat features known to be critical to a species, which is the focus of conservation planning (e.g., the Spring Mountains endemic butterflies). The development of relevant restoration treatments to achieve desired outcomes requires an understanding of the essential habitat features of the focal species, and the ecological processes necessary to increase the abundance and/or quality of these habitat features. Accordingly, it is not prudent to initiate and/or implement restoration activities until such information is available. In fact, many restoration attempts have failed, and resources have been wasted, because of insufficient knowledge regarding species' autecology (Montalvo and others 1997; Pullin 1996). In brief, it is critical to know what is damaged and what one should be repairing before repair attempts are initiated. However in the short-term it may be prudent to eliminate stressor impacts to reduce the potential threat so the species is able to persist even when the desired information to make a completely informed decision is unavailable.

Management Implications

Historically, actions such as limiting grazing or closing OHV trails have been some of the primary tools used by land managers in southern Nevada to reduce anthropogenic impacts to species of conservation concern. However, managers are increasingly faced with broader and more complex issues that cannot be effectively addressed by regionally or locally based management actions. For example, few if any options exist for local resource managers to directly combat effects associated with climate change or nitrogen deposition, even though they are responsible for ensuring the protection of the species directly or indirectly affected by such stressors. Research that can help disentangle local or regional effects from global effects would be especially useful for conservation planning and management of species of conservation concern. Additionally this would help focus management toward factors where there are actionable options.

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Chapter 7

Maintaining and Restoring Sustainable Ecosystems in Southern Nevada

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Introduction

Managers in southern Nevada are challenged with determining appropriate goals and objectives and developing viable approaches for maintaining and restoring sustainable ecosystems in a time of rapid socio-ecological and environmental change. Sustainable or "healthy" ecosystems supply clean air, water and habitat for a diverse array of plants and animals. As described in Chapter 1, sustainable ecosystems retain characteristic processes like hydrologic flux and storage, geomorphic processes, biogeochemical cycling and storage, biological activity and productivity, and population regeneration and reproduction over the normal cycle of disturbance events (modified from Chapin and others 1996 and Christensen and others 1996). Ecological restoration of stressed or disturbed ecosystems is an integral part of managing for sustainable ecosystems. The Society for Ecological Restoration International (SERI) defines ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SERI 2004).

Many of southern Nevada's ecosystems are being subjected to anthropogenic stressors that span global, regional, and local scales (Chapter 2), and are crossing ecological thresholds to new alternative states (Chapter 4 and Chapter 5). These alternative states often represent novel communities with disturbance regimes that differ significantly from historic conditions. Past management and restoration goals often focused on returning ecosystems to pre-disturbance conditions (Harris and others 2006). This approach assumes stable or equilibrium conditions and ignores changes in ecosystem processes due to land uses, increases in CO_2 concentrations, and climate change. A more realistic approach is to base management and restoration goals on the current potential of an ecosystem to support a given set of ecological conditions, and on the likelihood of future change due to a warming climate (Harris and others 2006). This approach requires understanding ecosystem resilience to anthropogenic disturbance and climate change, the alternative states that exist for ecosystems, and the factors that result in threshold crossings (Bestelmeyer and others 2009; Hobbs and Harris 2001; Stringham and others 2003; Whisenant 1999). It also requires the ability to predict how climate is likely to influence ecosystems in the future (Harris and others 2006).

This chapter addresses the restoration aspects of Sub-goal 1.3 in the SNAP Science Research Strategy which is to restore and sustain proper function of southern Nevada's watersheds and landscapes (table 1.3; Turner and others 2009). The effects of global, regional and local stresses on southern Nevada ecosystems are presented in Chapter 2. Here, we discuss appropriate objectives and develop guidelines for maintaining and restoring southern Nevada ecosystems. We then discuss the differences in ecological resilience to stress and disturbance and resistance to invasive species in southern Nevada ecosystems and describe restoration and management approaches for the different ecosystem types. We conclude with knowledge gaps and management implications.

Resistance and Resilience of Southern Nevada Ecosystems

The overarching objective for restoration and management of southern Nevada ecosystems is to maintain and restore sustainable ecosystems that are resilient to stress and disturbance and resistant to invasion. Resilience is defined as the capacity of an ecosystem to regain its fundamental structure, processes, and functioning (or recover) when subjected to stressors or disturbances like drought, livestock grazing, or wildfire (e.g., Allen and others 2005; Holling 1973; Walker and others 1999). In this context, resilience is a function of the underlying ecosystem attributes and processes that determine ecosystem recovery. Resistance is the capacity of an ecosystem to retain its fundamental structure, processes, and functioning (or remain largely unchanged) despite stresses, disturbances or invasive species. Resistance to invasion is a function of the biotic and abiotic factors and ecological processes in an ecosystem that limit the establishment and population growth of an invading species (D'Antonio and Thomsen 2004). The abiotic and biotic attributes and ecosystem processes that determine resilience to stressors and resistance to invasion can be illustrated with a simple conceptual model (fig. 7.1). Environmental characteristics as defined by climate, topography, and soils determine the abiotic and biotic attributes and processes of an ecosystem. In turn, the abiotic and biotic attributes and processes provide feedbacks to one another and determine the inherent potential of an ecosystem to support a given set of ecological conditions and plant species. Over time, climate, disturbance and stressors affect the abiotic and biotic attributes and processes and determine the current ecological conditions of the system. The current ecological conditions, as influenced by the legacy of past disturbances and stressors, determine resilience to disturbance and resistance to invaders at any point in time.

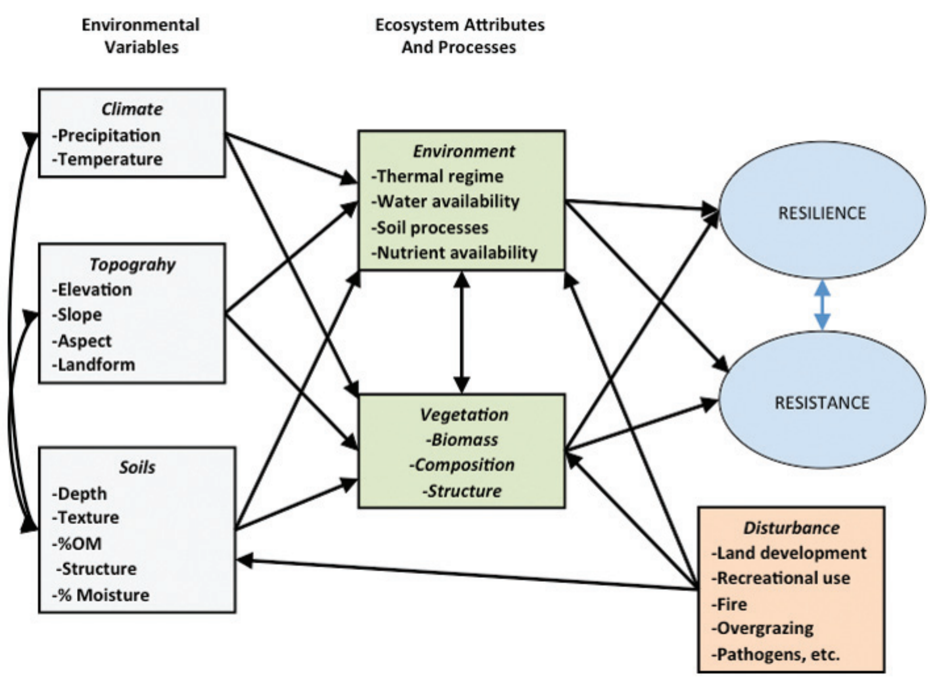

Figure 7.1—The environmental variables and site conditions that influenced resilience to disturbance and resistance to invasion. Disturbances can decrease ecological site conditions and negatively affect resilience and resistance.

Southern Nevada ecosystems differ in ecological resistance and resilience because of strong elevation/climate gradients and large differences in their environmental characteristics (Chapter 1). The Clark County Multiple Species Habitat Conservation Plan (MSHCP) categorizes 11 ecosystems based on elevation and soil moisture (fig. 7.2). In general, temperature regimes and effective precipitation are the primary drivers of ecological processes and determine overall resource availability and ecosystem productivity. The resilience of southern Nevada ecosystems to stresses typically increases along these environmental/productivity gradients (Brooks and Chambers 2011). These gradients also determine the likelihood that climate conditions are suitable for establishment of non-native grasses and other invaders (e.g., Chambers and others 2007; Condon and others 2011). Ecosystems influenced by elevated water tables and high levels of soil moisture are in a separate category, as environmental conditions can vary considerably among these ecosystems. Factors like soil and water chemistry are important drivers of ecosystem processes for these ecosystems.

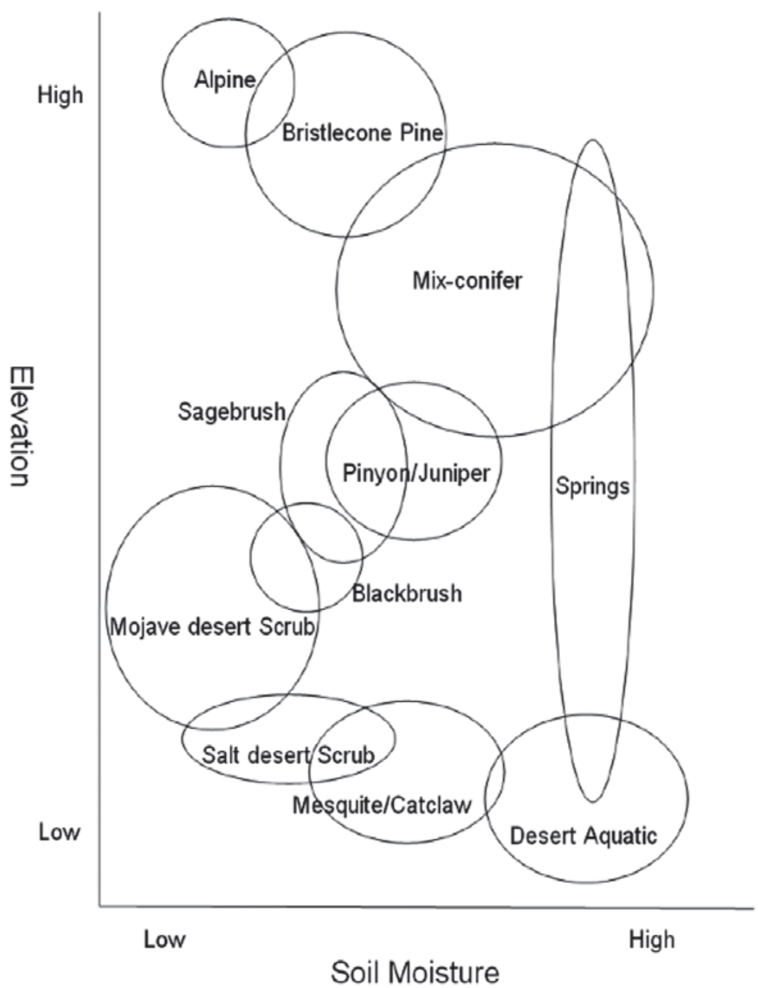

Figure 7.2—A conceptual model that categorizes 11 ecosystems of the Clark County MSHCP along two environmental gradients: elevation and soil moisture. This model is based on general knowledge of environmental gradients of ecosystems. The shape, size, and relative position of the ellipses and circles are hypothetical (from Desert Research Institute 2008).

Restoration Considerations for Southern Nevada Ecosystems

Restoration and management priorities and activities differ significantly among southern Nevada ecosystems because of large variation in their resilience and resistance. Overarching strategies are protection, prevention, and restoration (table 7.1). Passive restoration to eliminate or minimize stress is a component of protection and prevention; active restoration is a component of prevention and restoration. Guidelines for the restoration and management of the diverse ecosystems in southern Nevada can be developed based on an understanding of their relative resilience and resistance, the dominant stressors that affect them, and the actions most appropriate to maintain and restore them (table 7.2).

Table 7.1—An approach for categorizing management activities in southern Nevada ecosystems based on protection, prevention and restoration (modified from D'Antonio and Chambers 2006; Brooks and Chambers 2011).

Protection	
Focus	Ecosystems with low resilience and/or resistance, ecosystems of high conservation concern, and ecosystems at risk of crossing ecological thresholds to new alternative states.
Objectives	Eliminate or minimize current and future stressors.
Activities	Closure or active control of recreational use and burro and cattle grazing to allow natural regeneration; fire suppression in Mojave Desert scrub, blackbrush and lower elevation sagebrush and piñon and juniper ecosystems to prevent an invasive annual grass-fire cycle; control of placement and development of road and utility corridors, urban expansion, and solar energy projects to minimize fragmentation and surface disturbance.
Prevention	
Focus	Ecosystems with inherently higher resilience and/or resistance that are in moderate to high ecological condition.
Objectives	Maintain or increase resilience and resistance of areas with declining ecological conditions.
Activities	Vegetation management to decrease risk of high severity fires, maintain understory composition, and prevent invasion; mechanical vegetation management treatments to decrease decadent or over-dense shrubs and increase perennial herbaceous vegetation.
Restoration	
Focus	Ecosystems known to respond favorably to restoration treatments and ecosystems of conservation concern.
Objectives	Increase resilience and resistance of ecosystems by revegetating or rehabilitating areas disturbed by fire, recreational activities, road and utility corridors, urban expansion, solar energy projects, and other surface disturbances. Provide assisted migration for species being displaced by climate change.
Activities	Soil surface stabilization to curtail dust; seedbed preparation to mitigate soil physical and chemical disturbance and provide favorable conditions for plant establishment; transplanting or seeding native species adapted to the local environment and climate warming.

Table 7.2—Resilience and resistance characteristics of the major ecosystem types in southern Nevada and guidelines for appropriate management actions.

Ecosystem	Resilience and resistance	Guidelines for appropriate management actions
Alpine and Bristlecone pine	*Resilience* – Very low to low. Extreme temperatures, short growing seasons, slow growth, and low establishment rates. Low capacity to adapt/migrate with climate warming. *Resistance* – Moderate to high. Few annual species are adapted to extreme environment; resistance may decrease as climate warms.	*Protection* – Primary emphasis. Minimize stress from recreational activities, including firewood gathering. Monitor changes in temperature and precipitation and in species distributions and community composition. *Prevention* – Rarely warranted except to suppress fires with potential to spread. *Restoration* – Rarely warranted except for assisted migration of trees or revegetation of areas with die-off. Information on species environmental and establishment requirements is required.
Mixed conifer	*Resilience* – Moderate to high. Relatively high precipitation, long growing seasons, and moderate growth and establishment rates. Potential to migrate upslope with climate warming. *Resistance* – Moderate to low. Multiple non-native invaders adapted to environmental conditions; competition with invaders from established native plants can be high.	*Protection* – Control inappropriate recreational activities and overgrazing; detect and eradicate invasive species. *Prevention* – Warranted to decrease fuel loads, restore understory composition, and decrease invasion. Potential for Wildland Fire Use and prescribed fire where risk of large or high severity fire is low and fire spread can be controlled, and for tree thinning followed by surface fire or pile burning in WUI and areas with higher fuel loads. However, more information is needed on the responses of southern Nevada ecosystems. *Restoration* – Warranted following surface disturbance or in areas with insufficient fire tolerant understory species for site recovery after fire. Seed burial (drilling) or transplanting natives adapted to local site conditions and climate warming preferred.
Piñon and Juniper	*Resilience* – Moderate. Moderate precipitation, long growing seasons, moderate to slow growth and establishment. Potential for die-off at lower elevations with climate warming. *Resistance* – Low. Many non-native invaders adapted to environmental conditions; competition from established shrubs and herbaceous species dependent on site productivity and ecological condition.	*Protection*- Control inappropriate recreational activities and overgrazing; detect and eradicate invasive species; suppress fires at lower elevations and that threaten ecosystem integrity. *Prevention*-Warranted to decrease fuel loads, restore understory composition, and decrease invasion. Focus is on mesic sites in early to intermediate stages of tree expansion, and in moderate to high ecological condition. Potential for Wildland Fire Use and prescribed fire on productive sites at high elevation; mechanical treatments more appropriate on sites with low productivity. *Restoration* – Warranted following surface disturbance and in areas with insufficient fire tolerant understory species for site recovery after fire. Seed burial (drilling) or transplanting natives adapted to local site conditions and climate warming preferred.
Sagebrush	*Resilience* – Moderate to low. Types at higher elevations and with deeper soils have moderate resilience; types at lower elevations and on shallow soils have low resilience. *Resistance* – Moderate to low. Types at higher elevations are more resistant to annuals invaders than those at lower elevations. Resistance generally decreases as site productivity or herbaceous perennial species and ecological condition decreases.	*Protection*–Control inappropriate recreational activities and overgrazing, detect and eradicate invasive species, suppress fires at lower elevations and that threaten ecosystem integrity. *Prevention*– Warranted to restore or maintain sagebrush types, and increase understory species and resistance to invaders. Focus is on resilient and resistant sites. Potential for Wildland Fire Use and prescribed fire to control tree expansion, and shrub mowing and selective herbicides to decrease competition from overstory sagebrush. Information on ecosystem response is needed. *Restoration* – Warranted following surface disturbance and in areas with insufficient fire tolerant understory species for site recovery after fire. Seed burial (drilling) or transplanting natives adapted to local site conditions and climate warming preferred. Livestock closures required post-restoration to facilitate recovery.

(continued)

Table 7.2—(Continued).

Ecosystem	Resilience and resistance	Guidelines for appropriate management actions
Blackbrush	*Resilience* – Low to very low. Low precipitation, moderately high temperatures, episodic recruitment. Potential to migrate upslope with climate warming. *Resistance* – Low to very low. Environmental conditions conducive to establishment of invasive annual bromes. Low competition from native species due to low productivity.	*Protection* – Primary emphasis. Suppress fires, actively control cattle and burro grazing and inappropriate recreational activities, detect and eradicate new invaders. *Prevention* – Not warranted under most circumstances. *Restoration* – Warranted following surface disturbance and in areas with insufficient fire tolerant understory species for site recovery after fire. Seed burial (drilling) or transplanting natives adapted to local site conditions and climate warming preferred. Livestock closures required after fire and restoration activities to facilitate recovery of native perennial plants.
Mojave Desert scrub	*Resilience* – Very low. Extreme environmental conditions, episodic recruitment, slow ecosystem recovery. *Resistance*– Low. Environmental conditions of more mesic systems conducive to establishment of annual grasses; few species adapted to most extreme conditions. Low competition from natives due to low productivity.	*Protection* – Primary emphasis. Suppress fires, actively control inappropriate recreational activities and overgrazing by cattle, horses and burros, detect and eradicate new invaders. *Prevention* – Not warranted under most circumstances. *Restoration* – Warranted following surface disturbance and in areas with insufficient fire tolerant understory species for site recovery after fire. Seed burial (drilling) or transplanting natives adapted to local site conditions and climate warming preferred. Livestock closures required after fire and restoration to facilitate recovery of native perennial plants.
Riparian and Spring	*Resilience* –Low to moderately high. High water availability but high water temperatures, harsh water chemistry, and scouring floods. Water availability likely to decrease with climate warming. *Resistance* – Low. Many invasive species in a variety of taxa adapted to high availability of water.	*Protection*– Maintain or increase current water allocations and in stream flows, actively control inappropriate land uses, recreational activities and overgrazing, detect and eradicate new invaders. *Prevention*–Warranted to reduce non-native tamarisk and Russian olive and to manage fuels. Biocontrol, prescribed fire, mechanical treatments, or herbicides can be used, but restoration of native species must follow. *Restoration*– Warranted to maintain river and stream channels by manipulating flow regimes, and to restore or create habitat for native species of concern. Methods include manipulating water depths, velocities and temperatures to meet requirements for species establishment and persistence, and revegetating with native species adapted to the site conditions.

Consideration of the predicted effects of climate change on the different ecosystems and the implications for management will be needed to maintain and restore southern Nevada ecosystems. Climate change models predict high rates of temperature increase for desert ecosystems like the Mojave (Loarie and others 2009). By 2100, climate change is likely to result in the disappearance of some existing climate conditions, the appearance of some novel climate conditions, and the formation of new communities with no past or present analogs (Williams and Jackson 2007). Bioclimatic envelope models predict shifts in the distributions of keystone species like creosote bush (*Larrea tridentata*) (Rehfeldt and others 2006) and Joshua tree (*Yucca brevifolia*) (Cole and others 2011), and of invasive species like cheatgrass (Bradley and others 2009). Due to the rapid rate of change, many species may require assisted migration, and "transformative" restoration may be needed in areas that no longer have the climate conditions necessary to support the current set of species (Harris and others 2006; Bradley and others 2009).

Alpine Ecosystem

Alpine ecosystems occur on the Spring Mountains above 3,500 m. They are comprised of alpine fell-fields on exposed rocky, dry soils, and alpine meadows that occur in swales where soil moisture is higher and sand and silt soils accumulate (Clokey 1951). They have generally low resilience to disturbance and low productivity due to short growing seasons, temperature extremes, and slow growth rates (Chambers 1995). Few invasive species are adapted to the extreme environmental conditions. Because alpine species have slow growth and low establishment rates, the potential for adapting to a warming climate is low; because of their locations at the top of mountain ranges, the capacity to migrate also is low.

Modeling of species-environment relationships and potential changes in plant species distributions with a 3 °C increase in temperature for the White Mountains, California, indicated that species distributions would shift upwards and decrease in extent but that specific outcomes would depend on species affinities for various soil types (Van de Ven and others 2007). For a similar temperature increase in Great Basin alpine ecosystems, predicted extinction rates were 44% for mammals, 23% for butterflies, and 17% for plants (Murphy and Weiss 1992).

Restoration and management goals for alpine ecosystems in southern Nevada necessarily focus on protection due to their low resilience (table 7.2). Human activities are generally low, but stress from recreational activities should be minimized. A key aspect of managing these ecosystems is monitoring the rate and magnitude of change in the abiotic environment (temperature and precipitation) and in species distributions and community composition (Desert Research Institute 2008). North-facing slopes and certain soil types may serve as refugia for many native species (Van de Ven and others 2007), but these relationships are not well understood. Species loss in these fragile ecosystems from rapid warming may require assisted migration in the form of revegetation with species from lower elevation zones. Methods for restoring high elevation ecosystems are well-researched and include revegetation with seeds and transplants (Chambers 1997; Urbanska and Chambers 2002). Specific approaches for assisted migration, such as methods for species selection and matching species to newly available sites, have yet to be investigated.

Bristlecone Pine Ecosystem

The bristlecone pine ecosystem occurs in the Spring and Sheep Mountains at elevations of 2,700 m to 3,500 m on exposed, dry, rocky slopes and ridges in the subalpine zone (Pase and Brown 1982). This ecosystem is comprised of evergreen conifer forest dominated by widely spaced Great Basin bristlecone pine (*Pinus longaeva*) that frequently forms pure stands from the tree line down to its contact with limber pine (*P. flexilis*). Associated shrub species include dwarf juniper (*Juniperus communis*), Clokey mountain sage (*Salvia dorrii* var. *clokeyi*), and sagebrush (*Artemisia* spp.), but dense bristlecone pine forests often have low understory species richness and productivity (RECON 2000).

Similar to alpine ecosystems, cold temperatures, intense sunlight, low soil nutrients, a short growing season, and lengthy periods of snow cover result in low productivity and low ecosystem resilience (Holtmeier and Broll 2007). Recruitment is episodic and depends on local topography, soil types, short-term weather patterns and longer term climate, and, for bristlecone pines, seed predation/caching by rodents and birds. Recent research shows tree-ring growth in bristlecone pine within the region over the last century that is unmatched in millennia (3,700 yrs) indicating environmental changes that are probably linked to increases in temperature (Salzera and others 2009).

An advance of treeline has been documented for mountain ranges that have already exhibited temperature increases, and is predicted for other ranges as the climate warms (Grace and others 2002). Although seedling establishment of bristlecone pine may increase with warmer temperatures, the species may become more susceptible to pathogens and disease. White pine blister rust (*Cronartium ribicola*) was recently reported in Rocky Mountain bristlecone pine (*P. aristata*) (Blodgett and Sullivan 2004), and Great Basin bristlecone pine is a potential host for white pine blister rust (Kliejunas and Adams 2003). Mountain pine beetle (*Dendroctonus ponderosae*) may reproduce more rapidly due to climate warming and cause greater damage to bristlecone pines. Currently, fires are caused by lightning and are small and infrequent. Higher fuel loads due to warmer weather and increased tree growth plus deadwood caused by bark beetles may increase fire frequency (Desert Research Institute 2008).

As for alpine ecosystems, restoration and management goals for bristlecone pine ecosystems in southern Nevada focus on protection (table 7.2). Human activities primarily involve recreational use and firewood gathering for campfires, which can damage trees and initiate fires. These types of uses should be discouraged. Management should include monitoring the rate and magnitude of change in the abiotic environment (temperature and precipitation) and in species distributions and community composition (Desert Research Institute 2008). Understanding the population dynamics of bristlecone pine (recruitment and mortality) is essential for determining if assisted migration of the trees or revegetation of areas with high mortality is required. Understanding the environmental and establishment requirements of both the trees and associated species is necessary to determine appropriate revegetation methods.

Mixed Conifer Ecosystems

The mixed conifer ecosystem is comprised of three tree and shrub dominated communities that occur at 1,200 m and 3,200 m in elevation (RECON 2000): the white fir, ponderosa pine, and ponderosa pine/mountain shrub communities. The white fir community occurs in the Spring and Sheep Mountains on north and east-facing slopes at elevations between 2,200 and 3,200 m and is dominated by white fir *(Abies concolor*). Other tree species include bristlecone pine (*P. longaeva*) and limber pine (*P. flexilis*) at higher elevations, and ponderosa pine (*P. ponderosa*) at lower elevations. The ponderosa pine community covers the largest area of any conifer forest in southern Nevada, ranges from 1,200 m to 2,700 m in elevation, and is dominated by ponderosa pine. Associated tree species include white fir, bristlecone pine, limber pine, singleleaf piñon (*P. monophylla*), Utah juniper (*Juniperus osteosperma*), and mountain mahogany (*Cercocarpus* spp.). The ponderosa pine/mountain shrub community has less ponderosa pine and is co-dominated by mountain shrubs, like oak (*Quercus gambelii)*, mountain mahogany, snowberry (*Symphoricarpos albus*), and manzanita (*Arctostaphylos* spp.). Relatively high precipitation, mild temperatures, and long growing seasons result in moderately high ecological resilience in the mixed conifer ecosystem. Multiple non-native invaders are adapted to these communities decreasing ecological resistance.

Interactions among climate, fire, and pine bark beetles strongly affect the structure and composition of mixed conifer ecosystems. Overall growth rates in southern Nevada mixed conifer ecosystems are low, reflect those in other southwest ecosystems, and are strongly influenced by drought (Biondi and others 2011). In general, trees respond positively to winter-spring precipitation and negatively to spring-summer temperature (Biondi and others 2011). Recruitment is associated with moist and fire-free periods, while die-off is related to droughts lasting more than 10 years (Brown and Wu 2005). The likelihood of pine bark beetle outbreaks is increased by higher temperatures and forest homogeneity, and trees are most susceptible to beetles when drought stressed or after fire (Raffa and others 2008). As the climate warms, increases in pine bark beetle outbreaks and die-offs are likely for trees growing at the margin of their ecological tolerances. Upslope movement of tree populations will require favorable conditions for tree recruitment and lack of widespread fire.

Increases in tree densities and fuel loads and reductions in plant species diversity have occurred in many southwest mixed conifer forests due to factors like favorable climate for tree recruitment, overgrazing, and fire suppression (Allen and others 2002). Fuel loads and fire risk are increasing in some mixed conifer communities in southern Nevada (Abella and others 2011). Fire regimes and fire return intervals depend on the aridity and topographic characteristics of the site. Fire regimes vary from high frequency, low severity to mixed severity (Biondi and others 2011; Jamieson 2008; Kilpatrick 2009; Kitchen 2010). On an arid site (Mt. Irish), the fire return interval for fires that scarred at least 10% of recorder trees was 66 years (Biondi and others 2011). On a mesic site (Clover Mountains), comparable fire return intervals ranged from 17 to 34 years (Kilpatrick 2009). Many stands in the ponderosa pine community have limited extent and are characterized by old age trees, especially on drier mountain ranges (fig. 7.3). Understory species composition affects resilience to both fire and fuel treatments due to effects on tree regeneration, fire behavior and soil erosion (Allen and others 2002). Many of the understory shrubs in the ponderosa pine/mountain shrub community are fire tolerant and promote recovery after fire (fig. 7.3). Perennial herbaceous species increase resistance to annual grasses in all community types (Chambers and others 2007).

Restoration and management goals for mixed conifer ecosystems include protection and restoration, but emphasize prevention (table7.2). Most campgrounds and recreational activities occur in this type. Allen and others (2002) list 16 broad principles for restoring southwestern ponderosa pine ecosystems including preventing or minimizing crown fire, restoring or maintaining understory composition, and preventing invasion by non-native species. The focus is on resilient and resistant stands with climatic conditions and understory species that will ensure recovery. Considerable information exists on specific fire and fuels treatments for managing ponderosa pine and mixed confer ecosystems (Brown and others 2000). In a ponderosa pine community in Grand Canyon National Park, wildland fire use decreased fuel loads, reduced duff layers, and increased species richness of annual and biennial forbs (Laughlin and others 2004). Tree thinning coupled with understory burning decreased the risk of crown fire and increased stand resilience, but tree kill and understory response depended on climate and pre-treatment ecological conditions in other southwest ponderosa pine ecosystems (Fule and others 2005; Moore and others 2006). Because of the aridity and small extent of many of southern Nevada's mixed conifer ecosystems, and the number of species of conservation concern, the emphasis should be on use of thinning, and mechanical treatments until additional information is available on responses to fire treatments. Information also is needed on restoring landscape heterogeneity and the effects of climate change.

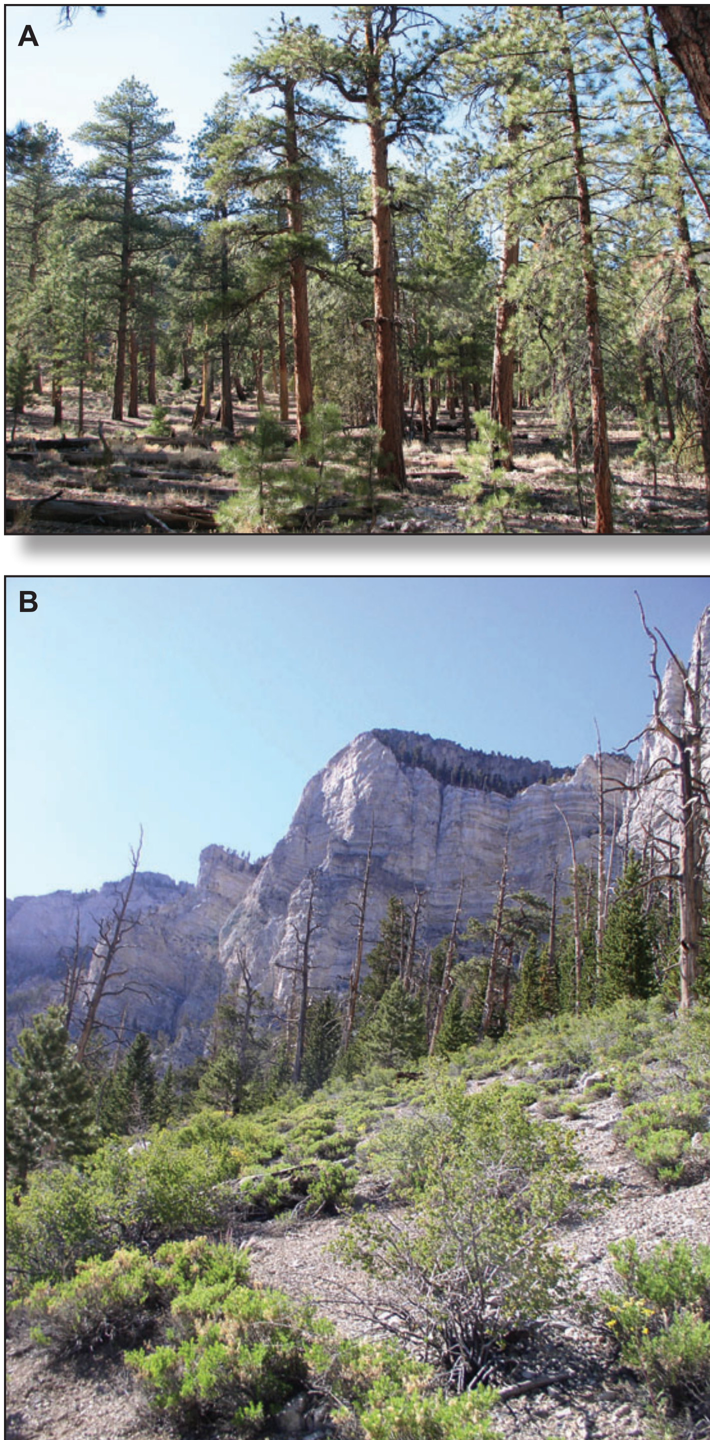

Figure 7.3—(A) An arid ponderosa pine community on the Sheep Range with a sparse understory of sagebrush. Many of these communities are of limited extent and are characterized by old aged trees. Historic fire return intervals were long and preventative management to control fuels needs to be exercised with caution. (B) A ponderosa pine/mountain shrub community on the Spring Mountains after a wildfire. This community is characterized by shrub species that resprout after fire and promote site recovery. Preventative management should focus on preventing crown fires and maintaining the understory (photos by Patti Novak-Echenique).

Piñon and Juniper Ecosystem

The piñon and juniper ecosystem occurs from 1,500 m to 2,500 m in the Spring, Sheep, Virgin, and McCullough Mountains (RECON 2000). Sagebrush co-exists with piñon and juniper at all elevations. At higher elevations, singleleaf piñon dominates, but co-occurs with other coniferous trees and shrubs like Gambel's oak (*Quercus gambelii*) and mountain mahogany (*Cercocarpus* spp.). At lower elevations, Utah juniper (*J. osteosperma*) dominates and Rocky Mountain juniper (*J. scopulorum*), western juniper (*J. occidentalis*), rabbitbrush (*Chrysothamnus* spp.) and blackbrush (*Coleogyne ramosissima*) are minor components. Singleleaf piñon and Utah juniper co-dominate at middle elevations. Relatively high precipitation, mild temperatures, and long growing seasons result in moderate resilience, but local conditions influence disturbance and treatment outcomes. Many non-native invaders are adapted to these communities and ecological resistance is low.

Piñon and juniper ecosystem in the southwestern United States respond to the high variation in precipitation with major pulses of woody plant establishment and mortality (Swetnam and Betancourt 1998). Water stress can trigger rapid and extensive dieback (Breshears and others 2005). Broadscale tree mortality can shift ecotones between vegetation types, alter regional distributions of overstory and understory vegetation, and change disturbance processes such as fire and erosion (Allen and others 2010). Drought-associated water stress also can increase susceptibility of trees to insects and other pathogens (Breshears and others 2005). The piñon ips beetle (*Ips confusus*) occurs in southern Nevada and is a species that can undergo broadscale outbreaks following high temperatures and drought (Breshears and others 2005).

Piñon and juniper expansion and infilling are occurring in southern Nevada shrublands due to a variety of factors including climate change, increased CO_2 concentrations, overgrazing, and fire suppression (fig. 7.4; Abella and others 2011; Miller and others 2008). The increase in trees has the potential to significantly increase fuel loads. Fire frequency, size, and severity in piñon and juniper ecosystems are strongly influenced by fuel loads and climate. Recent fire history studies in central Nevada and Mesa Verdi National Park, Colorado, indicate that historical fire regimes were characterized by small, infrequent and high severity fires, and that stand replacing fires occurred about every 200 to 400+ years (Bauer and Weisberg 2009; Floyd and others 2004; Romme and others 2009). Fires occurred with higher frequency during droughts and on more mesic sites (Bauer and Weisberg 2009).

Restoration and management goals in piñon and juniper ecosystems include protection and restoration, but emphasize prevention (table 7.2). Restoration goals include preventing or minimizing crown fire, restoring or maintaining shrubs and perennial herbaceous species in the understory, and preventing invasion by non-native species. The focus is on resilient and resistant ecosystems with sufficient perennial herbaceous species and shrubs for recovery. Resilient piñon and juniper ecosystems are typically on more mesic sites, in the early to intermediate stage of tree expansion (i.e., phase I to phase II woodlands; *sensu* Miller and others 2005), and in moderate to high ecological condition (fig. 7.4). Both prescribed fire and mechanical treatments, like shredding and cutting and leaving the trees, are used to reduce fuel loads and increase resilience in these ecosystems (Miller and others 2005; Monsen and others 2004; Pyke 2011). Mechanical treatments are typically of lower severity than prescribed fire and are used on sites with more severe environmental conditions and with a high risk of fire-tolerant invaders like cheatgrass. Because of the aridity of many of southern Nevada's piñon and juniper ecosystems, and the number of species of conservation concern, the emphasis should be on thinning and mechanical treatments until additional information is available on responses to fire treatments. Information also is needed on restoring landscape heterogeneity and the effects of climate change.

A

B

C

Figure 7.4— (A) Piñon expansion into a mountain big sagebrush ecological site type on the Desert National Wildlife Refuge. Preventative management to maintain the understory sagebrush community using mechanical tree removal, Wildland Fire Use or prescribed fire can be considered on sites with favorable climatic conditions and sufficient perennial herbaceous species and shrubs for recovery. (B) Old age piñon on a black sagebrush ecological site on the Desert National Wildlife Refuge. Protective management of old age stands located on harsh ecological sites should be considered. (C) A dense piñon stand on the Spring Mountains. Preventative management using mechanical treatments to decrease fire risk should be considered in WUI areas. Due to tree competition and understory depletion, restoration will be required following fire (photos by Patti Novak-Echenique).

Sagebrush Ecosystem

The sagebrush ecosystem typically ranges in elevation from 1,500 m to 2,800 m in the Spring, Sheep, and Virgin Mountains (RECON 2000). In southern Nevada, sagebrush species include big sagebrush (*A. tridentata*), low sagebrush (*A. arbuscula*), Bigelow sagebrush (*A. bigelovii*), silver sagebrush (*A. cana*), and black sagebrush (*A. nova*). The dominant sagebrush communities differ in response to local topography, soil type, and water availability. Big sagebrush community types can occur as relatively, large, open, and discontinuous stands, but often occur with trees species (piñon pine, junipers, ponderosa pine, mountain mahogany) and other shrubs (bitterbrush, rabbitbrush, snakeweed [*Gutierrezia sarothrae*], blackbrush, shadscale [*Atriplex confertifolia*], and spiny hopsage [*Grayia spinosa*]) (fig. 7.4) (Clokey 1951). Ecological resilience is a function of local site conditions and the community type. Higher elevation types with greater precipitation and productivity like *A. tridentata* ssp. *vaseyana* have moderately high resilience while lower elevation and less productive types like *A. tridentata* ssp. *wyomingensis* and *A. nova* have lower resilience (Brooks and Chambers 2011). Resistance decreases as elevation and productivity decrease (Chambers and others 2007).

Risks to sagebrush ecosystems include overgrazing, land use change, piñon and juniper expansion, invasion of non-native plants, and altered fire regimes (Wisdom and others 2005). Climate change poses a substantial additional risk. Sagebrush species are likely to respond to climate warming by moving northward or upslope in response to shifts in frost lines (Neilson and others 2005). Risk analyses of sagebrush types in southern Nevada that assessed the interactive effects of land use conversion, land use (roads, agriculture, etc.), and cheatgrass invasion indicated that sagebrush communities in southern Nevada were at greater risk of losing suitable habitat due to climate change than due to disturbance (Bradley 2010).

In southwestern and arid ecoregions, precipitation in seasons prior to the fire season is more highly associated with burn area than warmer temperatures or drought the year of fire due to the importance of fine fuel production (e.g., invasive annual grasses) (Littell and others 2009). However, increasing aridity may result in a decrease in area burned due to a reduction in fine fuels.

Restoration and management goals and methods vary for these diverse ecosystems due to differences in resilience and resistance (table 7.2). In general, the focus of restoration is on maintaining and restoring a desirable proportion of sagebrush types, increasing the abundance of perennial understory species that promote resilience, and increasing resistance to invasive species. Strategies for sagebrush types with inherently low resilience and resistance focus on protection and include eliminating stressors like inappropriate recreation, overgrazing, and fire. Prevention can be an effective strategy for sagebrush types with higher resilience and resistance. Wildland Fire Use and prescribed fire have been used in higher elevation types exhibiting tree expansion (fig. 7.4A), but additional information on fire effects are needed for southern Nevada ecosystems. Mowing and selective herbicides have been used to increase perennial herbaceous species by reducing competition from decadent or over-dense sagebrush. Restoring sagebrush ecosystems that have crossed ecological thresholds to invasive grass dominance is expensive, difficult, and of lower priority. Although methods exist for protection, prevention, and restoration of mesic sagebrush ecosystems (e.g., D'Antonio and others 2009; Monsen and others 2004; Pyke 2011), we still lack the necessary tools to manage and restore more arid sagebrush ecosystems. Sagebrush ecosystems are highly susceptible to climate change and we know little about assisted migration or transformative restoration.

Blackbrush Ecosystem

The blackbrush ecosystem occurs at elevations between 1,250 and 1,800 m in the transition zone between the Mojave Desert and Great Basin (RECON 2000). At upper elevations it integrates into the Utah juniper community, while at lower elevations it transitions into the creosote-bursage community. It is the dominant shrub in the understory of most Joshua tree communities. Shrubs associated with blackbrush include spiny hopsage, mormon tea, shadscale, desert thorn, and snakeweed. The blackbrush ecosystem has very little resilience to disturbance due to low effective precipitation, moderately high temperatures and episodic recruitment of blackbrush (Bowns 1973). Resistance to invasion by annual grasses, especially red brome (*Bromus madritensis* ssp. *rubens*), is extremely low because the environmental conditions that characterize this ecosystem are ideally suited to its establishment and reproduction.

Risks to the blackbrush ecosystem include overgrazing by cattle and burros, off-highway vehicle (OHV) and recreational activities, annual grass invasion, and altered fire regimes. Historically, the blackbrush ecosystem experienced small localized fires and recovery occurred within a few decades (Brooks and Matchett 2006). However, due to invasion by exotic annual grasses and an increase in fine fuel loads and fuel continuity, extensive areas of the blackbrush ecosystem have burned within the last decade (Chapter 4 and Chapter 5). Blackbrush is not fire-adapted and is incapable of resprouting following fire. Consequently, parts of this ecosystem are being converted to annual grass dominance and are susceptible to repeated burns (Brooks and others 2007).

In the blackbrush ecosystem, the focus of restoration and management is on protection coupled with restoration (table7.2). Protection of this ecosystem includes suppressing large fires and actively controlling overgrazing by wild horses, burros, and cattle. The characteristics of this ecosystem vary considerably over environmental/productivity gradients (fig. 7.5). Lower elevation blackbrush communities are characterized by thermic soils and often contain a minor component of creosote bush. Revegetation is difficult due to low spring and early summer moisture, increasing CO_2, and higher nighttime winter temperatures (Jones 2011; Zitzer 2009). The distribution of the creosote-bursage community is limited by nighttime winter temperatures (Webb and Bowers 1993) and is expected to move up-slope with climate change. Thus, at lower elevations within the blackbrush ecosystem, early seral shrubs from the creosote and bursage community may be better candidates for restoration than species from the blackbrush community. Higher elevation and more mesic blackbrush communities are characterized by mesic soils, and species from the blackbrush community are the best choice for seed mixes.

Considerable information exists on the establishment requirements of blackbrush including seed dispersal and longevity in the soil (Auger 2005; Zitzer 2009), seed dormancy, germination, and survival (Meyer and Pendleton 2005; Pendleton 2008; Pendleton and Meyer 2004), and the importance of mycorrhizae and biological soil crusts (Pendleton and others 1999). Blackbrush typically establishes under nurse plants, and establishment success of blackbrush may be increased by including other species with high seedling establishment in the seed mix (Abella and Newton 2009). Transplanting seedlings of blackbrush and the other dominant shrubs in the community into shrub islands that can serve as future seed sources also should be considered but several years of supplemental water may be required (Pendleton 2008; Winkel and others 1995). Blackbrush seldom produces large crops of seeds, but the seeds that are produced exhibit long-term viability (Pendleton and others, in press). This indicates that seeds can be harvested during mast years and stored until needed. Additional information is needed on relationships among

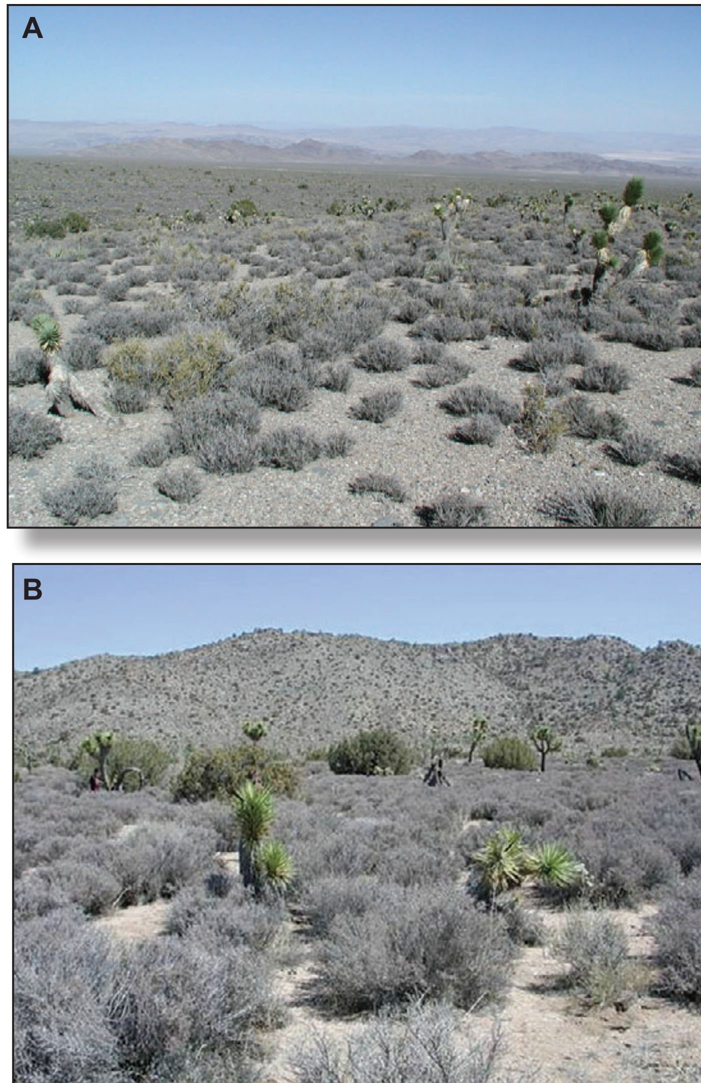

Figure 7.5—(A) A more arid blackbrush ecological site on thermic soils that exhibits low productivity and has a minor component of creosotebush (photo by Patti Novak-Echenique). (B) A more mesic blackbrush ecological site on mesic soils with slightly higher productivity. Note the presence of juniper (photo by Matt Brooks). Protective management should be emphasized on both site types. Due to ongoing climate change, restoration of the thermic site should include early seral species from the Mojave Desert scrub type.

climate, soil characteristics, and establishment of the species in both creosote/bursage and blackbrush communities if assisted migration and transformative restoration is to succeed.

Mojave Desert Scrub Ecosystem

Mojave Desert scrub occurs at elevations below 1,220 m and is the most widespread ecosystem in southern Nevada (~73% of Clark County) (RECON 2000). This type is characterized by three community types: Mojave Desert mixed scrub, mesquite/catclaw, and salt desert shrub.

Mojave Desert mixed scrub—Mojave Desert mixed scrub is unique because it includes a wide variety of distinctive soil types and plant communities often intermix. Bajadas, the most common landform, are dominated by creosote bush and white bursage (*Ambrosia dumosa*); subdominants include desert thorn (*Lycium andersonii*), shadscale, spiny hopsage, ratany (*Krameria erecta*), bladder sage (*Salazaria mexicana*), indigo bush (*Psorothamnus fremontii*), blackbrush, brittlebush (*Encelia farinosa*), and burro bush (*Hymenoclea salsola*) (RECON 2000). Sand dunes, gypsum soils, cliff/rock outcrops, and steep slopes occur as isolated patches that support Joshua tree, prickly pear cactus (*Opuntia spp.*), yucca (*Yucca* spp.), cholla (*Cylindropuntia* spp.), and hedgehog cactus (*Echinocereus* spp.).

Mojave Desert mixed scrub communities have low ecological resilience and have exhibited little resistance to invasive species (Brooks and Chambers 2011). Most long-lived Mojave Desert scrub species are poorly adapted to disturbances that remove aboveground biomass or kill plants, although most short-lived early seral species increase in abundance following disturbance. Reproduction of long-lived species depends on appropriate environmental conditions for either clonal regeneration and/or seedling establishment and is episodic (Webb and others 2009). The life history strategies of these species coupled with the harsh environment significantly increases the complexity of restoration.

Mojave Desert mixed scrub is subject to most of the stressors listed in Chapter 2, including urbanization, energy development, invasive species and the resulting increase in fire frequency, unregulated recreation, and OHV activity. Climate change further strains this ecosystem. The distribution of many Mojave Desert scrub species is limited by cold temperatures (Pockman and Sperry 1997; Webb and Bowers 1993), and climate models predict that Mojave Desert scrub species will move northward and upslope as temperatures continue to warm. One model predicts that northern Nevada and southern Idaho may have climates suitable for creosotebush by 2060 (Rehfelt and others 2006).

Invasion of non-native annual grasses (*Bromus madritensis* ssp. *rubens* and *Schismus barbatus*) and some forbs (e.g., *Brassica* spp.) has significantly increased fine fuel loads in Mojave Desert scrub vegetation and is resulting in unprecedented fires (Chapters 4 and 5). Years with high precipitation are associated with high fuel loads and large-scale fires (Brooks and Minnich 2006). Many woody desert species are fire intolerant and do not readily recover after fire; this results in progressive conversion to annual grass dominance, and an annual-grass fire cycle characterized by repeated fires (Brooks 2011).

Due to inherently low resilience and resistance of Mojave Desert scrub communities, restoration and management must focus on protection and restoration (table 7.2). In these ecosystems, protection includes eliminating or reducing stressors such as fire, dispersed recreational activities, OHV use, and overgrazing by wild horses, burros, and cattle. New utility-scale, alternative energy sites should be placed to minimize fragmentation and species loss.

The state-of-knowledge for restoring Mojave Desert scrub was recently summarized by Abella and Newton (2009), Webb and others (2009), and Weigand and Rogers (2009). Restoration activities should address the presence of invasive species, a potential increase in fire frequency, and current and projected climate conditions. Creosotebush, the dominant shrub, exhibits limited resprouting after disturbances that do not kill the plant; other shrubs like white bursage reestablish over time. Also, there has been some success with seeding and transplanting Mojave Desert scrub species when appropriate methods are used (Bainbridge 2007). Full recovery is slow and depends on an absence of repeated fire (Engel and Abella 2011). Similar to the blackbrush ecosystem, Mojave

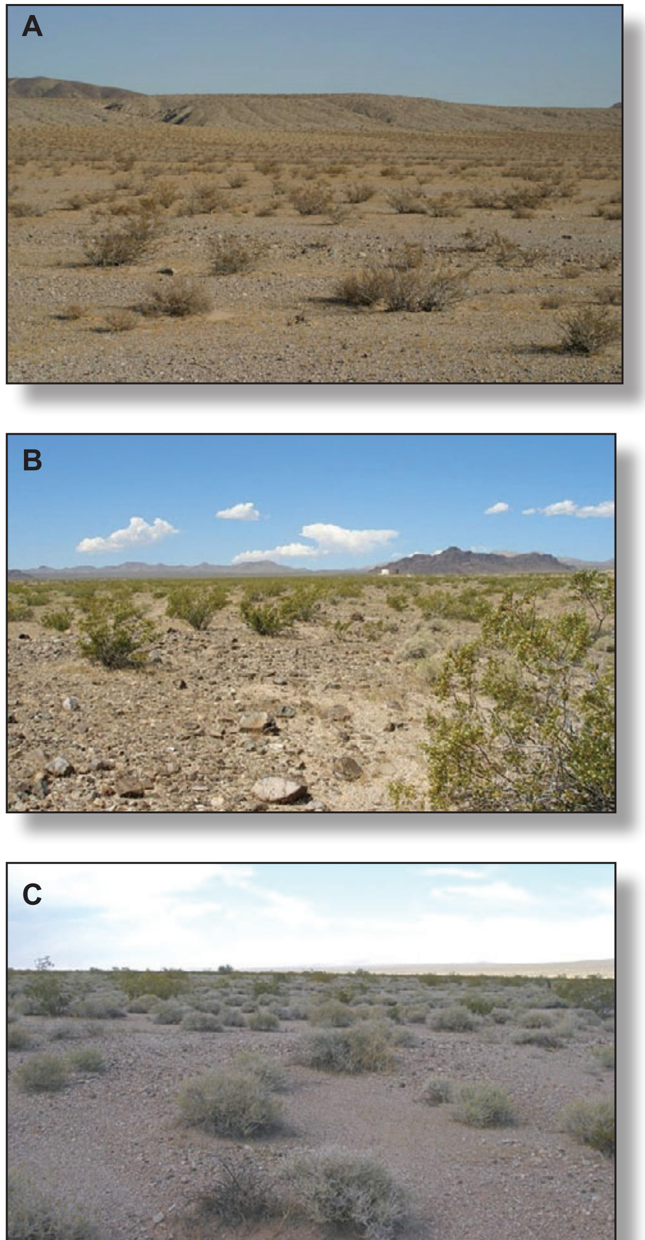

Figure 7.6—(A) An arid creosotebush ecological site with relatively low productivity (photo by Matt Brooks). (B) A slightly less arid creosotebush ecological site. (C) A severely disturbed site on Camp Ibis military base after 50 years of recovery (photos B and C by Patti Novak-Echenique). Protective management should be emphasized on both site types. Due to ongoing climate change, restoration of the less arid site should include species from the more arid type.

Desert mixed scrub communities are wide-ranging and occur over broad environmental gradients that influence resilience and restoration approaches (fig. 7.6). Some species in hotter and drier sites within Mojave Desert mixed scrub communities may be at or past thresholds of persistence due to the novel mix of stressors that include invasive species, warmer winters, and hot and potentially dryer summers. Recent increases in nighttime temperatures due to climate change have relaxed the biogeographical constraints on many desert species, and they can now establish at locations that were previously too cold (Kelly and Goulden 2008; Loarie and others 2009; Tylianakis and others 2008). Thus, restoration strategies for degraded sites at higher elevations should consider including species that are projected to migrate to these areas. Information is needed on the environmental tolerances of these species and their establishment requirements over the range of predicted climates.

Salt desert scrub community—The salt desert scrub ecosystem forms a mosaic within the Mojave Desert mixed scrub and blackbrush ecosystems. It is found between 800 and 1,800 m, and is associated with playas, basins, and poorly drained depressions with silty loam soils. The primary shrubs of the salt desert scrub community are shadscale, desert holly (*Atriplex hymenelytra*), Bailey's greasewood (*Sarcobatus baileyi*), desert thorn, Torrey saltbush, (*Atriplex torreyi*), winterfat (*Krascheninnikovia lanata*), bursage, fourwing saltbush (*Atriplex canescens*), mormon tea, horsebrush (*Tetradymia canescens*), and snakeweed (RECON 2000). Other shrubs include greasewood (*Sarcobatus vermiculatus*), blackbrush, iodine bush (*Allenrolfea occidentalis*), and creosotebush. This lower-elevation and very dry ecosystem has very low ecological resilience, but may have slightly higher resistance to invasive species than Mojave Desert mixed scrub due to low moisture availability. Salt desert scrub in the Great Basin is more resilient than in southern Nevada due to higher rainfall and cooler temperatures in the Great Basin.

Risks to the salt desert shrub ecosystem include utility-scale renewable energy development (particularly in playas), urbanization, burro and cattle grazing, recreational and OHV activity and accompanying dust production, invasive annual grasses, and associated increases in fire frequency. Urbanization is a primary concern as this ecosystem has the highest percentage loss to urban land development of all major ecosystems in the SNAP area (Chapter 2). Large areas of salt desert scrub have been lost to urban development in Green Valley/Henderson and in northwest Las Vegas. Climate change will cause additional stress.

Restoration and management priorities for this ecosystem are similar to those for Mojave Desert mixed scrub: control of recreational activities, including OHV use; careful selection of sites for alternative energy facilities; and maintenance of appropriate populations of burros. Limited information is available on restoration of salt desert shrub species, although seeding of *Atriplex* has had some success (Abella and Newton 2009). Maintaining this ecosystem in southern Nevada will require identifying those locations where it still occurs and prioritizing its protection in land use plans. Specific elements should include preventing fragmentation by maintaining minimum patch sizes.

Mesquite/catclaw community—The mesquite/catclaw community is a small component (~1%) within Mojave Desert scrub. It is comprised of screwbean mesquite (*Prosopis pubescens*), honey mesquite (*P. glandulosa*), and catclaw acacia (*Acacia greggii*) and occurs in patches (1 ha to >1,000 ha) where perennial groundwater is not more than 10 m from the surface. The greatest extent of the mesquite/catclaw community in southern Nevada was found previously in the Las Vegas Valley. Most of this community type now has been lost due to urbanization, OHV use, climate change and exotic species (Desert Research Institute 2008). Maintaining this community in southern Nevada will require identifying the locations where it still occurs and prioritizing its protection in land use plans to ensure that minimum patch sizes are maintained and fragmentation is prevented.

Riparian/Aquatic Ecosystems

In southern Nevada, the desert riparian/aquatic ecosystem occurs primarily along the Colorado River, Las Vegas Wash, and Virgin and Muddy Rivers at elevations below 600 m (RECON 2000). Water is perennial in the Colorado River, Las Vegas Wash, and Muddy River, but is intermittent in the Virgin River. In perennial reaches, the aquatic community includes fish and aquatic macroinvertebrates. The riparian community is characterized by woody, deciduous, and emergent obligatory and facultative wetland vegetation. Native woody vegetation includes Fremont cottonwood (*Populus fremontii*), black cottonwood (*Populus trichocarpa*), sandbar willow (*Salix exigua*), Goodding willow (*S. gooddingii*), velvet ash (*Fraxinus velutina*), desert willow (*Chilopsis linearis*), and honey mesquite. Woody vegetation along intermittent reaches is relatively sparse and consists mostly of desert willow and acacia (*Acacia* spp.). Due to high productivity and water availability, this ecosystem provides essential cover, water, food, and breeding sites for several endangered species and many other species of conservation concern. However, seasonally high water temperatures, harsh water chemistry, high turbidity, scouring floods, and sandy substrates result in moderate to low resilience. These systems exhibit low resistance to woody invaders like tamarisk (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*).

Riparian/aquatic ecosystems are some of the most degraded in southern Nevada (Desert Research Institute 2008). Stressors include altered flow regimes resulting from dams and diversions, impoundments, and channelization; invasive species and altered fire regimes; woodcutting; burro, wild horse, and cattle grazing; agricultural clearing; and urban and ex-urban development. The rapid rate of temperature increase and higher drought severity index predicted to occur with climate change (Loarie and others 2009) will likely result in decreased water availability for riparian/aquatic ecosystems.

Protection, prevention, and restoration are all important activities in these ecosystems (table 7.2). Surface water, groundwater, and sediment dynamics coupled with water and soil chemistry determine the composition and abundance of both aquatic organisms and plant species in these arid riparian/aquatic ecosystems (Anderson and others 2004; Briggs 1996). Specific activities are determined by the characteristics of the system and are usually conducted to maintain or improve channel and flow characteristics and to restore or create habitat for one or more species of concern. Protection is a cross-cutting activity that involves minimizing disturbance and sediment and chemical inputs from the diversity of stressors that affect these ecosystems. Prevention aimed at controlling invasive species also is a cross-cutting activity. Removal of woody invaders, including tamarisk and Russian olive, using biocontrol agents, like the saltcedar leaf beetle (*Diorhabda elongata*), herbicides, or cutting is widespread, but follow-up restoration activities and habitat trade-offs require careful consideration (Shafroth and others 2005; Shanahan and others 2011).

In the Lower Colorado River Basin, the Multi-Species Conservation Program focuses on four ecosystem types: cottonwood/willow, honey mesquite, marsh, or backwater. Active restoration/habitat creation involves assessing the physical, chemical, and biological conditions necessary for establishment and maintenance of species of concern (amphibians and native fish populations) and manipulating flow regimes to obtain the desired characteristics (Scoppettone and others 2005). This can include improving spring and stream connectivity, and restoring pools, riffles, and the natural substrate. The site is then revegetated with native plants adapted to the new conditions. In actively eroding systems like Las Vegas Wash, which has municipal and industrial wastewater inputs, erosion control, environmental monitoring, and wetlands restoration and enhancement are implemented to reduce erosion and address water-quality concerns (RECON 2000). Because of the importance of upstream activities and disturbances on downstream flows, sediment regimes and water quality, increased emphasis is being placed on large-scale watershed planning and regional collaboration (e.g., U.S. Army Corp of Engineers 2008).

Springs Ecosystems

Springs occur from approximately 250 m to 3,300 m elevation in all landscape settings (e.g., mountains, gullies, valley floors, hillside, etc.) in southern Nevada. The MSHCP reported 506 springs in Clark County. However, an inventory of the basic environmental and biological characteristics of most large springs (Sada and Nachlinger 1996, 1998) indicates that Clark County springs dry frequently and that less than 200 persistent springs occur in the county. The geology, climate, topographic position, aquifer size, and flow path of the water determine the hydrologic characteristics of springs. In turn, the hydrologic characteristics of springs structure spring environments and the biotic communities that they support (Sada and Herbst 1999, 2006; Sada and others 2001, 2000). In southern Nevada, springs are generally supported by mountain block, local, or regional aquifers with different environmental and biological characteristics (Knochenmus and others 2007; Mifflin 1968).

Springs in mountainous recharge areas are supported by mountain block aquifers. These springs are generally small and are perched, that is, they discharge water that flows along an impermeable layer near the soil surface. They are typically cold (<10 °C) with low chemical concentrations (specific conductivity <500 µmhos) and neutral pH (6.0 to 8.0). Harsh conditions in these springs are mostly attributed to natural factors such as periodic drying (seasonal or during droughts), scouring floods, and fire. Thus, they are characterized by moderately low resilience. Disturbances are mostly due to trampling and overgrazing by wild horses, burros, elk, and cattle, and recreational use. These springs are minimally affected by groundwater removal, but may be susceptible to drier conditions with climate warming due to low flows.

Local aquifers support springs that are often around the margins of valleys at lower elevations. These aquifers are generally larger than mountain block aquifers, and springs fed by local aquifers are more persistent, less affected by drought, and dry infrequently. Most local springs are cool (10 to <25 °C), their chemical concentrations are low (specific conductance <1000 µmhos), and their pH is generally neutral (6.0 to 8.0). These springs are characterized by moderately high resilience. However, most of these springs have been altered by livestock trampling, annual grass fires, diversions, and/or recreation. These systems also may be impacted by groundwater withdrawal, and decreased groundwater recharge due to climate change.

Springs that are supported by regional aquifers are generally large compared to mountain block aquifer and local aquifer springs. Regional aquifers extend through several topographic basins and encompass thousands of square kilometers. Most importantly, they are persistent over long periods of time (tens of thousands of years) and are minimally affected by drought conditions. Regional springs are warm (25 to 40 °C), their chemical concentrations are relatively benign (specific conductance of generally 500 to 1,000 µmhos, but may be as high as 1,500 µmhos), and their pH is generally neutral (near 7.4). These springs are minimally affected by natural events because they are large and located on valley floors where scouring floods are uncommon; thus, these springs also have moderately high natural resilience. However, most regional springs have been affected by past agricultural practices (pesticides, removal of vegetation, grazing by burros and cattle, ground water pumping, and surface diversions) and continue to be affected by altered flows, recreation, and grazing by horses, burros, and cattle.

As for riparian/aquatic ecosystems, restoration and management strategies for spring ecosystems must be based on their topographic setting, hydrologic characteristics, and macroinvertebrate and vegetation communities (Sada and Herbst 1999, 2006; Sada and others 2000, 2001). In addition, benthic macroinvertebrate and riparian communities of Mojave Desert and Great Basin springs generally differentiate along a physiochemical stress gradient where highly stressed springs support depleted communities composed of animals and plants that are more tolerant of harsh physicochemical environments than springs with less stressful environments (Fleishman and others 2006; Sada and others 2005). Protection of these systems requires maintaining sufficient water availability to support the existing aquatic organisms and riparian vegetation by reducing or minimizing ground water withdrawal and surface diversions. Protection also includes minimizing or eliminating stress due to grazing and trampling by cattle and burros and recreation. Prevention can be used to control invasive woody and herbaceous species. Restoration can be used to restore spring hydrology by eliminating diversions and vegetation communities by revegetation with the appropriate native species. For spring systems supported by regional aquifers with existing or potential stream channels, modification of flows can be used to create stream channels with the necessary water depths, velocities, and temperatures to support native species of concern, like the Amargosa pupfish (Scoppettone and others 2005).

Knowledge Gaps

Cross-cutting information needs include a better understanding of the factors that determine resilience and resistance in southern Nevada's diverse ecosystems and of the interacting effects of the region's stressors. Knowledge of the environmental conditions required for establishment and persistence of native plant species and methods for their restoration is also needed. Information needs specific to the region's stressors include climate change, land use, invasive species, and fire.

Climate Change. More accurate predictions of changes in both temperature and precipitation; ecosystem specific information on the effects of climate change on species distributions, disturbance regimes and recovery processes.

Land Use. Knowledge of the distribution and extent of current and future land uses and their effects on current and future ecosystem resilience; information on the minimum patch sizes and degree of fragmentation that ecosystems can tolerate; information on the amount and effect of N deposition on native ecosystems and annual invaders; land use planning tools to ensure land use is consistent with maintaining and restoring ecosystems.

Invasive Species. Increased knowledge of feedbacks to invasion from regional stressors like increased CO_2, altered fire regimes, and overgrazing; knowledge of the environmental conditions required for establishment and persistence of invasive plants and of their capacities to adapt and migrate in a warming environment; methods for controlling invaders and restoring natives that are consistent with ecosystem restoration and maintenance.

Fire. Increased knowledge of fire effects on annual species invasion and ecosystem recovery for the different ecological sites that characterize Mojave Desert scrub and blackbrush ecosystems; increased knowledge of the interacting effects of effective precipitation, ecosystem productivity, and understory species composition on fire return intervals for southern Nevada mixed conifer and piñon and juniper ecosystems; fire and fire surrogate tools for mixed conifer, piñon and juniper and sagebrush ecosystems.

Management Implications

Protection is a critical component of restoring and maintaining southern Nevada ecosystems due to the arid environment and numerous stressors. Preventative management is a viable option only in more mesic or higher elevation ecosystems that do not comprise much of the total land area. Restoration is challenging in all ecosystems. Maintaining sustainable ecosystems will require a greater focus on assessing ecological condition, prioritizing restoration and management activities, and selecting the most appropriate treatments. Monitoring and adaptive management will be essential.

Assessment and Prioritization

An integrated and consistent assessment of southern Nevada ecosystems and their relative resilience and resistance can be used to categorize and prioritize management and restoration activities. Addressing the widespread stressors affecting these ecosystems and providing habitat for species of concern requires a broad scale approach that crosses administrative boundaries. Most management plans now encompass landscapes with multiple project areas and are developed in consultation with partner agencies. Several tools already exist for developing landscape-scale and cross-boundary assessments. Soil surveys exist for most of southern Nevada including spring systems and lands managed by the BLM, most of Desert National Wildlife Refuge, and Lake Mead (USDA NRCS 2012). Soils characteristics, along with climate and topography determine the potential to support a given ecological site type (fig. 7.1). Draft ecological site descriptions (ESDs) exist for most of the region that has soils surveys (contact NRCS Nevada State Office, http://www.nv.nrcs.usda.gov/contact/). Soil types and ESDs can be used in a GIS environment as the basis for evaluating the relative resilience and resistance of the ecosystems in the region, and the degree to which current ecological conditions deviate from potential conditions. Recent research has developed geospatial tools for identifying critical habitat for species of concern in the Great Basin that could be used in southern Nevada (Meinke and others 2009). Methods also have been developed to examine linkages among adjacent ESDs and the interacting effects of landforms and disturbances (Bestelmeyer and others 2011).

The utility of this approach can be illustrated for the blackbrush ecosystem. ESDs are part of a land classification system that describes the potential of a set of climate, topographic, and soil characteristics and natural disturbances to support a dynamic set of plant communities (Bestelmeyer and others 2009; Stringham and others 2003). ESDs use state (a relatively stable set of plant communities that are resilient to disturbance) and transition (the drivers of change among alternative states) to describe the range in variation of plant communities (Stringham and others 2003). The reference state often includes several plant communities that differ in dominant plant species relative to time since disturbance. Alternative states describe new sets of communities that are separated by largely irreversible transitions (thresholds) and that may persist over time. A generalized state and transition model is presented for the blackbrush ecosystem (fig. 7.7). Different ecological sites occur within the blackbrush ecosystems that are differentiated by relative aridity (thermic vs. mesic soils). Alternative states and transitions differ for the two ecological site types and this has important implications in a warming environment.

Restoration and Management Approaches

Once an area has been prioritized for active restoration and/or management, a series of logical steps can be used to develop the restoration plan. These include identifying

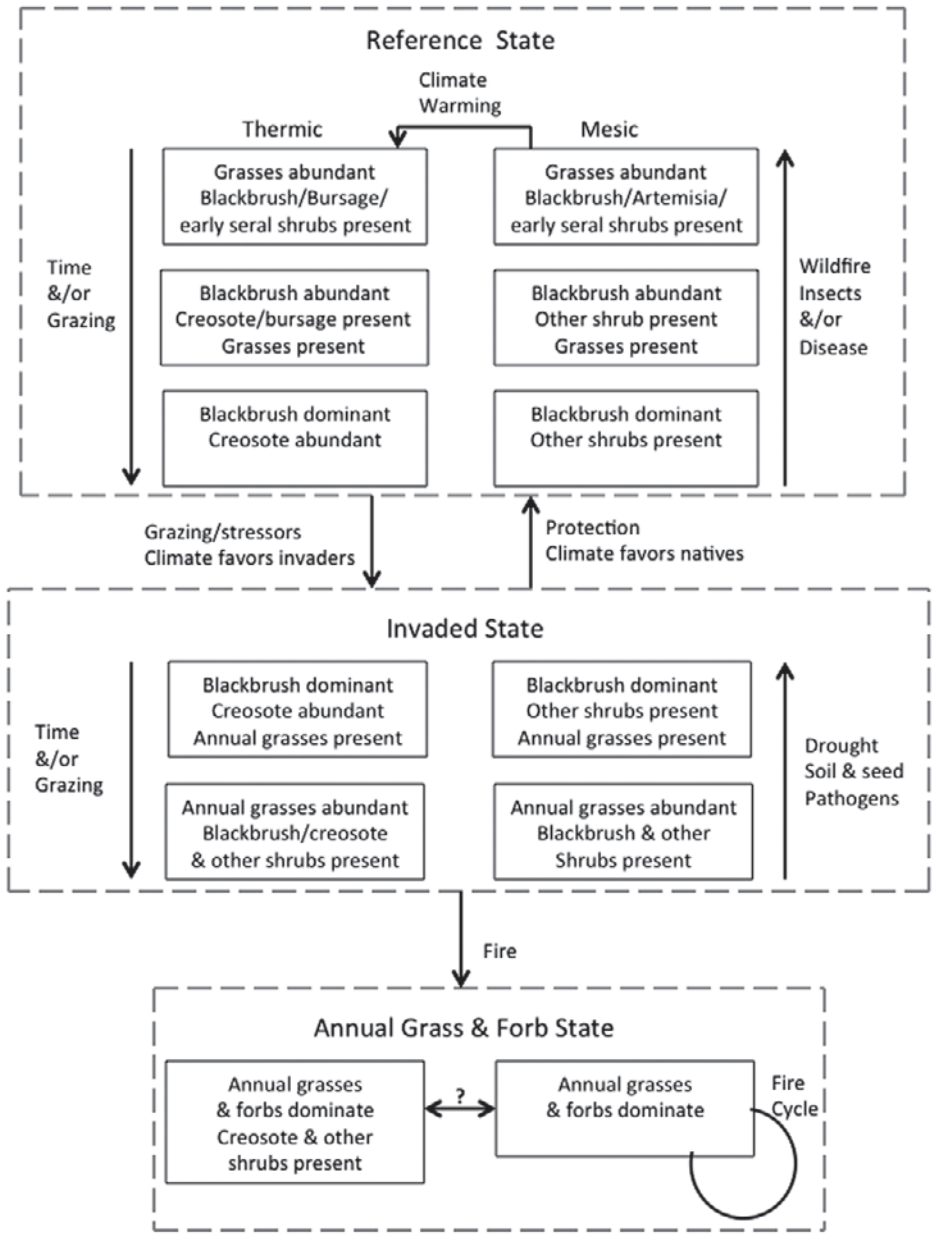

Figure 7.7—Hypothetical state and transition model for the thermic and mesic blackbrush ecological site types that considers potential transitions with a warming climate. The thermic state is more arid and has a minor component of creosotebush and bursage. For both reference states, disturbances that reduce blackbrush increases grass abundance; time and/or grazing increases shrub abundance. Grazing, stressors and climate conditions that favor invaders can result in transition to an invaded state. Time and or grazing results in greater abundance of annual grasses; drought and soil and seed pathogens that target annual grasses result in higher shrub abundance. Return to the reference state requires protection and climate conditions that favor natives. Fire can convert the invaded state to an annual grass and forb state and result in repeated fire. A warming climate may disfavor annual invaders and favor a creosote dominated state.

Table 7.3—General guidelines for conducting a restoration project in southern Nevada (modified from Miller and others 2007; Pyke 2011; Tausch and others 2009).

Steps in the process	Questions to be addressed
I. Identify landscape priorities and ecological sites	1. Where are priority sites for protection, prevention and restoration? Consider the landscape context. 2. What are the topographic characteristics and soils of the site? Verify soils mapped to the location and collect information on soil texture, depth and basic chemistry (pH, calcium carbonate, etc.) 3. How will topographic characteristics and soils affect vegetation establishment and erosion? Evaluate erosion risk based on topography and soil characteristics. 4. What is the potential native plant community for the site? Match soil components to their correlated ESD. This provides a list of potential species for the site.
II. Determine current state of the site	5. Is the site still within the reference state of the state and transition model for this ecological site?
III. Select appropriate action	6. How far does the site deviate from the reference state? 7. Do sufficient perennial shrubs and herbaceous species exist to facilitate recovery? No action is needed. 8. Are invasive species a minor component? Protection or preventative management may prevent conversion. 9. Do invasive species dominate the site while native life forms are missing or severely under represented? Active restoration is required to restore habitat. 10. Are species from drier or warmer ecological sites present? Restoration with species from the drier or warmer site should be considered. 11. Have soils or other aspects of the physical environment been altered? The site may have crossed a threshold and represent a new ecological site type requiring new site-specific restoration approaches.
IV. Determine post-treatment	12. How long should the site be protected before management land uses begin? In general, sites with lower resilience and resistance should be protected for longer periods. 13. How will monitoring be performed? Restoration effectiveness monitoring includes a complete set of measurements, analyses, and a report. 14. Are adjustments to the restoration approach needed? Adaptive management is applied to future projects by compiling information based on consistent findings from multiple locations.

landscape priorities and ecological sites, determining the current state of the site, selecting the appropriate action(s), and determining post-treatment management. A general approach that asks questions to identify the information required in each step is provided in table 7.3. These questions can be modified to include the specific information needed for restoration of different ecosystem types.

Monitoring Activities

Monitoring programs designed to track ecosystem changes in response to both stressors and management actions can be used to increase understanding of ecosystem resilience and resistance and to realign restoration and management approaches and implement adaptive management (Chapter 1). Information is increasing on likely changes in southern Nevada ecosystems with additional stress and climate warming, but a large degree of uncertainty still exits. Strategic placement of monitoring sites and repeated measurements of key abiotic (precipitation, temperature, evaporation) and biotic (dominant native and exotic species) variables and ecological conditions can be used to decrease uncertainty and increase the effectiveness of management decisions. Monitoring also can be used to track changes in regional and local stressors over time like the level of nitrogen deposition and the intensity of wild horse and burro grazing. Monitoring sites should span the environmental/productivity gradients and ecosystem types that occur in southern Nevada. In addition, the following areas of high priority should be monitored:

1. ecosystem types of small extent under development pressure like mesquite/catclaw and salt desert shrub;
2. ecosystems that support numerous species of conservation concern like springs and riparian areas;
3. ecotones between ecosystem types where changes in response to climate are expected to be largest (Loehle 2000; Stohlgren and others 2000);
4. ecological sites with different climatic conditions and soils that are exhibiting invasion and repeated fires; and
5. ecological sites with different climatic conditions and soils that are exhibiting tree expansion and increased fire risk.

Monitoring the response of ecosystems to management actions and active restoration also is of high priority as it provides information on treatment effectiveness that can be used to adjust methodologies.

Monitoring activities are most beneficial when consistent approaches are used among and within agencies to collect, analyze, and report monitoring data. Common databases can be used by agency partners to record and share monitoring data, like the Land Treatment Digital Library (USGS 2010), to facilitate this process. A restoration geodatabase was recently developed by southern Nevada agencies to facilitate the collection and sharing of data from each agency. This geodatabase includes an inventory and assessment of upland ecological disturbances, recommended restoration methods, documentation of restoration treatments, and monitoring of restored sites. Once this database is implemented, analysis of the data will help to identify trends and large-scale problems that can be addressed by the interagency restoration team, as well as to evaluate effectiveness of restoration treatments, determine the best techniques, and make adjustments on the ground as needed.

Protocols have been developed to guide field staff in data collection and decision making for the restoration of road disturbances (DeFalco and Scoles-Sciulla 2011). According to these protocols, implementation monitoring should be conducted for up to 2 years following restoration to evaluate effectiveness of restoration treatments, and ecological monitoring should occur approximately every 5 years to determine how ecosystem functions are recovering. Monitoring includes photo documentation and measuring plants (including non-natives), erosion features, soils (compaction, stability), and biological soil crusts.

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Chapter 8

Human Interactions With the Environment Through Time in Southern Nevada

Carol Raish

Introduction

Southern Nevada is rich in irreplaceable cultural resources that include archeological remains, historic sites, cultural landscapes, and other areas of significance to Native Americans and other cultural groups. The Southern Nevada Agency Partnership (SNAP) seeks to provide for responsible use of Southern Nevada's lands in a manner that preserves heritage resources and promotes an understanding of human interaction with the landscape. This chapter addresses Sub-goal 2.1 in the SNAP Science Research Strategy which is to develop an understanding of human interactions with the environment through time (table 1.3; Turner and others 2009). A review of human occupation in the region as derived from southern Nevada's cultural resources is presented with a focus on the following questions.

1. Did humans use varying environmental zones through time and how were these zones used?
2. What influences did humans have on the landscape through history?
3. Did changes in the environment influence human use and occupation of the landscape over time?
4. Did human interaction with other groups influence the environment or resource utilization? and
5. Did resource use vary through time?

The depth with which these questions can be discussed is dependent on the nature and extent of archeological survey coverage of the region (fig. 8.1) and the nature of the resources themselves. Gaps in knowledge and implications for regional management are reviewed in final sections of this chapter.

The area shows wide-ranging use of resources and environmental zones over time. The focus of this overview is on the time periods primarily informed by archeological sources, from roughly 11,950 BP (10,000 BC) to 100 BP (AD 1850). This time period encompasses the end of the Pleistocene/beginning of the Holocene until occupation by Euro-Americans. There is evidence, although scant, of human occupation of southern Nevada at the end of the Pleistocene. Groups producing these remains are viewed as nomadic hunters and scavengers of large fauna, who also undoubtedly utilized both small game and plant resources (Harper and others 2006). The Early Holocene represents a broad spectrum of adaptations to changing climatic conditions that were affecting Holocene plant and animal resources (Ezzo and Majewski 1996). The beginnings of agriculture, with continued important exploitation of wild resources and seasonal movement, are indicated prior to 2350 BP (400 BC) and increase in intensity until ca. 750/650 BP (AD 1200/1300). With the decline of agriculture as a major subsistence practice in the area around 750/650 BP (AD 1200/1300), archeological remains reflect

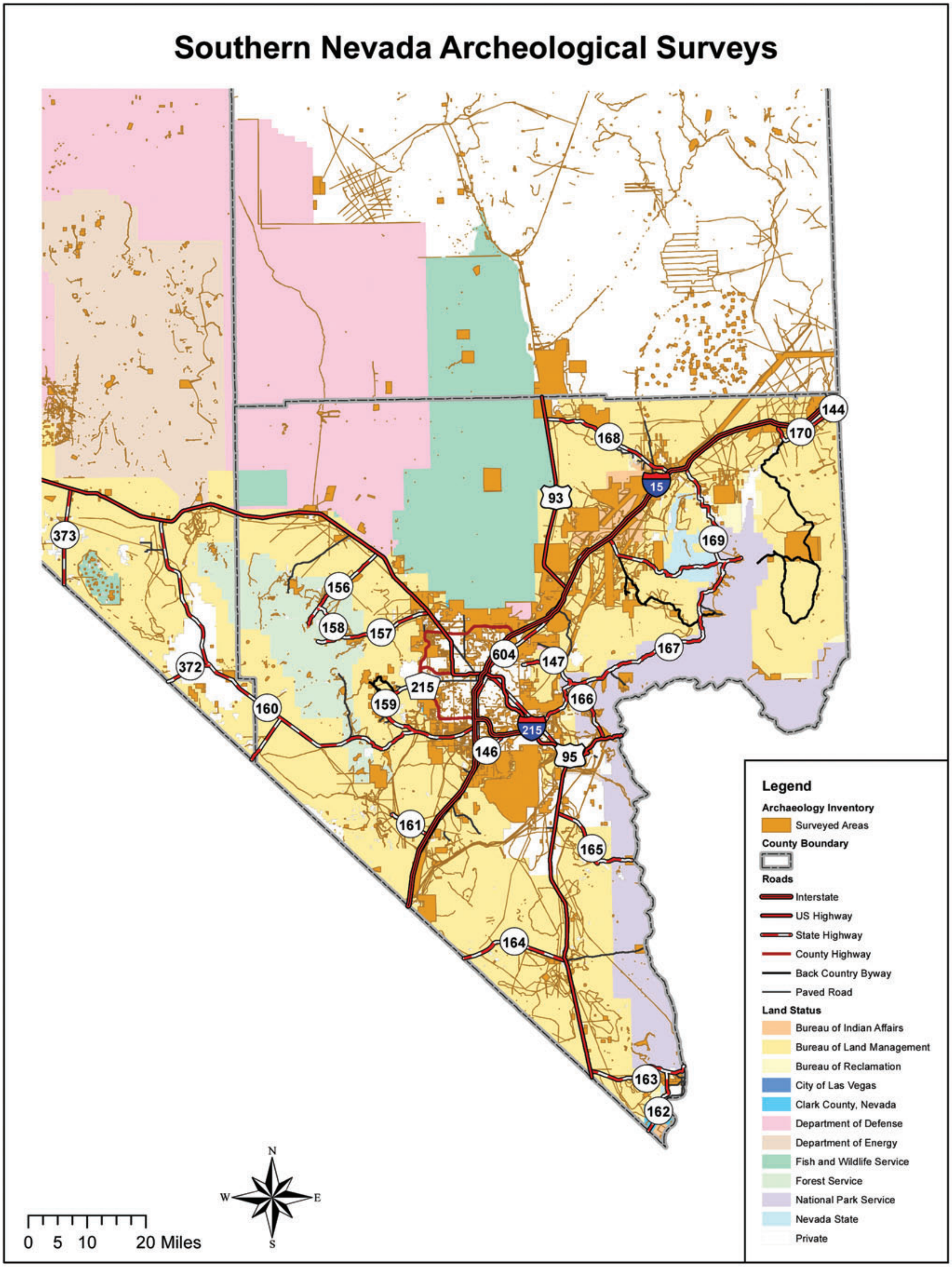

Figure 8.1—Map of southern Nevada archeological survey coverage.

a return to a more nomadic foraging way of life that was supplemented by smaller-scale agriculture (Ahlstrom and Roberts 2012; Altschul and Fairley 1989; Ezzo and Majewski 1996). This more mobile adaptation is associated with the Southern Paiute, who were residents of the region at European contact and who occupy southern Nevada today.

Focal Area

The area under study is mainly centered in southern Nevada's Clark County but lands in Lincoln and Nye Counties also are included, as well as a small portion of Mohave County, Arizona (fig. 1.1). The geographic focus includes areas surrounding Lake Mead, the Muddy and Virgin Rivers, and the Las Vegas Valley. It extends west to Sloan Canyon National Conservation Area, the Spring Mountains National Recreation Area, and Ash Meadows National Wildlife Refuge. Physiographic features important for human occupation in and surrounding the location include the Muddy and Virgin Mountains, Moapa and Virgin Valleys, the Valley of Fire, the Muddy and Virgin Rivers, the Las Vegas Valley, and the Spring Mountains (figs. 8.2 and 8.3). These lands encompass nine distinct ecosystem types and support multiple species of management concern (tables 1.1 and 1.2).

Culture History and Chronology

A variety of terms have been used to describe the cultural chronology of the region. Ezzo and Majewski (1996) list some of the more important designations and their associated time periods. We do not present all prior chronological schemes here, but correlate each sequence with the most common previously used names for the time period. In addition, different chronological schemes are currently used for the lands surrounding the Moapa and Virgin River Valleys, the Las Vegas Valley, and the Ash Meadows area of the Northern Mojave. These differences are based both in research history and in material culture variations. Thus, each of these geographic areas is discussed separately with the appropriate chronological terms (tables 8.1 and 8.2).

Paleo-Archaic 11,950-7,450 BP (10,000-5500 BC)

For this period and for the Middle and Late Archaic periods, the Las Vegas Valley and Northern Mojave area are included in the discussion owing to a similar chronological sequence (Ahlstrom and Roberts 2008; Roberts and Ahlstrom 2007). Diagnostic artifact overlap between the Paleo-Indian and Early Archaic has led Great Basin archeologists to designate the period Paleo-Archaic, as used here (Grayson 1993; Warren and Crabtree 1986). This period encompasses the end of the Pleistocene epoch and the first several thousand years of the Holocene (Harper and others 2006). It includes the earliest known human occupations in southern Nevada and also is referred to as the Lake Mojave period (Ezzo and Majewski 1996).

There has been considerable paleoenvironmental research in southern Nevada and the Great Basin that is relevant to this time period. These studies have derived data from packrat middens and from paleohydrological research on spring deposits and pluvial lake basins. Information from this research indicates that climatic changes from a moister, temperate regime to current climatic conditions began around 13,950 BP (roughly 12,000 BC) with deglaciation of the mountains within the area. A continuing trend toward aridity and drying of pluvial lakes is indicative of southern Nevada's climate in the Holocene, with an increase in succulents in lower environments and a movement of woodlands to higher elevations (Ezzo 1996).

Figure 8.2—Map of the Moapa and Virgin Valleys.

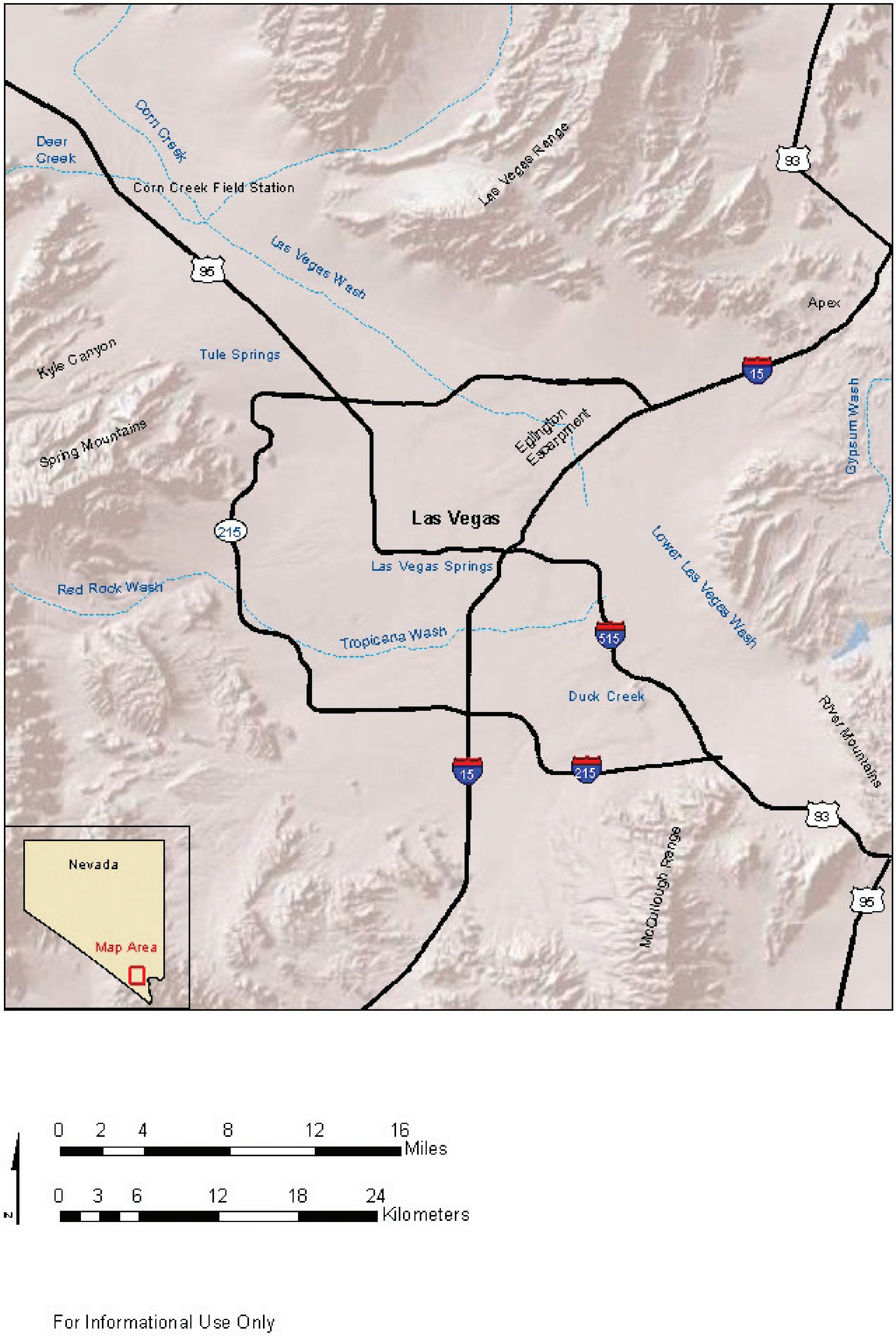

Figure 8.3—Map of the Las Vegas Valley.

Table 8.1—Chronological sequence for the Moapa and Virgin River Valleys (adapted from Ahlstrom and Roberts 2012[1]; Ezzo 1995[2]; Harper and others 2006[3]; Lyneis 2012[4]). Question marks indicate uncertain date range.

Period	Subperiod	Date range	Source
Paleo-Archaic		11,950-7450 BP (10,000-5500 BC)	3
	Paleo-Indian	11,450-10,950 BP (9500-9000 BC)	2, 3
	Early Archaic	11,150-7450 BP (9200-5500 BC	3
Archaic	Middle Archaic	7450-4950 BP (5500-3000 BC)	3
	Late Archaic	4950-2350 (?) BP (3000-400 (?) BC)	3
	Late Archaic/Early Agricultural	2350 (?)-1450 BP (400 (?) BC-AD 500)	3
Virgin Branch		1600-750/650 BP (AD 350-1200/1300)	1, 3, 4
	Moapa phase	1600-1400 BP (AD 350-550)	3
	Muddy River phase	1400-1200 BP (AD 550-750)	3
	Lost City phase	1200-800 BP (AD 750-1150)	3
	Mesa House phase	800-750/650 BP (AD 1150-1200/1300)	1, 3, 4
Late Prehistoric and Protohistoric		750/650-150 BP (AD 1200/1300-1800)	3, 4
Historical		150-0 BP (AD 1800-1950)3	

Table 8.2—Chronological sequence for the Las Vegas Valley (adapted from Roberts and Ahlstrom 2007).

Period	Subperiod	Date range
Paleo-Archaic		11,450-7450 BP (9500-5500 BC)
	Paleo-Indian	11,450-10,950 BP (9500-9000 BC)
	Early Archaic	11,150-7450 BP (9200-5500 BC)
Archaic	Middle	7,450-4950 BP (5500-3000 BC)
	Late	4950-1450 BP (3000 BC-AD 500)
	Terminal Late	1949-1450 BP (AD 1-500)
Ceramic	Early	1450-950 BP (AD 500-1000)
	Middle	950-450 BP (AD 1000-1500)
	Late	450-100 BP (AD 1500-1850)
Historical	Early	450-100 BP (AD 1500-1850)
	Late	100-50 BP (AD 1850-1900)

The majority of knowledge concerning the Paleo-Archaic comes from projectile points that are often found as isolated occurrences and that provide little information about lifeways in the Great Basin during this time. Evidence of occupation in southern Nevada itself is scant. Two artifact traditions are distinguished in the area during the period: fluted points, such as Clovis, and stemmed points, such as Lake Mojave (Grayson 1993; Harper and others 2006).

Clovis points are representative of the Paleo-Indian occupation found across the Americas. The points were used with the thrusting spear or atlatl (spear-thrower) and are generally considered to indicate the activities of nomadic groups that subsisted by hunting and scavenging Pleistocene megafauna, represented by mammoth, camel, horse, and bison. Paleo-Indian sites include camps, kill and butchering locations, and isolated projectile points (Cordell 1997; Harper and others 2006; Roth 1993). Clovis points are rare in the study area and are usually found in restricted contexts confined to lowland valleys and lake shores. No Clovis points have been found directly associated with Pleistocene megafauna in southern Nevada, nor have they been found in stratified, well-dated contexts (Roth 2012). The distribution of sites with these fluted points indicates that Paleo-Indian use of the area was sporadic but patterned, suggesting small-scale hunting expeditions into the area by highly mobile groups following game corridors, such as washes and valleys (Jones and Edwards 1994; Roth 2012).

The Great Basin Stemmed point series was defined at Pleistocene Lake Mojave, California (60 to 70 miles south of Ash Meadows National Wildlife Refuge), with sites having Lake Mojave projectile points and Silver Lake projectile points, as well as artifacts referred to as crescents (Grayson 1993; Warren and Crabtree 1986). The culture dates to between 11,150 and 7,450 BP (roughly 9200 to 5500 BC), which overlaps both the Paleo-Indian and Early Archaic periods. Stemmed points were first identified in lakeshore environments leading researchers to focus on marsh or lacustrine locales and subsistence resources. However, more recent work has identified stemmed points in a variety of other environments leading to the view that the makers of these points used additional plant and animal resources from various locations (Harper and others 2006; Roth 2012). In general, Paleo-Archaic sites do not contain identifiable features or ground stone, indicating an emphasis on hunting and gathering plant resources that did not require heavy grinding or parching (Roth 2012). The scarcity of Paleo-Archaic sites in southern Nevada and elsewhere undoubtedly reflects the depth at which these sites may be buried, the lack of intact, exposed surfaces, the nature and mobility of the subsistence adaptation, and the fact that Paleo-Archaic sites may not be recognized without diagnostic projectile points (Cordell 1997).

Middle Archaic 7450-4950 BP (5500-3000 BC)

The Archaic Period represents a broad spectrum adaptation to Holocene animal and plant resources that derived from environmental conditions similar to those of the present. The Archaic in North America seems to represent localized cultural traditions that developed out of Paleo-Indian traditions. Tools came to be more diverse as groups adapted to the mosaic of environments resulting from the climate transition from the Pleistocene to the Holocene. Movement between ecological zones for resource procurement undoubtedly occurred (Ezzo and Majewski 1996; Fowler and Madsen 1986). The Middle Archaic adaptation centers on generalized foraging and a broad spectrum economy (Basgall 2000). Middle Archaic sites are generally small with sparse artifact assemblages indicating short-term use by small, mobile groups (Lyneis 1982). During these times, plant procurement and processing tools, storage cists, and snares and traps for small game came into use. Artifacts of the Middle and Late Archaic include large, diagnostic projectile points attached to darts for use with the atlatl; thus, the Middle Archaic is also referred to as the Pinto period after the Pinto point (Ezzo and Majewski 1995; Warren and Crabtree 1986).

Middle Archaic sites and components are known from the Tule Springs area, the Eglington Escarpment, along Duck Creek, and at the Corn Creek Dunes site in the Las Vegas Valley. Pinto points also are reported from lithic scatter sites in the Moapa area (Ezzo and Majewski 1996). Middle Archaic sites also are known from the Ash

Meadows area in the Amargosa Valley, a relatively lush valley with a variety of wild resources including marsh resources, mesquite beans, and piñon nuts (Roth 2012). Site types include isolated projectile points; rockshelters; larger artifact scatters presumably representing re-use over a long period of time; lithic scatters; and fire-cracked rock generally considered indicative of roasting pits.

Pinto period sites in southern Nevada seem to be located near water sources such as drainages and remnant pluvial lakes. Unusually arid conditions are thought to have driven the settlement pattern (Ezzo and Majewski 1996). The toolkit contains items for hunting and processing game as well as milling implements indicating some reliance on plant food sources requiring processing. Milling stones and mortars increase throughout the Archaic. Sites with features and ground stone are much more common than during the Paleo-Archaic, suggesting a shift toward increased processing activities. These sites are widespread and occur in multiple ecological zones, showing the growing importance of plant foods (Lyneis 1982; Roth 2012). Sites with features and ground stone in the piñon-juniper zone indicate piñon use during this period (Roth 2012).

Late Archaic 4950-2350 BP (?) (3000-400 BC ?)

The question marks in the date range indicate that the date range is uncertain. The Late Archaic, or Gypsum period (table 8.1), is discussed as having a climatic shift toward greater precipitation and an increased diversity of plant resources available to southern Nevada groups. Thus, the period shows a continuing, increased emphasis on both plant and hard-seed processing and a greater occurrence of milling implements on Gypsum sites (Ezzo and Majewski 1996). Mortars and pestles indicate mesquite bean processing. Greater use of valley floors also may indicate a growing importance of mesquite in the diet, although it was not a staple resource until later periods (Roth 2012). Piñon was still exploited in the uplands, and one site in the Gold Butte area of the eastern portion of the project area also has agave roasting pits indicating the use of agave during the period. In addition, hunting of both large mammals (such as big horn sheep) and small mammals appears to have played an important role in resource procurement during the period (Harper and others 2006).

Gypsum Cave, the type site for the Gypsum Point, is located east of the northeastern edge of the Las Vegas Valley (Ezzo and Majewski 1995; Harrington 193; Roberts and Ahlstrom 2007) and has Late Archaic radiocarbon dates. Gypsum period components also occur in the Corn Creek Dunes area, along Duck Creek, in the southeastern corner of the Las Vegas Valley (Brooks and others 1975), in the Ash Meadows region, the Yucca Mountain/Forty Mile Wash area and around the Muddy and Virgin Rivers (Roth 2012). Late Archaic sites include caves, rockshelters, campsites, roasting pits, hearths, and scatters of flaked and ground stone. Site locations indicate that groups continued a mobile strategy seasonally exploiting ecological zones from a wide range of elevations and landforms (Ezzo and Majewski 1996; Roth 2012). The Gypsum period is also the time when long-distance trade goods, such as marine shell from California, appeared in the region (Lyneis 1982). Ceremonial sites appear during the time period indicated by caves used for ritual purposes, rock art, and specialized artifacts such as intentionally broken and painted dart fragments. Split twig figurines occur in the region (Fowler and others 1973; Roth 2012).

Sites of the Middle and Late Archaic can be difficult to identify because the generally small, mobile groups who produced them tended to leave a scanty and dispersed occupation record. In addition, and similar to Paleo-Archaic archeological remains, identification is also difficult if no diagnostic projectile points are present. Thus, many Archaic sites may be misclassified (Lyneis 1982). These problems apply most particularly to surface lithic scatters identified during archeological surveys.

Late Archaic/Early Agricultural 2350 (?)-1450 BP (400 (?) BC-AD 500)

The question marks in the date range indicate that the date range is uncertain. From this point on, Las Vegas Valley and Mojave Desert research use a different chronological scheme and are discussed separately in following sections. The Early Agricultural encompasses the Lowland Virgin Moapa phase 1600-1400 BP (AD 350-550), which corresponds to the Basketmatker II (BM II) and the first half of the BM III in the Pecos Classification used on the Colorado Plateau and in the Four Corners area. These time periods represent the beginning of the Virgin Branch Ancestral Puebloan [(Virgin Anasazi), referred to as the Western Virgin Puebloan archaeological culture by Ahlstrom and Roberts (2012)]. This occupation is located in portions of northern Arizona, southwestern Utah, and southern Nevada (Ezzo and Majewski 1996). The Lowland Virgin area (Lyneis 1995) lies at the western edge of the Virgin Branch occupation, comprising the Virgin and Muddy River Valleys and surrounding areas. On the east, the Virgin Branch is bordered by the Kayenta Ancestral Puebloan. On the north, west, and south mobile groups bordered the region (Ezzo and Majewski 1996).

The Early Agricultural and earlier portions of the Moapa phase, like BM II, lack ceramics and retain use of the atlatl as reflected by larger, corner and side-notched dart points (Lyneis 1995). Pit structures and rockshelters with semi-subterranean storage cists are associated with BM II and the Early Agricultural in the area. Pit structures are found in groupings of one to five with interior hearths and clay floors. These groupings generally lack separate storage features, which may suggest seasonal or temporary use (Clark 1984; Ezzo and Majewski 1996; Lyneis 1995; Shutler 1961). There is substantial evidence of maize farming during the period with materials coming from the Upper and Lower Moapa Valleys and from the uplands east of the Virgin River Valley. This evidence is derived from radiocarbon dates obtained directly from maize samples indicating the presence of maize horticulture by the AD 200s and possibly in the AD 100s. Remains of beans and cucurbits (squash/pumpkin/gourd) are also present (Ahlstrom and Roberts 2012).

Studies indicate mobility in the Moapa phase with small groups probably occupying sites on a temporary and/or seasonal basis. Access to both upland resources and farm land in the valleys is shown by site locations. This indicates a weaker commitment to agriculture than in later times (Myhrer 1986). Wild plant species maintained an important role in subsistence as did hunted game (Lyneis 1995).

Muddy River Phase 1400-1200 BP (AD 550-750)

The Muddy River phase corresponds roughly to the latter portions of BM III with many of the same diagnostic attributes. Grayware ceramics, the bow and arrow, two-handed manos, and basin and slab metates (grinding implements) appear in the archeological record during this time period. Small, stemmed and notched points suggest use of the bow and arrow (Lyneis 1995; Shutler 1961).

Both pit structures and Basketmaker components have been identified from this period. Fourteen pit structures from four different sites in the Upper and Lower Moapa Valley were excavated by Harrington and associates (Shutler 1961). Also, 17 sites were found to contain Basketmaker components in the Moapa Valley, indicating that sites tended to be evenly distributed throughout the valley (Clark 1984). The excavated pit structures varied in size with some designated as habitations, while other, smaller ones are considered to be storage structures. The information obtained from these studies indicates that pit structures usually occurred in small groups of five or fewer as in the previous phase, had plastered floors, and were generally circular in shape with some having hearths (Ahlstrom and Roberts 2012; Ezzo and Majewski 1996). Two pit structures excavated on Black Dog Mesa in the Upper Moapa Valley date to the BM III and possibly the later Pueblo I Lost City Phase (Ahlstrom and Roberts 2012). Both structures provided botanical evidence for the cultivation of maize and cucurbits, as well as the use of amaranth and tansy mustard.

Pit structures were located on mesas above the valley and on low knolls in the valley, suggesting that farming of the valley floor agricultural land was becoming more important (Shutler 1961). The observation that sites were evenly distributed throughout the valley (although the best agricultural land is in the lower portion of the valley) indicates that foraging and use of a wide range of ecological zones remained important during the phase (Clark 1984). Upland resources such as agave were used throughout the period (Ahlstrom and Roberts 2012). The settlement pattern and resource use were not significantly different from that of the previous phase. Interaction with other groups is demonstrated by ceramics presumably imported from areas to the east (Lyneis 1992b).

Lost City Phase 1200-800 BP (AD 750-1150)

The Virgin Branch Lost City phase corresponds to Pueblo I-II of the Pecos classification. During this phase the Virgin Branch population peaked and expanded into the Las Vegas Valley. Settlements became larger and surface structures appeared during the later portions of the phase (Harper and others 2006; Lyneis 1995). The technological changes of the prior phase continued with increased ceramic variation in both imported and locally produced varieties. Increases in ceramics and ground stone milling implements demonstrate an increasing emphasis on agriculture (Myhrer 1989).

Habitation sites tended to be located on low knolls on the valley floor in proximity to agricultural land, with a greater concentration in the lower part of the Moapa Valley than in the Muddy River phase. This locational preference is considered to be another indicator of the growing importance of agriculture (Clark 1984); although upland resources, such as agave, were used throughout the period (Ahlstrom and Roberts 2012). Irrigation in the form of small diversion dams along the slow-flowing, spring-fed Muddy River is inferred during these times (Ezzo and Majewski 1996; Lyneis 1995; Shutler 1961).

Pit structures, with associated storage cists or above-ground masonry storage rooms, were used for habitation during the early portion of the phase (Lyneis 1995). The storage cists are often arranged end-to-end in an arc, sometimes attached to the pit structure itself (Lyneis 1995). During the later portion of the phase, surface living rooms were generally placed within a curving alignment of storage rooms that defined a courtyard space shared by small groups of one or a few families.

A well-known site of the period that is located on the Muddy River in the Lower Moapa Valley is Main Ridge. The site is unusual because of its large size and capacity to house up to 100 people in a series of courtyard groups, which are as closely placed as the topography allows. Subsistence remains from the site indicate cultivation of maize, squash, and beans and exploitation of a variety of wild plants such as cattails, prickly pear cactus, amaranth, saltbush, goosefoot, tansy mustard, and grasses. Faunal remains included those of desert bighorn, rabbits and hares, birds, and desert tortoise (Harry 2008; Harry and Watson 2010). Ceramics date the site to a relatively brief period around 900 BP (AD 1050) (Lyneis 1992b). Main Ridge is described as being ideally suited for interaction with settlements along the Lower Virgin River and to the east. Non-local goods indicate interactions with other groups and include ceramics from the Kayenta and northern San Juan areas, as well as beads and shell ornaments from the south and west (Lyneis 1992b).

*Mesa House Phase 800-750/650 BP (AD 1150-1200/1300)**

Population in the Lowland Virgin area declined and the extent of occupation decreased during the Mesa House phase, which corresponds to Early PIII in the Pecos Classification (*More recent information by Lyneis (2012) discussed in Ahlstrom and Roberts (2012) has extended PIII in the area to AD 1300). By the end of this phase, the Virgin Branch cultural tradition was no longer apparent in southern Nevada (Harper and others 2006). Material culture during the phase was similar to that produced during the previous Lost City phase, especially in terms of flaked and ground stone tools. The difference between artifacts of the phases centers on ceramics with the presence of new types of decorated wares originating in the upper Virgin area and the Kayenta area to the east. Both turquoise and salt were mined and possibly traded (Ezzo and Majewski 1996; Shutler 1961). Maize, squash, and beans were cultivated and a variety of wild plants were exploited including those from upland areas. An increase in the number of projectile points during the Mesa House phase led Hayden (1930) to suggest increasing warfare during the time period.

Known sites are located in the Lower Moapa Valley and are situated on mesas or other landforms above the valley floor, which suggests a defensive location (Lyneis 1996). These include Mesa House, Three Mile Ruin, and Adam 2. Rooms are primarily surface habitation and storage structures that almost completely enclose a courtyard. Sites are considered to be larger than simple households but still relatively small. For example, of 33 structures in Mesa House's formal layout, only three to five are habitation rooms (Lyneis 1986, 1995, 1996; Shutler 1961). The available research indicates that kivas (religious/ceremonial structures) are not present in Lowland Virgin Branch occupations (Lyneis 1995).

Ezzo and Majewski (1996) discuss various views on the end of the Virgin Branch or "abandonment" in the area. Warfare with other groups moving into the region (Shutler 1961), climatic deterioration in the form of severe drought (Larson and Michaelson 1990), and collapse of Ancestral Puebloan society at the end of PII with a breakdown of links with Mexico are briefly presented. Lyneis's discussion of the topic (1992a,b, 1995, 1996) is most convincing with consideration of climatic and environmental change, demography, changes in trade networks, and assimilation or competition with the Paiute. She argues that none of the models alone is sufficient to explain the end of the Virgin Branch in the area stating that "just as for other parts of the northern Southwest, understanding the processes of abandonment and the fate of the populations remains a major challenge" (Lyneis 1995: 235).

Las Vegas Valley—Terminal Late Archaic 1949-1450 BP (AD 1-500), Ceramic Period 1450-100 BP (AD 500-1850)

North Mojave—Late Archaic to 1450 BP (AD 500), Late Prehistoric-Ceramic 1450-150 BP (AD 500-1800)

Terminal Late Archaic—The Terminal Late Archaic in the Las Vegas Valley encompasses the period during which pit structures, agriculture, and the bow and arrow came into use in the area, with the introduction of ceramics at the beginning of the following time period. Evidence of farming in the southeastern corner of the Las Vegas Valley on the bank of Las Vegas Wash has radiocarbon dated contexts that produced maize pollen or charred kernels. The earliest of the date ranges in this area are from 2050-1700 BP (100 BC-AD 250) and from 2300-2000 BP (350-50 BC) (Ahlstrom and Roberts 2012).

In the Mojave the bow and arrow appear between 1650-1450 BP (AD 300-500) (Ahlstrom 2005) with the appearance of ceramics several centuries later. Sites and components from the Las Vegas Valley include a campsite and a pit structure at the Clark County Wetlands Park in Las Vegas Wash. The site is consistent with those from the Muddy River in demonstrating use of pit structures and the bow and arrow prior to ceramics (Roberts and Ahlstrom 2007).

Ceramic Period—The Early Ceramic (1450-950 BP, AD 500-1000) corresponds to the following sequences: Patayan I, Basketmaker III and Pueblo I, and the Muddy River and early Lost City phases in the Moapa and Virgin Valleys. It also corresponds to the early portion of the Late Prehistoric-Ceramic in the Mojave sequence. Sites from this time period include pit structures, rock shelters, roasting pits, storage features, rock rings, hearths, and artifact scatters located throughout the Las Vegas Valley. Maize was grown during the period and wild plant foods, such as mesquite pods, hedgehog cactus fruit, and chenopods, remained important (Ahlstrom and Roberts 2012).

The earlier portion of the Ceramic period in the Valley features Rose Spring arrow points and prehistoric Puebloan grayware, while the later portion has Cottonwood Triangular and Desert Side-notched points with Paiute and some Tizon brownwares. In earlier times (pre-750 BP, AD 1200), these sites show more intensive, longer term use and are considered to be habitations; later sites reflect less intensive, shorter term use and are designated campsites (Roberts and Ahlstrom 2007). During the early portion of the Late Prehistoric, Ceramic from 1450-750 BP (AD 500-1200) in the Mojave Desert projectile point assemblages contain corner-notched Rose Spring and un-notched Cottonwood Triangular points, along with milling stones, manos, and mortars and pestles (Ahlstrom and Roberts 2008; Warren and Crabtree 1986).

Grayware pottery, primarily Virgin Branch, occurs more frequently on sites in central and northern portions of the Valley from Las Vegas Springs north. Buff and brownwares (Patayan, Paiute brownware, and Tizon Brown) are more prevalent on sites in the southern portion of the Las Vegas Valley. These differences suggest contacts with Patayan groups to the south along the Lower Colorado River as indicated at sites in the Duck Creek and Lower Las Vegas Wash areas. Patayan archeological remains are associated with ancestral Yuman-speaking groups, who live along the Lower Colorado today (Roberts and Ahlstrom 2007).

Sites with a predominance of grayware indicate contacts with Virgin Branch peoples to the northeast in the Moapa Valley. These contacts demonstrate routes of travel between the areas (Roberts and Ahlstrom 2007). Various sites have mixed assemblages of Patayan, Virgin Branch, and Paiute brownware pottery, indicating repeated short-term movement into the Las Vegas Valley by different groups (Seymour 1997). Conversely, the Las Vegas Valley could have had a resident population that established contacts with both Virgin Branch groups to the northeast in the Moapa and Virgin River Valleys and with groups to the south along the Colorado River (Roberts and Ahlstrom 2007). At the Corn Creek Dunes site in northern Las Vegas Valley both Great Basin Brown Ware and Pueblo utility ware (grayware) were made locally (Lyneis 2011). There is still considerable discussion and uncertainty about the cultural affiliation of some sites in the Valley and discussion over whether indigenous populations adopted or acquired outside technology or whether migrant populations moved into the area.

The ceramic data seemingly show that outside contacts in the Early Ceramic period were with the Virgin Branch area and those in the Middle and Late periods were with the Patayan area to the south along the Lower Colorado River. In the Middle Ceramic, Paiute pottery appeared in the Valley. However, there is considerable debate about the entrance of the Paiute into the valley, as well as the cultural affiliation of sites, which is discussed in a following section.

In the Northern Mojave during the early Late Prehistoric-Ceramic there is evidence of contact with Virgin Branch populations in the form of pottery that has been found across southern Nevada and into southeastern California (Warren and Crabtree 1986). These pottery sherds could represent trade or the presence of Puebloan groups foraging in the area (Warren and Crabtree 1986).

The Middle Ceramic (950-450 BP, AD 1000-1500) in the Las Vegas Valley roughly matches the Patayan II period and Pueblo II and III. In the Virgin Branch sequence the Middle Ceramic corresponds with the late Lost City and Mesa House phases up to abandonment by the Virgin Branch at roughly 750/650 BP (AD 1200/1300). The Middle Ceramic also corresponds to the Late Prehistoric-Ceramic from 750-450 BP (AD 1200-1500) in the Mojave sequence. Both Ancestral Puebloan and Patayan ceramic types often occur with equal representation on sites of this time period perhaps indicating ties to both groups (Roberts and Ahlstrom 2007). In the later part of the period, after the end of the Virgin Branch occupation of the Lowland Virgin area, Patayan and Paiute pottery become more prevalent.

Most Middle Ceramic sites are located in well-watered locales, such as near springs, and consist of pit structures, rockshelters, roasting pits, and hearths. Two apparent multi-room pueblo structures are located at the Big Spring Site toward the center of the Las Vegas Valley. Sites of the period indicate the use of both wild and domesticated resources including maize, cucurbits (squash/pumpkin/gourd), yucca fruits and pods, hedgehog cactus, and C*henopodium* or *Amaranthus* seeds. There is substantial evidence for the consumption of desert tortoise (Roberts and Ahlstrom 2007). Defining artifact characteristics of this period in the Mojave area include continuing use of Cottonwood Triangular points with the addition of Desert Side-notched points by around 750 BP (AD 1200).

With the later pre-European contact periods, sequences and archeological information converge in the Las Vegas Valley, the Muddy and Virgin River Valleys, and Ash Meadows National Wildlife Refuge area in the Northern Mojave. In the Las Vegas Valley, the Late Ceramic corresponds to the Patayan III period. However, the frequency of Patayan types actually declines as the frequency of Southern Paiute Brownware rises (Roberts and Ahlstrom 2007). After the abandonment of the region by the Virgin Branch Puebloan groups, archeological remains indicate a return to a more mobile foraging way of life with a subsistence base of hunting and gathering supplemented by small-scale agriculture (Ezzo and Majewski 1996). Late Ceramic sites comprise rockshelters, roasting mounds, and open shelters. These sites have evidence of the use of both domesticated and wild resources such as agave, mesquite seeds, prickly pear cactus seeds, domestic squash seeds, coyote melon, and desert tortoise (Roberts and Ahlstrom 2007).

The Northern Mojave produces evidence for occupation during the post 750 BP (AD 1200) times of the Late Prehistoric-Ceramic in the form of both projectile points and pottery. The Ash Meadows area crosses the territories of the Western Shoshone and the Southern Paiute in the 1800s (Livingston and Nials 1990). Evidence demonstrates a nomadic foraging lifeway with horticulture in small fields near well-watered areas (Ahlstrom and Roberts 2008; Livingston and Nials 1990).

The entry of the Southern Paiute into southern Nevada is a topic of continuing interest that has been reviewed and debated by a number of researchers. Aikens and Witherspoon (1982) and Goss (1977) argue that the group arrived in Southern Nevada in the Early or Middle Archaic based on linguistics, settlement patterning, and persistence of certain projectile points through time. Lyneis (1982, 1994) and Warren and Crabtree (1986) argue that they arrived no earlier than 950 BP (AD 1000) and possibly not until after abandonment by the Virgin Branch Ancestral Puebloan based on the view that Virgin Branch and Southern Paiute material culture items do not co-occur and that where items from both groups are present, the Southern Paiute artifacts overlie those of the Virgin Branch (Ezzo and Majeweskis 1996). Southern Paiute sites in the region are difficult to identify with respect to time period because of a lack of chronological control, leading to uncertainty concerning their attribution to the prehistoric, protohistoric, or historic periods (Ezzo and Majewski 1996).

Protohistoric and Historic Periods ca. 350-120 BP, ca. 120 BP to present (ca. AD 1600-1830, ca. AD 1830 to present)

The general emphasis of this review is on the primarily pre-European contact periods in southern Nevada that are informed by archeological materials. Thus, the following periods of initial contact with Europeans (Protohistoric) and later Euro-American settlement (Historic) are presented in less detail. At the time of European contact, regional residents were the Southern Paiute Tribe, as well as the Chemehuevi Tribe (included with the Paiute). The Southern Paiute Tribe is made up of independent bands, or groups. Each band has its own government. The Southern Paiute Tribe was located in the more southerly portions of the area and the Western Shoshone in the more westerly section (Euler 1966; Kelly and Fowler 1986; Steward 1938). The Mojave and Hualapai Tribes were located to the south and southeast. There was considerable interaction among these groups as they moved in and out of Southern Nevada (Ruppert 1976). Information on the Southern Paiute (Nuwuvi) is the focus of this discussion.

Southern Paiute habitation structures known archaeologically and ethnographically consisted of wickiups (a conical frame of branches covered with layers of bark, grass, or brush) in winter and brush shelters in summer (Inter-Tribal Council of Nevada 1976). Material culture comprised a wide range of basketry forms for storage, transport, resource-gathering, and cooking, as well as ceramics in some groups (Fowler and Dawson1986; Fowler and Fowler 1981; Kelly 1964; Stewart 1942). Baskets were apparently favored over the heavier pottery owing to the nomadic Paiute lifestyle. Other items of material culture included the bow and arrow, nets, woven items, grinding implements, and flint knives, with trade items such as shells and cloth (Euler 1966).

The Southern Paiute subsistence base emphasized hunting, foraging, and farming in the valley bottoms. They used many plants and animals ranging from insects and small mammals to deer and mountain sheep. Wild plant foods were prickly pear, yucca, piñon nuts, grass seeds, agave, acorns, wild grapes, and roots. These wild plant foods, primarily gathered by the women, were the dietary mainstay, with mesquite beans and pods of considerable importance. Men were the hunters. Maize, beans, squash, sunflower, and amaranth were farmed (Kelly 1964; Ruppert 1976).

Resources were generally obtained in a seasonally transhumant round (seasonal movement to gather resources), which varied from group to group and habitat to habitat. Farming was normally not intensive; older people often cared for the fields while the remainder of the group gathered resources in other locations (Ezzo and Majewski 1996; Inter-Tribal Council of Nevada 1976; Kelly and Fowler 1986). Most sources agree that the nuclear family was the primary unit of social organization for the Southern Paiute with aggregation and dispersal of larger and smaller groups throughout the year (Euler 1966; Kelly 1964; Steward 1938). As Euro-Americans increased in numbers in the region, the Native Americans were forced to congregate in bigger groups to survive (Inter-Tribal Council of Nevada 1976).

The first reported direct European contacts were with the Spanish in the late 1700s with the expeditions of Garcés and of Domínguez and Escalante, who were attempting to establish a route between Santa Fe, New Mexico, and Monterey, California. Although the expedition did not succeed in reaching its goal because of the onset of winter, part of their route became a portion of the Old Spanish Trail, that consisted of previously existing trails used for raiding and trading (Harper and others 2006).

After the explorers, trappers, and traders extended their operations into the area, an active slave trade began that lasted from the late 1700s to the mid-1850s. Captives, often Southern Paiute, were transported along the Old Spanish Trail between California and New Mexico. Prior enemies of the Southern Paiute, such as the Ute and Navajo, conducted slave raids in the region as they went between Spanish, and later, Mexican settlements. These raids seriously impacted the people of the Moapa and Las Vegas Valleys forcing them away from favorable agricultural lands, depopulating some Southern Paiute bands, and increasing their hostility and fear of travelers and other outsiders (Euler 1966; Harper and others 2006; Kelly and Fowler 1986). Slave raiding continued in the region until the mid-1850s when steps taken by the Mormons and the territorial legislature ended the trade (Harper and others 2006; Kelly and Fowler 1986).

Mormon (Church of Jesus Christ of Latter-day Saints) influence in the general region began with their entry into Utah in 1847 and continues today. Mormon activity and settlement in southern Nevada have been well documented by Sterner and Ezzo (1996) drawing on information from the Church Educational System (LDS 1993). Thus, the Mormon Era will not be discussed in detail in this overview other than to note briefly the impact of permanent Mormon settlements on the Southern Paiute.

During the 1850s, the Old Spanish Trail became the Mormon Road, which brought settlers and other travelers to the area (Harper and others 2006). Increased Euro-American settlement displaced the Southern Paiute from long-used agricultural, foraging, and hunting lands, which became depleted by livestock grazing and larger farming operations. Interactions with Mormon settlers increased so that by the 1870s the majority of Southern Paiute had direct contact with Euro-Americans, with some settling near Mormon communities (Kelly and Fowler 1986).

Expansion of Euro-American settlement led to increasing hostilities. In 1873, an executive order was issued setting aside 3,900 square miles (10,101 square kilometers) to form the Moapa River Reservation. The reservation was expanded in 1874 then sharply reduced to 1.5 square miles (2.4 square kilometers) in 1875 to accommodate complaints from white settlers within the reservation lands. In 1982, the reservation was increased to its present size of 112 square miles (180 square kilometers) after a petition to congress from the Moapa Band of the Paiute (Ezzo and Majewski 1996; Inter-Tribal Council of Nevada 1976).

In 1951, the Southern Paiute filed a claim with the Indian Claims Commission, which was resolved in 1965 with a monetary settlement (Inter-Tribal Council of Nevada 1976). Portions of the money from the settlement were invested in improvements to the reservation's business enterprises. In 2011, there were 287 enrolled Tribal members with approximately 180 members living on the reservation. The total population was estimated at 425 residents (http://www.xeri.com/Moapa/moapa.htm). The Southern Paiute have persevered over the years in the face of many obstacles and hardships associated with Euro-American occupation and settlement of the area and are actively working to preserve their heritage in publications detailing their history and culture (Alley 1986; Ezzo and Majewski 1996).

Knowledge Gaps and Management Implications

Knowledge gaps concerning southern Nevada's past, as derived from the archeological record, result from several sources. Chief among them are the extent of archeological survey coverage (the most common means of identifying cultural resources) and the nature of archeological survey itself. Approximately 783,756 acres (317,174.8 hectares) or 7 percent of the lands under consideration have been surveyed for archeological resources (de Dufour, personal communication; fig.8.1). Thus, a large portion of the area has received no coverage. Because Federal agencies are required to assess the effects of their ground-disturbing activities on cultural resources[1], much of this survey coverage is on Federal lands, which may bias the time period, nature, and types of remains found. Managers must always take these regulations into consideration when planning ground-disturbing projects.

Because of the sparse nature of archeological survey coverage, basic inventories of cultural resources are needed. In particular, inventories that are not associated with planned development projects are desirable to expand surveyed lands and address gaps in coverage. Complete coverage of the public lands in the study area is not a realistic goal because SNAP offices manage over 7 million acres. That is a huge area to meet the "complete survey" expectation, which would require over 500 man-years to survey with 30-meter transects at 2-miles per hour (Ronning, personal communication 2012a). In addition, cultural resource recording standards, as well as the sites themselves, will continue to change over time. A more realistic goal for regional-scale inventory would be to expand and improve the sample of lands that have been examined and sites that have been located and recorded. Landscapes could provide context for apportioning the available survey effort, which should be partially based on measuring the redundancy in information collected on cultural resources from particular environmental zones. Because cultural resources represent finite, non-renewable resources that must be protected for the future, an important goal of inventory is to provide baseline information for measuring changes in the condition of sites through time (Lancaster and others 2006).

In addition to the basic need for greater survey coverage, several studies have identified both specific and more general information gaps and have provided recommendations for addressing them. A major recommendation from the working group on the Information and State-of-the-Science Summary developed for the Ecosystem Health Assessment of Southern Nevada Project (Lancaster and others 2006) was to prepare a new Historic Context for the region that would provide current information on cultural groups and chronologies, occupational sequences, settlement patterns, and resource use through time. Such a Historic Context would structure and promote research important to southern Nevada agencies (Lancaster and others 2006). This document has been prepared in draft form, and is used in this review (Roberts and Ahlstrom 2012a).

Other general recommendations from the working group include compiling region-wide data sets featuring both survey and excavation data. This data base would also include layers suitable for GIS with information on plant communities, springs, surface geology, soils, and other pertinent resource information reflective of the close association between archeological sites and their environmental surroundings. It is planned that the Nevada Cultural Resource Inventory System (NVCRIS) will meet this function. This

[1] Section 106 of the National Historic Preservation Act of 1966 (NHPA) requires Federal agencies to take into account the effects of their undertakings on historic properties, and afford the Advisory Council on Historic Preservation (ACHP) a reasonable opportunity to comment. The historic preservation review process mandated by Section 106 is outlined in regulations issued by ACHP. Revised regulations, "Protection of Historic Properties" (36 CFR Part 800), became effective January 11, 2001.

project is managed by the Nevada State Historic Preservation Office (SHPO), which is in the process of compiling the data from the Cultural Resource Management (CRM) records. The work is funded by the Preserve America project with money provided by the Southern Nevada Public Land Management Act (SNPLMA) project (Ronning, personal communication 2012b). The working group also recommended producing "finder's guides" to identify locations of existing collections of materials and records to assist researchers in locating available information on the region's cultural resources. Another suggestion was to foster interdisciplinary studies of past environments and encourage interaction among archeologists, paleoenvironmentalists, and those who analyze biological specimens from archeological contexts (Lancaster and others 2006).

More detailed discussions of needed research are found in the draft Prehistoric Context for Southern Nevada (Roberts and Ahlstrom 2012a). The Context presents research themes focusing on chronology, settlement patterns/systems, subsistence, technology, contacts and exchange, the magico-religious realm, and archeological cultures and ethnicity (Roberts and others 2012). Each topic is discussed by time period—Paleoarchaic and Archaic, Puebloan, and Post-Puebloan—with data requirements presented for each theme by time period.

In another chapter, Roberts and Ahlstrom (2012b) review various data gaps in southern Nevada archeology and suggest detailed data recovery and analytic methods to obtain the maximum information possible. They review a broad range of research questions including effects of climate changes, identification of non-diagnostic lithic scatters, and the need for greater emphasis on subsistence studies in the core Virgin Branch area, etc. The authors also recommend methods for survey, testing, and excavation, including backhoe trenching, where appropriate, to identify buried features. In order to locate deeply buried Paleo-Indian and Archaic sites during intensive surveys, examination of the geomorphological characteristics of the study areas before fieldwork begins to explore the possibility of completely buried sites is suggested (Eckerle and others 2011). They also suggest more extensive test excavations when there is a potential for intact buried deposits (Wintch 2011). Taking advantage of analytic techniques such as radiocarbon dating of perishables like baskets and sandals and recovering DNA samples from agave quids and coprolites (fossilized feces) is discussed. Such techniques can be applied to both recently discovered and curated items (Roberts and Ahlstrom 2012b).

The most common data recovery technique on Federal lands is still the archeological survey. By their nature, archeological surveys locate surface remains, although additional information may lie buried beneath the surface. Cultural resource sites may be missed because they are difficult to identify from the surface. Sites from the earlier time periods in particular, such as Paleo-Indian, Middle Archaic, and Late Archaic, can be difficult to find because there are fewer of them, they are generally smaller, and may be buried more deeply. The commonly found surface lithic scatters, often produced by nomadic hunting and foraging groups but also produced by more sedentary peoples, can be notoriously difficult to date or assign to a particular cultural group if no diagnostic projectile points or potsherds are present. Managers in the area must take the limitations of archeological surveys into consideration when planning ground-disturbing projects to ensure that all sites are protected and free from damage as required, or that potential damage is mitigated by data recovery as mandated under the Federal regulations of Section 106[1].

Interpretive scenarios must also take into account the ongoing possibility that discovery of previously unknown resources will alter time lines and chronological schemes. The previously discussed recommendations made in the Draft Prehistoric Context for Southern Nevada (Roberts and Ahlstrom 2012a) address these issues and make recommendations to assist managers in dealing with the difficulties inherent in interpreting the archeological record.

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Chapter 9

Preserving Heritage Resources Through Responsible Use of Southern Nevada's Lands

Carol B. Raish

Introduction

Southern Nevada's cultural resources (heritage resources) include archeological remains, sacred sites, historic sites, and cultural landscapes of significance to Native Americans and many other groups. Locating, maintaining, and protecting these special places are part of the mandate of Nevada's Federal and state agencies. This chapter addresses Sub-goal 2.2 in the SNAP Science Research Strategy, which is to preserve these resources through responsible use of southern Nevada's lands (table 1.3; Turner and others 2009). It explores non-destructive means of identifying, recording, and protecting cultural resources. Cultural resources at risk, risk factors, and needed measures to protect them are discussed, with a focus on non-destructive preservation and protection measures. Selected methods of non-destructive identification, recording, and analysis of sub-surface remains are also reviewed.

Cultural Resources at Risk

Nevada is one of the fastest growing states in the country. According to the 2010 U.S. Census, the population grew by 35 percent since 2000 and by 66 percent the previous decade. Nevada is the only state that has maintained a growth rate of 25 percent or greater for the last three decades (www.census.gov/prod/cen2010/briefs/c2010br-01.pdf). In southern Nevada, the population of Clark County (1,951,269) grew by 42 percent from 2000 to 2010. In-migration from other states has contributed strongly to these growth patterns, with newcomers often having little knowledge of the role and importance of the state's history. These population growth trends have considerable influence on how the state preserves its past (NVSHPO 2004, 2012).

Agency reports identify both natural and human-caused threats to heritage sites (USDI BLM 2000: 5-7):

- Increasing visitation,
- Increasing use of public lands for permitted projects,
- Insufficient staffing and funding for cultural resource programs and law enforcement,
- Looting and vandalism, and
- Urban sprawl and development.

Urban growth and development in and surrounding southern Nevada cities impact the heritage resources in the area. Development can lead to resource destruction as construction increases and homes and businesses are built on previously undeveloped lands. In addition, urban growth has increased recreation pressure on public lands. According to the Nevada Comprehensive Preservation Plan (NCPP) (NVSHPO 2004, 2012), increased pressure on resources from urban growth, recreation, and the use of all-terrain vehicles (ATVs) has resulted in increased vandalism and illegal looting (collecting artifacts and/or excavating on an archeological site without a permit) on previously remote and inaccessible sites.

As one senior Bureau of Land Management (BLM) official noted: "BLM has complete regulatory ability to control the impacts on cultural resources of its permit applicants; however the greatest threat to cultural resources today is coming from the rapid increase in recreational access, with essentially no regulatory control, or enforcement capacity in place to deal with growing impacts" (Jarvis 2006: 7). Another official indicated that increasing visitation to public lands is resulting in both intentional and unintentional damage from collection, vandalism, and surface disturbance. "Remote areas, once protected by their distance from populated areas, are now within easy reach of the hardy and well-equipped hiker, off-highway vehicle user, and urban and suburban resident" (Jarvis 2006: 27).

Adding to the problem is the fact that law enforcement officers and cultural resource staff are unable to monitor activity on all the archeological and historical sites across the vast landholdings of the Federal agencies. A report describing Federal agency site protection efforts (Swain 2007) describes the approximate ratio of acres per agency law enforcement officer. The figures are for the BLM, U.S. Forest Service (FS), National Park Service (NPS), and U.S. Fish and Wildlife Service (FWS). While this ratio varies within subunits of the agencies, it serves to indicate the degree of police presence on the public lands. Each of the four agencies employs professional cultural resources management staff and Law Enforcement Officers (LEOs). These professionals have a wide range of tasks, which ultimately result in a relatively small percentage of time in the field visiting or monitoring archeological sites. The BLM and FS manage about 455,000,000 acres (184,131,967.22 hectares) between them but have only one LEO per 1,000,000 acres (404,685.64 hectares). The NPS manages ca. 84,000,000 acres (33,993,593.95 hectares) with one LEO for every 56,000 acres (22,662.40 hectares) and the FWS has 93,000,000 acres (37,635,764.73 hectares) with one LEO for every 104,000 acres (42,087.31 hectares; Swain 2007).

Although the exact level of enforcement that would be needed to reduce looting and vandalism across the Federal landscape is uncertain, a project from Joshua Tree National Park, located in the Mojave Desert to the east of Los Angeles, sheds light on the topic. During 1993, the park received special archeological protection funding for the systematic monitoring of cultural sites. A long-term volunteer with extensive knowledge of the park and its archeological sites was hired to conduct the monitoring. The site monitor spent each workday visiting archeological sites and documenting their condition. He visited sites near front country campgrounds as well as sites 5 or more miles from the nearest road. After 1993, the Park received no additional funds for site monitoring (Swain 2007).

From 1985 to 2005, excluding 1992 and 1993, an average of 9.6 looting incidents per year was documented. By contrast, in 1992 and 1993, the average number of documented incidents per year was 101. Over 200 Archaeological Resources Protection Act (ARPA) violations were documented during 1993 alone. The data from Joshua Tree National Park tend to show that only a very small percentage of the looting activity on the public lands is actually discovered and documented during any given year (Swain 2007). Intensive monitoring can lead to a much higher discovery rate, with presumed positive impacts for site protection. The visibility of regular monitoring and LEO presence also can serve as a deterrent to looting and vandalism (McAllister, personal communication 2012).

"Threats to archaeological and historical sites (are not) confined to looting and vandalism, as recreational activities, urban sprawl, overuse and natural erosion are increasingly taking their toll on our Nation's irreplaceable treasures" (USDI BLM 2000: 4). Historic structures, both in the cores of urban areas and in rural areas with severely declining populations are also at risk from destruction by development and lack of funding for maintenance and restoration. Some structures also have been destroyed by arson (NVSHPO 2004, 2012).

Cultural Resource Protection Measures and Organizations

Federal agencies in southern Nevada use and recommend a number of measures to assist in protecting heritage resources (Jarvis 2006: 27-28). Chief among them are the following:

- Public education and outreach programs.
- Cultural resource site monitoring.
- Law enforcement for cultural resources.

Public Education and Outreach

Public education and outreach efforts range from preparing sites and structures to receive visitors with trails, signage, and other protection measures such as fencing, to active public involvement programs like Passport in Time operated by the FS (USDA FS 2011). Rapidly increasing recreational access requires public education concerning the importance and fragility of archeological and historic sites. Cultural resource professionals express enthusiasm for the positive effects of their education programs on recreational users, believing that education will reduce potential negative impacts of increasing visitation to public lands. Many feel most of the inadvertent damage to resources could be averted by various current education programs. There is the belief that when the public is made aware of the fragility and uniqueness of these resources, they will be careful not to damage them (Jarvis 2006). Some of the most successful programs involve public participation, like Passport in Time, but they reach a more limited audience. Brochures and information kiosks can also be effective teaching tools by reaching a wider audience. They are especially effective when they are attractive, current, and appropriately placed near the resource in question.

BLM uses two non-profit partners—Tread Lightly, Inc. and the Leave No Trace Center for Outdoor Ethics, Inc.—to educate visitors concerning proper treatment of cultural resources, as well as the public lands in general (Jarvis 2006). However, many southern Nevada BLM managers think that there is insufficient funding to support education programs and direct protections like closing roads and trails, building enclosures and fences with gates, and other physical barriers to prevent site damage (Jarvis 2006).

Several agencies have long-running, successful, national public involvement programs. These include Passport in Time Program (USDA FS 2011), Adventures in the Past, which includes Project Archaeology (USDI BLM 2011), and a relatively new Geotourism Partnership project (USDI FWS 2008). The National Park Service (NPS) has a long history of both cultural and environmental education efforts. As examples of these efforts, the U.S. Forest Service, Passport in Time Program (PIT) pairs professional agency archeologists and historians with volunteers on national forests throughout the country. PIT projects include archeological survey, excavation, rock art recording and restoration, archival research, oral history gathering, and many others (USDA FS 2011).

Project Archaeology, a part of Adventures in the Past, is a national education program for teachers of upper elementary and mid-school students that trains the teachers and provides curriculum materials for teaching the students to value and care for their archeological and historic heritage (USDI BLM 2011). These education programs attract a substantial number of volunteers and are very favorably received. Several agencies also have participated in the Preserve America Grant program administered by the NPS (Advisory Council on Historic Preservation), which provides matching grants to support preservation efforts through heritage tourism, education, and historic preservation planning. However, the Preserve America Grants were not funded for 2011 and funding for 2012 is uncertain (USDI NPS 2011a).

A Nevada-specific program, Preserve Nevada, is a non-profit organization dedicated to preservation of the state's cultural, historic, and archeological heritage. The Board of Directors is selected from different parts of the state and is designed to bring the perspective of a committed and experienced group of preservationists to the task of meeting the special needs of Nevada's resources. Preserve Nevada works with the Public History program at the University of Nevada, Las Vegas, and provides the opportunity for graduate students to gain experience and training by working closely with the Board of Directors on many of the organization's projects. The students meet with National Trust leaders, represent the organization at a variety of functions, and work with both state and local governments on planning and development issues. This work provides the students with experience and contacts for their future careers in preservation. The Preserve Nevada project builds bridges between the community and the university, between education and advocacy, and between methods and practices, training a new generation of preservation professionals (NVSHPO 2011).

It should be noted that the Nevada Comprehensive Preservation Plan (NCPP) (NVSHPO 2004) also recommends the use of college interns to assist the Nevada State Historic Preservation Office (NVSHPO) and Federal staffs in archeological, architectural, and historic surveys and in preparing National Register nominations.

Other examples of creative outreach and education programs come from Lake Mead National Recreation Area, which has an active education and interpretive program featuring educational programs, field trips, and volunteer experiences. Education programs include not only cultural resource activities but also activities from other science programs for students and teachers. There is a Hispanic outreach program and a Hispanic community partnership program involving all the SNAP agencies, such as the BLM, FS, FWS, and, of course, NPS. There are also Professional Development Education opportunities that have been developed by the SNAP Education Staff for teachers. Some specific examples of historic and cultural programs for students include "Hiking Through History" focusing on Hoover Dam and the U.S. Government Railroad and "Puzzle Pieces of the Past" focusing on archeological sites and artifacts (Rowland, personal communication 2012).

The NPS Submerged Resources Center in Denver has worked at Lake Mead in cooperation with the Woods Hole Oceanographic Institution filming underwater archeological sites in the lake. These include an airplane that crashed into the lake and infrastructure related to the construction of Hoover Dam. These are used in a program to teach children not only about the submerged archeology of the lake but also about other issues related to the lake such as water monitoring and problems with the invasive quagga mussel (Seeb, personal communication 2012).

Cultural Resource Site Monitoring

Monitoring the condition of heritage resources is an important part of agency responsibilities to their lands. Unfortunately, there is rarely sufficient staff to undertake comprehensive site monitoring on a realistic scale and time frame, as mentioned previously (Swain 2007); volunteers are often used to meet this need. In its comprehensive plan, the NVSHPO recommended establishment of a site stewardship program to accommodate the public's desire to become involved in historic preservation activities and to take into consideration the small size of state and Federal heritage and preservation staffs and budgets (NVSHPO 2004).

In 2004, the Southern Nevada Agency Partnership (SNAP) Interagency Cultural Site Stewardship Team created the SNAP Cultural Site Stewardship Program (CSSP). Partners in the SNAP CSSP include NPS, BLM, FWS, FS, and U.S. Bureau of Reclamation (USBR), Nevada Department of Cultural Affairs (NDCA), Lost City Museum (LCM), and Nevada State Historic Preservation Office. The program is managed under a cooperative agreement with the University of Nevada-Las Vegas, Public Lands Institute (UNLV-PLI). The UNLV-PLI Program Manager provides a variety of services including recruitment of volunteer site stewards, standardized training, reporting of monitoring results to the appropriate Federal agency, and public outreach. The program is composed of volunteers who serve as site stewards to monitor at-risk sites for natural or man-made damage, which is reported to the responsible land manager (USDI NPS 2007).

The volunteer site stewards participate in training sessions and monitor their assigned sites at least four times per year. To date, over 540 volunteer site stewards have been trained. They have donated over 16,100 volunteer hours and driven over 212,000 miles. Stewards have reported over 645 significant impacts that have resulted in criminal investigations, and have informed management actions including closing of unapproved roads, development of a Road Designation Plan, and removal of graffiti from rock art sites. The program has been very successful and has received several awards including the 2007 U.S. Department of the Interior Cooperative Conservation Award, Certificate of Commendation from Senator Harry Reid, and the Preserve America Steward Award from First Lady Michelle Obama in 2010 (Phillips 2011).

Effective site monitoring should include frequent site inspections that are apparent to site visitors and are undertaken by well-trained and enthusiastic volunteers, who are adequately supervised by agency staff (Livingston and others 2005). As discussed in the Sloan Canyon Plan (Livingston and others 2005), since agencies depend upon volunteers to accomplish the monitoring, they are faced with the problem of administering volunteers who have few sanctions to correct inappropriate behavior. The vast majority do an outstanding job, while a few do not. The plan also points out that site monitors themselves should be monitored by agency staff because stewardship programs can provide a good cover for looters and a place to discover previously unknown information on site locations. Despite these cautions, the majority of site stewards do an enthusiastic and valuable job of extending the "eyes and ears" of Federal staff to protect fragile heritage resources.

Law Enforcement for Cultural Resources

Federal agency law enforcement plays an important role in protecting archeological and historic remains from looting and vandalism. However, Federal heritage resource professionals believe that there are far too few agency LEOs (Swain 2007; USDI FWS 2008). Agencies work with other law enforcement partners, such as other Federal enforcement agencies, state and local police, and sheriff's departments, to augment their numbers, although many local police and sheriff's departments are not trained in ARPA enforcement. In general, most law enforcement personnel from the Federal agencies have basic ARPA training (McGaha, personal communication 2012), as recommended by Swain (2007).

There have been various successful ARPA prosecutions in recent years that have increased awareness of the problem of looting on archeological sites. BLM enforcement personnel have had some highly publicized and successful enforcement actions taken against organized thieves stealing archeological artifacts from public lands (Jarvis 2006: 28). The USFS has successfully prosecuted an ARPA case resulting in replacement of a petroglyph to its original location. The NPS had a successful prosecution of a man sentenced to time in Federal prison and ordered to pay restitution for defacing petroglyphs with paintballs in the Grapevine Canyon area of Lake Mead National Recreation Area. "This sentence comes as a result of the hard work of park rangers, special agents of the National Park Service Investigative Services Bureau and the U.S. Attorney's Office. We are pleased with the result," said Bill Dickinson, superintendent of Lake Mead National Recreation Area. "What's important about this case is that it started with a visitor calling 911 to report the illegal activity" (USDI NPS 2011b). Despite such successes, there are still too few law enforcement officers to protect the cultural resources on the extensive public lands of the state (USDI FWS 2008). As discussed in a BLM report on Cultural Resources on Public Lands (Jarvis 2006: 28): "For every criminal caught in an ARPA (Archaeological Resources Protection Act) violation, it is believed that many more violations go un-discovered, much less un-prosecuted."

In addition, as public access and criminal activity increase on public land, LEOs are spread even more thinly. Law enforcement priorities are now being focused on drug interdiction, homeland security issues, and control of undocumented immigrants (Jarvis 2006). To assist in closing the gap, Federal land managers have not only turned to volunteers but some are developing and using remote protection technology such as concealed video surveillance cameras, especially in remote areas that appear to be secluded and may lead thieves to feel that they will not be detected (Livingston and others 2005; USDI FWS 2008).

Non-Destructive Techniques for Identifying, Recording, and Analyzing Archeological and Historic Remains

Standard non-collection archeological survey remains the preeminent technique used to identify surface remains and features. These techniques are well documented and will not be reviewed in this discussion. The focus here will be on select geophysical surveying systems that non-invasively and non-destructively map subsurface features. The following techniques are presented:

- Ground penetrating radar (GPR)
- Magnetometry
- Soil resistivity

These techniques are useful where excavation is undesirable, too costly, or otherwise not possible. They can assist managers in determining which areas to avoid during construction or other land-disturbing activities and which areas may require additional testing or excavation. Non-invasive methods do not destroy the archeological record as it is investigated, but they do require special equipment and training and can be costly (Archeology Mapping: http://www.archeologymapping.com 6-2-2011; Shott 1996). In addition, the land coverage rate is low owing to the nature of the methods and the time needed to implement them. Thus, they are mainly practical at small scales and are not cost-effective in replacing standard archeological survey techniques. They are better for defining features within known archeological sites than conducting large-scale surveys. Natural variations in soil texture, moisture, and soil inclusions affect the efficacy and reliability of these techniques. Because they record archeological features as anomalies against the background soil, they must be recalibrated for each set of local soil conditions (Bevan 1996; Shott 1996).

Ground Penetrating Radar (GPR)

GPR is a geophysical method that uses radar pulses to image the subsurface, generating cross-sectional views of underground features. GPR is able to detect a wider variety of buried materials than other geophysical instruments. It can detect metal, wood, stone, brick, and air-filled voids and is suitable for locating lenses of debris as well as refilled pits and ditches (Bevan 1996). As such, the technique has been used to locate graves, occupation surfaces, walls, floors, and foundations. The technique works best in sandy, weakly stratified soil or soil with horizontal strata. If the soil is clayey or is saline, the depth of penetration is so low or shallow that the technique is not useful. The radar antenna operates best when close to the ground, so areas with considerable brush or boulders are more difficult to survey (Bevan 1996).

As an example of GPR use, a study was conducted in southern Utah to examine the buried remains of religious/ceremonial architecture in one valley (Conyers 2009). The investigator thought that large circular depressions might be the remains of large kivas (ceremonial structures), indicating a connection to the influential Chacoan area to the south. The GPR analysis of the features showed that they were small, family-sized kivas with associated roomblocks, which did not support strong connections to Chaco Canyon. The study's author states that the GPR analysis allowed placement of the structures within the landscape context of their local valley, facilitating the examination of prehistoric social context and inter-regional interaction without excavation (Conyers 2009).

Magnetometry

Magnetic surveying, or magnetometry, is one of the most popular of the geophysical methods used for rapid, non-destructive assessment of subsurface features. Magnetometry provides archeological information because various human activities can alter the local magnetic content of the soil. Every type of material has singular magnetic properties, even those that are not commonly viewed as magnetic. Distinct subsurface materials can cause local disturbances in the earth's magnetic field, which are then detectable with magnetometers. The main limitation of the technique is that subtle features of interest may be obscured by highly magnetic geological or modern materials, such as iron. The technique is not affected by soil moisture or temperature. The only climatic problem is the decreased performance of batteries in very cold weather (Weymouth 1996).

Magnetic surveys are especially useful for locating ferrous materials; fired materials such as brick, roof tiles, kilns, hearths, and burned daub; middens, pits, trenches, activity areas, and graves. The technique also is able to locate structural features including walls, floor surfaces, and foundations (Archeology Mapping: http://www.archeologymapping.com 6-2-2011).

A large-scale magnetometer survey in Germany mapped subsurface features dating to the period from 7500-6900 BP (5550-4950 BC) representing longhouses (Posselt 2002). The maps produced from the survey showed considerable fine detail including postholes and small ditches related to the wood and plaster walls. This type of detail can be used to target future excavations or reduce the need for and/or the extent of excavations (Posselt 2002).

Soil Resistivity

Soil resistivity survey, or resistivity survey, has grown in use since it was first introduced for archeological work in the mid-1940s in England. The technique can be used to locate compacted surfaces; graves; trails and pathways; structural features such as walls, floor surfaces, and foundations; and differences in soil compaction (Archeology Mapping: http://www.archeologymapping.com 6-2-2011; Gaffney 1996). Problems with the technique include the fact that archeological features may be masked by later activity at the site and some agricultural activities such as plowing may increase "soil noise" to the point that anomalies produced by buried features are not recognized (Gaffney 1996).

In most systems, metal probes (electrodes) are inserted into the ground to obtain readings of local electrical resistance. Most systems use four probes mounted on a rigid frame. Soil resistance is affected by the presence of subsurface features that are higher or lower in resistivity than the surrounding soil. The patterns of soil resistance are recorded, plotted, and interpreted. Information from resistivity survey is often used to complement other geophysical methods, such as magnetometer surveys. Areas of beach on Rapa Nui (Easter Island) were successfully examined using this type of combined technique to locate subsurface features associated with the island's large ceremonial platform and statues (Larson and others 2003).

Knowledge Gaps and Management Implications

Southern Nevada's heritage resources are at risk from a variety of factors including large-scale urban development and sprawl, as well as increased recreation use and access to previously remote, undisturbed areas. The Federal agencies that manage these vast acreages and irreplaceable resources remain understaffed and underfunded resulting in substantial management challenges. Nonetheless, they have implemented public education and outreach projects, volunteer site monitoring efforts, and law enforcement programs in attempts to protect the areas at risk. Continued research is needed to assess the effectiveness of these programs and develop additional means of cultural resource protection that can be implemented with limited funding (Lancaster and others 2006, 2007).

When implementing projects, managers must address issues associated with protection and preservation of known sites as well as identifying and protecting any newly discovered sites. There are significant knowledge gaps relating to southern Nevada's past, as derived from the archeological record. Only 783,756 acres (317,174.8 hectares), or 7 percent of the lands under consideration, have been surveyed for archeological resources (fig.8.1). Thus, a large portion of the area has received no survey coverage.

Because of the sparse nature of archeological survey coverage, basic inventories of cultural resources are needed. In particular, inventories that are not associated with planned development projects are desirable to expand the acres of surveyed lands and address gaps in coverage. Complete coverage of the public lands in the study area is not a realistic goal owing to the cost involved and because SNAP offices manage over 7 million acres (2,832,799 hectares), a huge area to meet the "complete survey" expectation. That would be over 500 man-years to survey with 30-meter (32.8 yard) transects at 2 miles (3.22 kilometers) per hour (Ronning, personal communication 2012). In addition, cultural resource recording standards, as well as the sites themselves, will continue to change over time. A more realistic goal for regional-scale inventory would be to expand and improve the sample of lands that have been examined and of sites that have been located and recorded. Because cultural resources represent finite, non-renewable resources that must be protected for the future, an important goal of inventory is to provide baseline information for measuring changes in the condition of sites through time (Lancaster and others 2006, 2007).

By its nature, archeological survey locates surface remains, while additional information may lie buried beneath the surface. The geophysical surveying systems discussed in this chapter may prove useful in augmenting cultural resource information and assisting managers in determining which areas to avoid during construction or other land-disturbing activities and which areas may require additional testing or excavation. However, these methods are limited in applicability and do not replace standard archeological surveys.

A major recommendation from the working group on the Information and State-of-the-Science Summary developed for the Ecosystem Health Assessment of Southern Nevada Project was to prepare a new Historic Context for the region to structure and promote research important to the agencies (Lancaster and others 2006). Such a context has been prepared in draft form (Roberts and Ahlstrom 2012).

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Chapter 10

Recreation Use on Federal Lands in Southern Nevada

Alice M. McSweeney

Introduction

Providing for appropriate, diverse, and high quality recreational use of southern Nevada's lands and ensuring responsible visitor use is an ongoing challenge for the Federal agencies that manage the majority of the area (fig. 1.1). Over 87 percent (61,548,000 acres out of Nevada's 70,275,000) of Nevada's lands are administered by the Federal government, which is the highest percentage in the nation (DeLoney 2004). Some of the largest values are for the counties of southern Nevada. The amount of Federal land in Clark, Lincoln, and Nye Counties estimated from the Nevada State Library and Archives in 2000 was 89.4 percent; 98.2 percent; and 92.4 percent respectively (http://nsla.nevadaculture.org/index.php). This chapter addresses Sub-goal 2.4 in the SNAP Science Research Strategy which focuses on recreation use on Federal lands in southern Nevada (table 1.3; Turner and others 2009). The demands for various types of recreational opportunities are discussed and the ways in which Federal agencies can provide quality recreational experiences without compromising resources are explored. Also discussed are current visitor use patterns and services provided by the designated recreation areas in southern Nevada.

Nevada's Population

There is a correlation between population growth and an increase in outdoor recreation. The rapidly growing population of southern Nevada results in an increase in recreational demands on the area's public lands, and an associated shift in demographics brings changes in recreation tastes and preferences.

Two significant factors influence recreationists and the natural resource base that supports outdoor recreation in Nevada. One is the fact that the State of Nevada ranks first in Federal lands; and the second is the highly urbanized population of the state, in which 94 percent resided in urban areas in 2000 (DeLoney 2004). According to the 2010 U.S. Census, the population of Nevada (2,700,551) grew by 35.1 percent since 2000. Nevada is the only state that has maintained a growth rate of 25.0 percent or greater for the last three decades and, until the recent economic downturn, was the fastest-growing state for five straight decades (U.S. Census Bureau 2011a). In southern Nevada, the population of Clark County (1,951,269) grew by 41.8 percent since the 2000 Census. The city of Las Vegas (population 583,756) grew by 22.0 percent; Henderson (population 257,729) grew by 47.0 percent; and North Las Vegas (population 216,961) grew by 87.9 percent since 2000 (U.S. Census Bureau 2011b).

Nevada's population is heavily concentrated in metropolitan counties and, while population growth has been significant across the state, population increases in Clark County far exceed those in other areas. Over 1.9 million people, or more than 72 percent of Nevada's 2.7 million residents, live in Clark County. In addition, the state's minority population has grown rapidly from 16.8 percent in 1980 to 45.8 percent in 2010. Growth of the Hispanic population has been especially rapid in Nevada. In 2010, 26.5 percent of the state's residents were of Hispanic origin (WRDC 2011). The highest proportion of Hispanics (29.1 percent) resides in Clark County, which also has significant Black (10.5 percent) and Asian (8.7 percent) populations. Over 22 percent of Clark County residents are foreign born and 32.1 percent of persons above the age of 5 years speak a language other than English at home (U.S. Census Bureau 2012). The Clark County School District, 5th largest in the nation (Sable and others 2010) has a racial/ethnic distribution of 41% Hispanic, 14.1% Black, 34.6% White, 9.6% Asian, and 0.7% Native American. Just over 18% of students have limited English proficiency (CCSD 2010). The increasing demographic diversity of southern Nevada can lead to difficulties in educating a diverse urban population about recreational issues.

Outdoor Recreation Issues

The 2003 Statewide Comprehensive Outdoor Recreation Plan (SCORP) developed by the Nevada Division of State Parks (NDSP) is Nevada's 8th edition of such a plan since the passage of the Federal Land and Water Conservation Fund Act of 1965. The plan provides review and study of recreational use within the State and presents the expectations of Nevadans regarding outdoor recreation. The plan's goal is to increase and improve the quality of outdoor recreation opportunities to meet the needs of the citizens of Nevada as well as the State's many visitors. SCORP identifies the top outdoor recreational issues facing Nevada and recommends actions to address each issue (DeLoney 2004).

The issues and recommendations reflect results of participant responses from a public input process through a mail-in survey titled "Nevadans Outdoors – a Survey on Outdoor Recreation in Nevada." A function of the plan is to provide information and recommendations that will minimize uncertainty in the decision making process of allocating outdoor resources. The dominant concern of the respondents was to keep Federal lands open for a wide variety of outdoor recreation activities while protecting the state's natural resources. According to the SCORP study, Nevadans understand the necessity of balancing recreational use with natural resource conservation (DeLoney 2004).

The eight top recreation issues derived from the SCORP study are (1) public access to public lands for diverse outdoor recreation, (2) funding parks and recreation, (3) providing recreational trails and pathways, (4) balancing the protection of Nevada's natural, cultural, and scenic resources with user demands, (5) protecting water resources as vital components of Nevada's recreational base, (6) interpretation and education of outdoor recreation opportunities, (7) increasing demand from Nevada's growing population on outdoor recreation resources and suppliers, and (8) coordination and cooperation among recreation providers (DeLoney 2004).

The following expanded discussion of the issues is drawn from participant responses in the 2003 SCORP report. Keeping Nevada's abundant open space accessible was ranked as the most pressing issue. The growing need to protect, maintain, and increase public access to public lands in Nevada reflects a demographic population growth and reduction of open space nation-wide. Development, particularly in the urban interface, was cited as a major threat to public land access (DeLoney 2004).

Issue number two states that existing levels of funding for outdoor recreation are inadequate to meet the needs of Nevada. As noted by participants, maintenance of outdoor recreation areas and facilities (Federal, state, and local) has not kept pace with demands created by a rapidly growing population and increasing numbers of out-of-state visitors (DeLoney 2004).

The third issue calls for provision of recreation trails and pathways throughout Nevada's rural and urban areas. As with other issues, population increase is a major factor; the promotion of recreation-based tourism adds to the demand. Connectivity is important for recreational trails and for transportation needs in urban areas such as in Clark County. This requires cooperation between agencies when trails are to cross through differing jurisdictions (DeLoney 2004).

Respondents emphasized in the fourth issue that responsible use is essential to conserve the natural resources that make areas attractive to recreationists. Public education and active law enforcement were cited as means of protecting valuable resources. "There is no such thing as non-consumptive outdoor recreation activity…The degree of consumption is dependent on the outdoor recreational activity and the outdoor recreationist engaged in the activity" (DeLoney 2004: 26).

Water resources, listed as fifth, must be protected to maintain the quantity, quality, and accessibility needed for public recreation. However, recreational use of water often competes with other uses such as water for human and municipal consumption or for agricultural use. Another consideration is the fact that wildlife also depend on the limited water resources (DeLoney 2004).

The sixth issue involves provision for environmental, cultural, and heritage interpretation and educational programs. Suggestions include:

1. Educate the general population, the youth of the state, new residents, and visitors about natural resources and outdoor recreation activities;
2. Provide information that allows families to make safer choices concerning their outdoor recreation plans; and
3. Provide greater accessibility for those with impairments (DeLoney 2004).

As Nevada's multi-cultural population continues to expand, there is an issue of greater recreational demands on resources and suppliers. With an increasing number of recreationists, there is a change in the types of interests they choose to pursue. There is a shift from "the old traditional" uses of hunting, fishing, and camping to such activities as off road vehicle use and rock climbing. There are also changes in visitor types to a more urban population who expect recreation enhancements (toilets, developed campsites, brochures, and site interpretation). These increasing recreation demands require funding, planning, and staffing. At the same time, consideration must be given to reducing the added impacts to natural resources (DeLoney 2004).

Coordination and cooperation between public and private recreation providers was the final issue discussed in the SCORP study. There is concern that various recreation interests are becoming polarized against each other and that lack of cooperation and duplication of effort result in a waste of taxpayers' money. Needs were expressed for more cooperation between agencies and more use of volunteers (DeLoney 2004).

SNAP Interagency Recreation and Wilderness Planning

There are four Federal land management agencies in southern Nevada that oversee eight congressionally designated resource areas. The Bureau of Land Management (BLM) oversees the Red Rock Canyon and Sloan Canyon National Conservation Areas (NCAs) and approximately 3.4 million acres of lands outside of the National Conservation Areas (Reardon, personal communication 2011b). The National Park Service (NPS) administers Lake Mead National Recreation Area (NRA). The United States Forest Service (USFS) manages Spring Mountains National Recreation Area (NRA). The United States Fish and Wildlife Service (USFWS) is responsible for the Desert National Wildlife Refuge Complex, which is comprised of four distinct National Wildlife Refuges (NWRs): Ash Meadows NWR, Desert NWR, Moapa Valley NWR, and Pahranagat NWR (SNAP 2002).

In 2002 the Federal managers of SNAP directed the four agencies (BLM, NPS, USFW, and USFS) to conduct interagency recreation management and to form the Interagency Recreation Team. The team's vision is to provide interagency collaboration in the planning and management of recreational opportunities, facilities, and services while honoring the natural setting and complementing the quality of life in southern Nevada. The team's mission is for agencies to work together and with the surrounding communities to promote natural and cultural resource stewardship by providing appropriate and sustainable recreation opportunities (SNAP 2002).

Accomplishments include completion of the National Visitor Use and Monitoring Survey and an inventory of over 9,000 miles of roads and trails. The survey and inventory will serve as a foundation for Recreation Area Management Plans, which will identify roads and trails on Federal lands, including connections to adjacent urbanized communities. In addition to planning, the Recreation Team is working with the Education Team to provide public information for recreation opportunities on Federal lands through outreach products, including the OHV Adventure Guide and the forthcoming interactive and recreation opportunities maps and non-motorized trail guide (Reardon, personal communication 2011a).

The SNAP Recreation Team initiated recreation visitor sampling on all SNAP lands using a single monitoring program based on the USFS National Visitor Use Monitoring (NVUM) program. Collectively, these NVUM reports provide comprehensive statistics on recreation use, visit characteristics, visitor spending, and the satisfaction of recreationists with recreation opportunities and resource conditions. Although the individual Federal agencies have differing management objectives, this information is useful given the proximity of these lands to each other and the shared potential base of local recreationists and tourists (SNAP 2010).

Nearly 3,000 visitors were surveyed during the 2005-2008 sampling period; data collected were used to assess visitor use of the public lands that comprise SNAP. The 2,896 visitor-completed surveys were fairly evenly distributed throughout the year, representing the full range of seasonal activities available on SNAP lands. Over all, the most popular activities reported were hiking and viewing natural features. There were differences in the popularity of recreation choices across agencies, because management objectives, topography, and recreation resources differ from agency to agency. For example, on BLM lands there was a greater percentage that listed driving for pleasure and rock climbing as primary activities; water-based recreation was most prevalent on NPS lands; viewing wildlife was listed as the primary activity on USFWS lands; while camping was listed as the primary activity on USFS land (SNAP 2010).

Based on the results of the NVUM sampling approach, recreation use on BLM, USFWS and USFS lands during the survey period (2005-2008) amounted to 2.7 million public land visits annually. The National Park Service has a locally developed estimate for recreation use and counted 6,263,530 visits to Lake Mead National Recreation Area in Nevada during 2009. When the NPS locally developed recreation estimate is combined with the estimates for the other agencies, using the NVUM sampling data, recreation use for the SNAP agencies sums to more than 9 million visits (SNAP 2010).

The BLM and NPS manage major land bases in southern Nevada, and account for nearly 90 percent of the area's recreation use. The survey determined that approximately 53 percent of visits are by people who traveled less than 50 miles from home to participate in some form of recreation. More than half of the visits were from Nevada residents. People traveling greater than 500 miles from home made up 25 percent of visits, and slightly over 5 percent were foreign visitors. Recreation visits to SNAP lands generate economic activity (motel/hotel, restaurant, fuel, groceries, etc.) to communities surrounding agency lands (SNAP 2010).

The overall satisfaction rating of the four SNAP agencies indicated that the vast majority of visitors surveyed were at least "somewhat satisfied" with their visit. Individually, the BLM had the highest rating. Visitor satisfaction for each was greatest at developed sites and lowest at undeveloped sites. Satisfaction was consistently lowest overall for services such as information, signage, and employee helpfulness. Areas identified as needing attention included restroom cleanliness, information provided, signage, and trail condition. Over 90 percent of responses indicated a satisfactory perception of safety (SNAP 2010). Informational maps and signage were the items most frequently cited as increasing the perception of safety.

Agencies also are working to develop interagency Wilderness Management Plans. The first interagency Wilderness Management Plan in the nation was completed for the Muddy Mountains Wilderness, which is jointly managed by the BLM and the NPS. Plans for North McCullough, South McCullough, and Wee Thump-Joshua Tree Wilderness Areas have also been completed by the BLM. Planning is underway for other jointly managed areas such as El Dorado, Ireteba Peaks, Spirit Mountain, Pinto Valley, Jimbilnan, Black Canyon, Bridge Canyon, and Nellis Canyon and the remaining six designated Wilderness areas—Mt. Charleston, Rainbow Mountain, La Madre, Jumbo Springs, Lime Canyon, and Arrow Canyon. Additionally, SNAP and the Friends of Nevada Wilderness are working in partnership to establish a Wilderness Steward Program. Wilderness maps with interpretive and educational information are also under development (Holland 2011, personal communication; SNAP 2011a).

Bureau of Land Management (BLM)

Red Rock Canyon National Conservation Area (NCA)—Red Rock Canyon National Conservation Area is located approximately 17 miles west of the Las Vegas strip. It was designated in 1990 to preserve the environmental, cultural, and scenic qualities of the area for present and future generations. Red Rock's dramatic visual attraction is the result of a geologic thrust of grey limestone up and over younger red sandstone, 65 million years ago (USDI BLM 2010a).

The NCA consists of two distinct areas. The northern portion is mostly undeveloped and primitive and includes designated wilderness areas. The southern portion features a 13-mile scenic drive, visitor's center, picnic areas, camp sites, and over 100 miles of trails. The visitor's center contains extensive interpretive exhibits and provides environmental education opportunities. Recreational activities include birding, hiking, horseback riding, and rock climbing. Also available to visitors are informative walks and talks, demonstration programs, and educational series (USDI BLM 2010a).

Red Rock Canyon NCA has three major goals. One is to provide for public enjoyment and visitor experience. This involves visitor safety and satisfaction, while promoting understanding and appreciation of the area. A second goal is the enhancement of appropriate recreational opportunities by improving and expanding the trail system, campground, and other high-use visitor areas. Also considered are the impacts of human activity, removal of public safety hazards, and coordination with other trails and maps within adjacent urban areas. The third goal is the preservation of Red Rock Canyon's resources. This involves ecosystem restoration, landscape rehabilitation, wildlife management, and cultural resource protection. It is expected that proposed fee increases needed to achieve these goals will have a minimal impact on most visitors; social benefits should outweigh the economic costs (USDI BLM 2010a).

Sloan Canyon National Conservation Area (NCA)—Sloan Canyon National Conservation Area was designated by Congress in 2002 to preserve a portion of southern Nevada's Mojave Desert. The Northern McCullough Wilderness is entirely contained within the NCA. Sloan Canyon NCA encompasses 48,438 acres and forms the mountainous southern skyline of the cities of Las Vegas and Henderson. It contains scenic resources, wildlife habitat, and archaeological sites, most notably the Sloan Canyon Petroglyph Site. Sloan Canyon is located approximately 20 miles southeast of the City of Las Vegas and borders the City of Henderson, Nevada. It is situated at the edge of a rapidly urbanizing valley. Residential and business development is expected to border much of the northern and western edges of the Conservation Area (USDI BLM 2009).

Recreation in the form of hiking, mountain biking, equestrian, and illegal off-highway vehicle (OHV) use have become more prevalent in the northern portion of Sloan Canyon NCA as urban growth in the Las Vegas Valley encroaches. The more rugged and isolated southern portion receives limited visitation, primarily cross-country hiking and equestrian use (BLM 2010b). Activities encouraged in the North McCullough Wilderness include hiking, horseback riding, and wildlife observation. Vehicles, including mountain bikes, are prohibited within the Wilderness. (USDI BLM 2010b)

Red Rock Canyon and Sloan Canyon NCAs represent just two of the areas the BLM Southern Nevada District manages that are enjoyed by the public. Although most lands managed by BLM do not contain recreational improvements, hundreds of miles of trails are available for exploration as well as 15 wilderness areas and 22 Areas of Critical Environmental Concern, totaling over one million acres. BLM Public Lands located outside the National Conservation Areas comprise over 3.4 million acres and include popular recreation areas, such as Logandale and Gold Butte, that provide additional recreation opportunities such as OHV riding (Logandale), rock crawling, camping, hiking, hunting, cultural resources, and scenic driving. Other treasured areas include Nellis Dunes and Big Dune for OHV thrill-based recreation (Reardon, personal communication 2011a; Ronning, personal communication 2012).

In order to plan for these varying uses and link with the BLM's 2001 Strategy for Motorized Off-Highway Vehicle Use, the agency is developing a non-motorized Trails Master Plan to meet the needs of hiking, equestrian, and mountain biking groups. The trail network would connect with the trails of Henderson's Open Space and Trails Plan (City of Henderson 2005). The intention is to manage for public use and enjoyment while protecting the NCA's sensitive resources (USDI BLM 2009).

The BLM's 2001 Strategy for Motorized Off-Highway Vehicle Use was an effort to determine and implement management solutions designed to conserve soil, wildlife, water quality, native vegetation, air quality, heritage, and other resources, while providing for appropriate motorized recreational opportunities (USDI BLM 2001). The OHV Guide to Public Lands within Clark County provides users with information on where roads and trails are open to motorized recreation as well as tips on safety, responsible riding, and potential impacts to the environment (SNAP 2011c).

National Park Service (NPS)

Lake Mead National Recreation Area (NRA)—Established as America's first National Recreation Area, Lake Mead NRA was set aside as a unit of the NPS in 1964 to provide recreation for visitors and to preserve the natural and cultural resources of the area. The NRA encompasses over 1.5 million acres of land and includes two man-made lakes. Hoover and Davis Dams backed up the Colorado River as it flows through this extremely arid region and created Lake Mead and Lake Mohave respectively. Open year round, these lakes/reservoirs provide a startling contrast with the surrounding desert ecosystem and are a great attraction to recreationists (USDI NPS 2011a).

The western most portion of Lake Mead is located approximately 30 miles east of the city of Las Vegas at the base of the River Mountains. There are nine main access points to the lake. The NRA stretches north to Overton, east to the Grand Canyon National Park, and south to Laughlin and Bullhead City (USDI NPS 2011a). In 2010, visits to Lake Mead NRA totaled 7,080,758. The projected number for 2011, with an increase of 0.9 percent, is 7,146,008. In 2012, with an expected decrease of -1.9 percent, visitor numbers are forecast to total 7,011,264 (Street 2011).

According to the NPS Single Agency Report (2009) the primary activities, accounting for over half of visits to Lake Mead and Lake Mohave, are swimming, fishing, and motorized water activities. About 54 percent of visits to Lake Mead are by local area residents on day trips away from home; in contrast, there are a greater percentage of nonlocal residents on day trips to Lake Mohave (USDI NPS 2009). While the waters are a great attraction to many, Lake Mead NRA offers a myriad of other recreation opportunities to its visitors. Such activities as backcountry exploration driving, biking, camping, hiking, horseback riding, hunting, photography, and wildlife observation draw visitors to the desert landscape. In addition, the National Park Service offers a variety of ranger-led programs throughout the year. Guided hikes are presented at both Lake Mead and Lake Mohave throughout the fall and winter seasons (USDI NPS 2011a).

Recreation decisions at Lake Mead are based on the General Management Plan (USDI NPS 2011b). The NPS is addressing recreation and access within Lake Mead through development concept plans, such as plans for Katherine Landing and Cottonwood Cove (USDI NPS 2011c). The official website of Lake Mead NRA is an excellent source of information for the prospective visitor. Along with maps and facts about the area, the NPS offers detailed advice on safety precautions, essential equipment, and any regulations that pertain to various activities such as boating, fishing, hiking, hunting, or horseback riding. Throughout the literature there are reminders to respect the animals and plants that occur in the area (USDI NPS 2011a).

In a 1997 study by Graefe and Holland, the two most serious problems cited by lake users were crowding by personal watercraft operating too close together and litter along the shore. Forty-three percent reported observing unsafe boating situations. Shoreline litter was identified as a problem needing management attention at Lake Mead NRA. Lake users expressed great support for aggressive enforcement of safety rules and regulations (Graefe and Holland 1997).

U.S. Forest Service (USFS)

Spring Mountains National Recreation Area (NRA)—Spring Mountains NRA encompasses more than 316,000 acres in the Humboldt-Toiyabe National Forest. The General Management Plan (GMP) for Spring Mountains NRA includes goals, objectives, desired future conditions, and standards and guidelines for the entire NRA as well as specific direction for each of the four management areas: Developed Canyons, Mt. Charleston Wilderness, West-side, and Mt. Stirling (USDA FS n.d.a).

The Forest Service-managed NRA is located in Clark County, Nevada, 30 minutes west of downtown Las Vegas, and shares its eastern boundary with Red Rock Canyon NCA. The Spring Mountains, with its wide range in elevation, provides a haven for wildlife and a vital watershed fed by numerous springs. This mountain range serves as a quick get-away for urban residents of the Las Vegas metropolitan area. High elevations and cooler temperatures in proximity to the large population base offer visitors a welcome respite from the prevalent valley heat (http://www.fs.usda.gov/wps/portal/fsinternet/).

Spring Mountains NRA contains three Federally designated wilderness areas; Mt. Charleston, La Madre Mountain, and Rainbow Mountain (also in the Red Rock Canyon

NCA). Mt. Charleston, elevation 11,918 feet, is the third highest peak in Nevada and the only peak in southern Nevada that rises above treeline. The diverse life zones range from desert to alpine and support a wide variety of wildlife. The Spring Mountains provide habitat for more than 25 plants and animals found nowhere else on earth. Visitors are reminded to protect the animals and plants of the area that depend on Spring Mountains as an "island in the desert" (USDA FS n.d.b).

Spring Mountains NRA is a year-round recreation area and, owing to its great variation in elevation and temperature, offers a wider array of recreational opportunities compared with the rest of southern Nevada. Camping, picnicking, and hiking are available in the warmer months. Other activities include horseback riding, mountain biking, rock climbing, hunting, and wildlife viewing. There are opportunities for snow-based activities in winter (USDA FS n.d.b). According to the Single Agency Report, visitors to Spring Mountains NRA identified the top five recreation activities as viewing natural features, hiking/walking, relaxing, driving for pleasure, and viewing wildlife. Developed camping was also listed as a top "main" activity (USDA FS 2006).

There are 51 miles of hiking trails on Spring Mountains NRA. Most are open to horseback riding, with the exception of the upper section of the Bristlecone Trail. Riding is discouraged in areas of dangerously steep terrain or heavy visitor use. Mountain biking is limited to specific trails as posted and is prohibited in wilderness areas. Off-highway vehicle (OHV) use is restricted to roads and trails designated as "Motorized Trail" or "Forest Road." The visitor guide lists travel advice, safety tips, trail and boundary restrictions, and warns against littering and disturbance of cultural sites (USDA FS n.d.b).

U.S. Fish and Wildlife Service (USFWS)

Desert National Wildlife Refuge (NWR) Complex—The Desert NWR Complex, encompassing more than 1.6 million acres of land, is located in Clark, Lincoln, and Nye Counties of southern Nevada. The Complex consists of four separate refuges, Ash Meadows NWR, Desert NWR, Moapa Valley NWR, and Pahranagat NWR. Visitor services are primarily focused on wildlife-dependent recreation and vary at each refuge. The four refuges also provide resources that are important to local culturally affiliated tribes (USDI FWS 2009a).

Ash Meadows National Wildlife Refuge (NWR)—The Ash Meadows NWR is located approximately 90 miles northwest of Las Vegas and 30 miles west of Pahrump in the Amargosa Valley of Nye County. A day-use area, the refuge currently expects over 50,000 visitors annually. Ash Meadows NWR is comprised of over 23,000 acres of spring-fed wetlands and alkaline desert uplands. Providing habitat for at least 24 plants and animals found nowhere else in the world, Ash Meadows contains the greatest concentration of endemic life of any locale in the United States. This desert oasis is a major discharge point for an underground aquifer system stretching 100 miles to the northeast (USDI FWS 2011a).

Wildlife-dependent activities at Ash Meadows include bird watching, photography, wildlife observation, environmental education, interpretation, and hunting (in the fall). Picnicking and hiking are the major non-wildlife activities (USDI FWS 2009a). The refuge office (open weekdays 8AM to 4PM) offers brochures and leaflets, bird lists, an interpretive kiosk, and access to the Crystal Springs Interpretive Boardwalk Trail. Point of Rocks Boardwalk and Longstreet Boardwalk are two other interpretive trails (USDI FWS 2011a).

Rules, regulations, and safety advice are stated clearly in Ash Meadows NWR literature. Such activities as fishing, off-highway vehicles (OHVs), horseback riding, and collecting of artifacts or natural objects are prohibited on the refuge. Strict regulations are enforced during hunting season, including restrictions regarding use of hunting dogs, and reminders regarding trespass on private land in-holdings (USDI FWS 2011a).

Ash Meadows NWR works with a variety of agencies and organizations in the management of the refuge. Partnerships include Death Valley Natural History Association, Death Valley National Park (NPS), Southern Nye County Conservation District, U.S. Geological Service (USGS), local land owners, and others (USDI FWS 2009b).

Desert National Wildlife Refuge (NWR)—The Desert NWR is located immediately north of the rapidly expanding cities of North Las Vegas and Las Vegas. The western portion of the Refuge contains military withdrawn lands that are closed to public access (USDI FWS 2009b). Currently the refuge expects over 68,000 visitors annually (USDI FWS 2011b).

The largest refuge in the contiguous United States, the Desert NWR includes more than 1.5 million acres (over 2,300 square miles) of rugged mountain ranges and panoramic valleys. Elevations ranging from 2,200 feet to nearly 10,000 feet and corresponding variation in rainfall (less than 4 inches at lower elevations to greater than 15 inches on the highest peaks) have created diverse habitats that are suited to a wide variety of flora and fauna. Desert NWR is home to 52 species of mammals and over 320 species of birds. It forms one of the largest intact blocks of desert bighorn sheep habitat remaining in the southwest (USDI FWS 2005).

Wildlife-dependent recreational activities available on the Desert NWR include wildlife observation, photography, environmental education, interpretation, and hunting (limited). Non–wildlife-dependent recreational activities include primitive camping, picnicking, backpacking, and hiking (USDI FWS 2009a). "There are several unmaintained social trails used regularly by the public, including Hidden Forest, Gass Peak, Bird Song Loop and trails around Corn Creek" (Yost, personal communication 2012). Rules, regulations, and safety advice are stated clearly in Desert NWR literature. Cellular telephone coverage is limited in the area. The roads are primitive, no fuel or service is available in the refuge, and road warnings are posted for safety. Only licensed street-legal vehicles are allowed on the backcountry roads. Use of All-terrain Vehicles (cycles and quads) is not permitted within the refuge. Travel into the backcountry is best appreciated by foot or horseback (USDI FWS 2005).

Moapa Valley National Wildlife Refuge (NWR)—The Moapa Valley NWR is located approximately 60 miles northeast of Las Vegas in Clark County. The refuge is situated within the Moapa Valley south of State Highway 168 and the upper Muddy River, between Interstate 15 and U.S. Highway 93 (USDI FWS 2009b). Moapa Valley NWR is only open on Saturdays and Sundays (9 a.m. to 3 p.m.) from Labor Day through Memorial Day. This is due to the refuge's small size, fragile habitats, and ongoing restoration work (USDI FWS 2011c).

Moapa Valley NWR encompasses 116 acres and is part of a system of thermal springs at the headwaters of the Muddy River, which eventually flow into Lake Mead. These springs provide riparian and aquatic habitats for sensitive birds, bats, and fish. Most notably, the refuge protects an endangered population of the endemic Moapa dace (a small fish commonly found throughout the waters of the Muddy River system) and supports a diversity of birds including breeding populations of the endangered southwestern willow flycatcher. Hiking, picnicking, interpretation, environmental education, wildlife viewing and photography are recreational activities available at Moapa Valley NWR (USDI FWS 2009b). Moapa Valley was the first refuge in the National Wildlife Refuge System to be created for an endangered fish (USDI FWS 2011c).

Pahranagat National Wildlife Refuge (NWR)—The Pahranagat NWR is located approximately 90 miles north of Las Vegas at the southern end of the Pahranagat Valley in Lincoln County. Pahranagat NWR consists of 5,380 acres of marsh, open water, native grass meadow, cultivated cropland, and riparian habitat. This diversity of habitat supports over 230 species of migratory bird and other resident wildlife. There are four main water impoundments. The refuge expects over 32,000 visitors annually (USDI FWS 2011d).

Wildlife-dependent recreation activities include interpretation, environmental education, (USDI FWS 2009a) wildlife observation, fishing, and hunting. Bird watching is popular on this refuge; bird lists are available online, at the refuge office, or at information centers located throughout the refuge. Bird abundance and diversity are highest during spring and fall migrations. Camping and picnicking are permitted along the eastern shoreline of Upper Pahranagat Lake (USDI FWS 2011d). There are two unmaintained trails, Davenport and a loop around Upper Lake, but hiking is permitted throughout the refuge (Yost personal communication 2012).

Pahranagat NWR works with a variety of other agencies and organizations in the management of the refuge. Among others, these partnerships include National Audubon Society, Nevada Department of Wildlife, U.S. Bureau of Reclamation, Great Basin Bird Observatory, Bureau of Land Management, University of New Mexico, Northern Arizona University, and NPS Exotic Plant Management Team (USDI FWS 2009b).

Ongoing Recreation Issues on Federally Managed Lands

Population growth, development, proximity of urban areas to public lands, and growing popularity of outdoor recreation have translated into a high demand for a variety of recreational opportunities on Federal lands and waters. Over the past four decades, forms of motorized recreation such as OHVs, snowmobiles, and personal watercraft, as well as other recreational activities such as mountain biking and hang gliding, have gained in popularity. These newer forms of recreation intersect with more traditional forms of recreation such as fishing, canoeing, bird watching, hiking, horseback riding, hunting, and camping. Use of OHVs on Federal lands has been particularly contentious with critics raising concerns over potential damage to wildlife habitat and land and water ecosystems and diminished experience for recreationists seeking quiet and solitude (Calvert and others 2010). Despite differences in management objectives, topography, and recreation resources agencies are faced with many common issues. They struggle with needs for adequate facilities, funding, law enforcement, and staff. At the same time they must balance the demands of an ever increasing, dynamic population with stewardship of the various natural and cultural resources under their management. As the recreational preferences of the public evolve with greater interests in activities such as climbing, driving, and organized events, increased planning, education, and enforcement are required for effective management.

Regional Trail Planning and Outreach

Partnerships between agencies (Federal, state, regional, and local), non-profits, businesses, individual citizens, and community partners played a critical role in the establishment and management of trails in southern Nevada. An interest in preserving open space and in development of interconnecting trails has evolved over the past decade due primarily to the region's population explosion and a desire for improving quality of life. The proposed 113-mile Vegas Valley Rim Trail would serve to bind many land management areas, recreational destinations, municipalities, and agencies together (Baca 2010; Reardon, personal communication, 2011b).

Because of its proximity and access to public lands, Las Vegas Valley is gaining recognition as an outdoor recreation destination. The Cities of Las Vegas and Henderson have both completed open space planning efforts. The ultimate goal of these plans is to create and maintain a world-class, interconnected open space and trails system through the action of citizens, the business community, and city, county, state, and Federal agencies. These municipal plans are designed to provide a ring of open space and wildlands that will encircle the Greater Las Vegas area and protect scenic, ecosystem, and cultural resources (City of Henderson 2005; Clark County 2009).

Most of the corridor rests on BLM-managed lands, suggesting the need for continual coordination between the local communities and the Federal agencies. Lands being considered in the plan are outside the congressionally defined land disposal boundary and are primarily BLM-managed lands that are not congressionally designated for conservation. Given the possibility that the disposal boundary might be expanded as it has in the past, those public lands with the highest resource values could remain in public ownership or in some other form of protection to protect recreational opportunities in addition to conserving resource values. Lands bordering Las Vegas Valley that are designated for conservation by Congress include the Desert NWR, Lake Mead NRA, Sloan Canyon NCA, and Red Rock Canyon NCA (Clark County 2009). Lands designated locally for conservation include the Rainbow Gardens and River Mountains Areas of Critical Environmental Concern (BLM) and the Boulder City Conservation Easement (Boulder City and Clark County).

Knowledge Gaps and Management Implications

Southern Nevada's rapidly increasing population has resulted in an increase in recreational demands on public lands, while an associated shift in demographics has altered recreation tastes and preferences. There are changes in visitor types to a more urban population who expect more expensive recreation enhancements such as full-service camping facilities. In addition, an increasing number of visitors come from a wide range of cultural backgrounds. For example, subtle differences in leisure time preferences of Hispanics distinguish them from other ethnicities, and understanding such differences is a critical factor in serving the increasing Hispanic population (Adams and others 2006). Many new residents have recently migrated from other countries where English is not the primary language and who may or may not have experience with the traditional forms of recreation highlighted in this report. These changes to the profile of recreation in the area emphasize the need for additional information and management strategies to meet future demands and trends. Managers will need to plan for changes in facilities and recreation area emphases as well as additional education strategies to accommodate these new visitor preferences and types.

Stemming in part from southern Nevada's population expansion, there is an accelerated impact on natural, cultural, and scenic resources. Although some impacts are being recorded through resource monitoring, it is not fully known if they are related to recreation use. In addition, protection and conservation of water resources must be considered owing to competing interests and conflicting demands of recreationists. Identification and protection of these resources need to be undertaken and accounted for in management plans. Public education and law enforcement are essential components of this process.

Increased urbanization and development adjacent to public lands provide the southern Nevada population with easy access to nearby public lands for recreation. As off-highway vehicle (OHV) use and recreational climbing gain in popularity, research is needed to identify the potential impacts of such activities (SNAP 2011b). These are forms of recreation that impact the environment and are a common concern of the agencies managing public lands. Research is needed to identify recreation trends on public lands and ways to meet the needs and demands of recreationists without compromising the resources (SNAP 2011b).

Recreational use of all-terrain vehicles (ATVs) has resulted in an increase in vandalism and illegal looting (unauthorized excavation and removal of artifacts) on cultural sites that were previously inaccessible (NVSHPO 2004). These remote areas, once protected by distance, are now within easy reach of the off-road vehicle user and well-equipped urban/suburban resident. Cultural resource professionals look for positive effects from their heritage education programs. They believe that such education has the potential to reduce negative impacts and inadvertent damage from recreational use on public lands by making the public aware of the fragility and uniqueness of the resource. Frustration remains over insufficient funding for law enforcement and management actions such as closure of roads and trails or construction of physical barriers for prevention of site damage (Jarvis 2006).

Changes in communication technology have affected how people get information regarding potential visits to recreation areas and associated activities. For instance, visitor guides are now available online. "Online meet-up groups are a new way people find out about hikes and may be taking the place of commercial operators or demand for agency led activities. Understanding the volume of visitation, providing information to leaders to ensure resource damage is avoided, etc. is all needed" (Ronning, personal communication). There is a trend for recreationists to desire enhanced interactive interpretive and educational programs as well as upgraded visitor centers. Funding and staffing of recreation areas and facilities must be sufficient to keep pace with these increasing demands.

Administrative and political pressures on agencies that divert effort away from activity that directly benefits ecosystems affect long-term effective management of the land. Loss of landscape knowledge when agency staffs are transferred to other locations is another serious problem. Other needs are interagency cooperation and education of recreation visitors. Lack of resources such as staffing, infrastructure, and budget affect the ability of agencies to manage southern Nevada ecosystems (Lancaster and others 2006).

Southern Nevada's growing population influences recreation activity on Federal lands and impacts the area's natural resources. The State of Nevada, with its great proportion of public lands, is blessed with an abundance of natural resources. The parks and open spaces of southern Nevada are valued as popular recreation and tourist destinations for Nevadans and visitors to the Las Vegas metropolitan area (DeLoney 2004). While these areas are beneficial to human populations as healthy retreats from urban life, they are essential as habitat for many native species of flora and fauna. Therefore, it is imperative to consider the effects of increasing recreation demands on natural resources. Cooperation and collaboration among the four Federal land management agencies and with southern Nevada's adjacent communities is necessary to achieve the goals of promoting natural and cultural resource stewardship while providing appropriate and sustainable recreation opportunities (SNAP 2002).

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Chapter 11

Science-Based Management of Public Lands in Southern Nevada

Matthew L. Brooks and Jeanne C. Chambers

Introduction

Landmark legislation provides guiding principles for land management planning in southern Nevada and the rest of the United States. Such legislation includes, but is not limited to, the Forest Service Organic Administration Act of 1897 (16 U.S.C. 473-478, 479-482 and 551), National Park Service Organic Act of 1916 (U.S.C. Title 16, Secs. 1-4), Wilderness Act 1964 (P.L.88-577), National Environmental Policy Act of 1969 (P.L 91-190), Endangered Species Act of 1973 (P.L. 91-205), National Forest Management Act of 1976 (P.L. 94-588), and Federal Land Policy and Management Act of 1976 (P.L. 94-579). The acts establishing congressionally designated areas within southern Nevada, such as Lake Mead National Recreation Area, Spring Mountains National Recreation Area, and Desert National Wildlife Refuge, also contain guidelines for the management of these lands. These documents variously require preservation of natural and cultural resources and wilderness character, protection of species, and prevention of undesirable environmental effects from land management actions. These requirements must be met while allowing for multiple “uses” of certain public lands (e.g. recreation, ranching, resource extraction, renewable energy development, etc.) to the degree that they do not threaten preservation, protection, and prevention goals. Many considerations come into play in the development and implementation of land management plans and actions. The planning process requires a balancing act that sometimes pits one need or priority against another. When priorities align, management actions can have multiple benefits. In some cases, specific priorities can trump other needs and priorities and receive disproportionate consideration. Overall, the management of public lands is a very complicated and sometimes contentious process.

Science provides an objective way to help weigh quantifiable information and draw conclusions about the effects of past and potential future land management policies, decisions, and actions. When effectively integrated into adaptive management, science-based information can reduce uncertainties, increase knowledge, and improve decision making. However, the specific science information needed for effective management is often lacking or difficult to access or interpret. Science is typically reported in scientific journals as discrete units describing individual studies with other scientists as the primary audience. Translations of these studies and syntheses of multiple studies into formats that can be readily used in land management planning efforts are often lacking. Identifying and articulating the highest priority science and research needs is one of the primary purposes of the Southern Nevada Agency Partnership (SNAP; http://www.SNAP.gov) Science and Research Team (Chapter 1; Turner and others 2009). The SNAP Science and Research Strategy (Strategy) calls for a synthesis report to be written every 5 years summarizing the state of knowledge, information gaps, and management implications of scientific information as it relates to the SNAP Strategy goals (Turner and others

2009). This General Technical Report serves as the first SNAP Science and Research Synthesis Report (Synthesis Report) commissioned by the Science and Research Team. The Synthesis Report is mostly based on information from the peer-reviewed scientific literature, and is itself peer reviewed and constitutes a new contribution to the scientific literature. This final chapter addresses Sub-goal 2.3, which is to manage current and future authorized southern Nevada land uses in a manner that balances public need and ecosystem sustainability, and Sub-goal 2.5, which is to promote an effective conservation education and interpretation program to improve the quality of resources and enhance public use and enjoyment of southern Nevada public lands. It summarizes information from the previous chapters on what scientific information is known currently and what remains largely unknown, and it discusses how science can be used to make future management decisions that balances public needs and ecosystem sustainability.

Current Scientific Understanding and Information Needs

Ecosystem stressors associated with human activities, wild horse and burro and livestock grazing, and altered fire regimes have been the traditional focus of land managers in southern Nevada. Concerns about invasive species emerged during the 1990s, and perhaps even greater concerns regarding climate change, energy development, and water development arose during the 2000s. The current challenge is to understand how to manage these many, and often interacting, stressors to maintain ecosystem sustainability. This task is more daunting today than it was only a few decades ago because of the rapidly expanding human population, the increase in the number of stressors of significant concern, and the need to address both public access and resource issues on Nevada's public lands.

The effect of climate change on ecosystem sustainability is perhaps the greatest unknown stressor with respect to current management planning in southern Nevada. The science is clear that anthropogenic caused climate change is occurring on a global scale and that longer and more intense droughts and increased temperatures are becoming increasingly more likely in the deserts of southwestern North America (Chapter 2). However, the precise nature of these changes are not yet known and the scaled-down predictions necessary for determining the most effective management actions have yet to be developed. Also, it is not clear how these conditions will interact with other ecosystem stressors that land managers can potentially control.

The current state of science can help tease out some of the most significant stressors threating ecosystem sustainability in southern Nevada (Chapter 2). However, there is much more that remains unknown regarding these stressors and potential ecosystem responses. The sections that follow summarize these primary knowns and unknowns, and suggest research priorities for the major management topics in southern Nevada.

Water and Water Use

The hydrology of southern Nevada is characterized by regionally limited recharge areas within mountain ranges, and interbasin flow from adjacent regions. Discharge occurs through seeps and springs, evapotranspiration, subsurface flow out of the region, and pumping (Chapter 3). The Colorado River (Lake Mead) and its tributaries (the Muddy and Virgin Rivers), along with Las Vegas Wash, form the major fluvial systems in the area. Although recharge from precipitation can vary widely among years, large subsurface aquifers historically buffered interannual fluctuations in ground water levels across much of southern Nevada. This means that the discharge from springs and seeps was maintained for long periods of time, supporting locally endemic species and their habitat (Chapter 6). Accelerated rates of ground water pumping during recent decades now affects discharge patterns threatening spring and seep ecosystems, and projected increases in pumping may pose even greater ecosystem threats in the future.

In order to effectively manage water resources in southern Nevada, it is important to understand future patterns of ground water recharge. Predictions of a warmer climate, potentially higher evapotranspiration rates, and more variable precipitation could dramatically alter ground water dynamics. An understanding of these potential future scenarios is critical to ensure that current planning decisions related to ground water pumping and water use do not adversely impact ground water resources or otherwise cause significant and potentially irreversible environmental degradation. (See Chapter 3 for a detailed discussion of information needs related to water and water use in southern Nevada.)

Invasive Species

The concern associated with invasive species on wildlands in southern Nevada gained prominence following President Clinton's Executive Order 13112 in 1999 and the development of a national strategy for management of this ecosystem stressor. At that time, the science to support this mandate was not very extensive, as invasion biology had only emerged as a major branch of ecology during the 1980s. During the past few decades there has been a tremendous amount of new information generated regarding biological invasions worldwide.

In southern Nevada it is now clear that the main invasive plants of concern in upland areas are annual species, especially red brome (*Bromus rubens*) and Mediterranean split-grass (*Schismus* spp.), which are associated with altered fire regimes. Riparian areas are most threatened by perennial plants, especially Tamarisk (*Tamarix* spp.), which can compete with native plants, degrade wildlife habitat, and potentially alter hydrologic and fire regimes. Aquatic plants are not yet recognized as major threats to the degree that their invasive analogs in terrestrial ecosystems are. However, there are a few poised to invade southern Nevada that could become aquatic ecosystem transformers, including Eurasian water-milfoil (*Myriophyllum spicatum*) and giant salvinia (*Salvinia molesta*).

Various non-native terrestrial animals are also of significant management concern in southern Nevada, ranging from ants, dogs, and cats, to free-roaming cows and equids (Chapter 4). The effects of species like ants and dogs and cats are related primarily to competition with or predation on native species, but habitat alteration by cows and equids is also a major concern. Non-native aquatic animals range from the quagga mussel (*Dreissena rostriformis*), American bullfrog (*Rana catesbeiana*), red swamp crayfish (*Procambarus clarkia*), to various fish species. Threats from these species include altered food web dynamics and predation on native species.

Perhaps one of the most significant unknowns relates to the ability to accurately predict future patterns of spread for existing invasives, establishment and spread of new invasives, and the relative and cumulative threats posed by all invasive species in southern Nevada. This information, and an understanding of the feasibility for controlling the different species, is critical for prioritizing management actions among the plethora of non-native and potentially invasive species in this region. (See Chapter 4 for a detailed discussion of information needs related to invasive species management in southern Nevada.)

Fire History, Effects, and Management

It is generally understood that fire has been infrequent in most of southern Nevada since the last ice age, which ended approximately 10,000 years ago (Chapter 5). What is less recognized is that some landscapes have continuously experienced at least moderate fire frequencies during this time period. These include sagebrush, piñon-juniper, and mixed conifer ecosystems, and in these areas fire may be an important ecosystem process. However, the vast majority of the current southern Nevada landscape is dominated by blackbrush and lower elevation vegetation types that did not support frequent fire historically and where large and/or frequent fires are ecosystem stressors. Key fire management messages that can be derived from current science are that (1) potential effects of fire should be evaluated in the context of ecosystem type, fire behavior characteristics, and site-specific characteristics (e.g. fire history); (2) fire suppression is ultimately the most effective way to manage fire at middle and lower elevation where fire was historically infrequent, but wildland fire use or fire surrogates may be appropriate under certain circumstances at higher elevations; and (3) the post-fire rehabilitation/restoration tools that are currently being used at middle to lower elevations appear to be ineffective or poorly evaluated (Chapter 5).

Information is needed on both long-term ramifications of fire in middle and upper elevation vegetation types (i.e., blackbrush and above), and post-fire management of lower elevation vegetation types dominated by creosotebush (*Larrea tridentata*) and saltbush (*Atriplex* spp.). In all future fire studies, the potential influence of climate change should be considered to place the results in the context of climate projections for the next decades through the end of the current century. (See Chapter 5 for a detailed discussion of information needs related to fire history, effects, and management in southern Nevada.)

Species of Conservation Concern

Aside from the desert tortoise, which has been studied more than any other species in southern Nevada, relatively little is known about the life history characteristics and specific habitat requirements of most species in this region (Chapter 6). This includes the species covered under the Clark County Multiple Species Habitat Conservation Plan. Research has often focused on mitigation strategies to protect sensitive species without a full understanding of the life history and ecophysiological constraints on the species and the stressors that are causing their declining status.

With so many unknowns associated with the many species of concern in southern Nevada, it is a challenge to prioritize which species should be the focus of scientific research and which questions should be addressed. The default is often to focus on species that agencies have specific legal requirements to protect (e.g., Federally listed). Development of effective conservation plans requires an understanding of the life history characteristics, habitat requirements, and specific stressors affecting the listed species. These plans may initially lack the desired level of detail. However, critical information needs can be identified in the planning process and new research projects coupled with habitat and population monitoring can be used to develop an effective adaptive management program. (See Chapter 6 for a detailed discussion of information needs related to species of conservation of concern in southern Nevada.)

Maintaining and Restoring Sustainable Ecosystems

The overarching objective for land managers in southern Nevada is to maintain and restore sustainable ecosystems that are resilient to disturbance and resistant to invasion (Chapter 7). The ecosystems types within southern Nevada differ significantly in both their environmental characteristics and dominant stressors and, consequently, in their resilience to disturbance and resistance to invasive species. In order for restoration and management strategies to be effective, they must account for these differences. A useful decision support framework based on ecosystem resilience and resistance distinguishes among (1) protection from current and future stressors; (2) preventive management actions designed to increase resilience and resistance of areas with declining ecological conditions; and (3) restoration activities following disturbance or other ecosystem degradation (table 7.1). This framework allows for customized guidelines for each of the major ecosystems types in southern Nevada (table 7.2). An integrated and consistent assessment of southern Nevada ecosystems and their relative resilience and resistance can be used to prioritize management and restoration activities using this framework. Monitoring programs designed to track ecosystem changes in response to both stressors and management actions can be used to increase understanding of ecosystem resilience and resistance, realign restoration and management approaches, and implement adaptive management.

Cross-cutting information needs for restoration and management of southern Nevada's diverse ecosystems include a better understanding of the factors that determine resilience and resistance and of the interacting effects of the region's stressors. They also include knowledge of the environmental conditions required for establishment and persistence of native plant species and methods for their restoration. (See Chapter 7 for a detailed discussion of information needs related to maintaining and restoring sustainable ecosystems in southern Nevada.)

Human Interactions with the Environment Through Time and Preserving Heritage Resources

Southern Nevada has been continuously inhabited by humans at least since the end of the last ice age (Chapter 8). This period marks the shift from a more mesic and temperate climate to the more arid desert climate that exists today. During most of the post ice age Holocene (i.e., the last 12,000 years), human occupation was characterized by small nomadic bands that migrated seasonally following resources needed for subsistence. During the last few thousand years, larger settlements emerged that were associated with a move towards more agricultural societies in the riverine bottomlands. The first Europeans travelled to southern Nevada in the late 1700s, and by the middle 1850s settlers were steadily migrating into the region along the Old Spanish Trail (later the Mormon Road) and displacing Native Americans from their agricultural, foraging, and hunting lands. Settlers also brought with them horses and livestock that were having significant effects on the landscape as early as the 1800s, and these stock animals have been continuously present on through to the present (Chapter 2).

Population levels moved upward with the construction of Hoover Dam in the 1930s, but really increased substantially during the past few decades resulting in urban sprawl, increased development within public lands, and increased visitation to remote areas of southern Nevada (Chapter 9). This has resulted in the loss of cultural sites through development, looting, and vandalism. Public education, law enforcement, and monitoring of cultural sites are widely recognized as ways to minimize damage to these sites. However, agency resources are generally insufficient to address all of these needs.

The major remaining information gap is the limited extent of archeological survey coverage; only 7 percent of Southern Nevada has been surveyed, primarily within the Las Vegas Valley and associated with development projects (Chapter 8). A complete survey for the region is not realistic, but additional targeted surveys that expand and improve the sample of lands examined would go a long way towards improving the baseline information in the region. More comprehensive links between archeological sites and their environmental settings would increase understanding of potential interactions between humans and ecosystem conditions. Also, continued research is needed to evaluate the effectiveness of public education and outreach, volunteer site monitoring, and law enforcement programs in achieving the objectives of reducing damage to and loss of cultural sites. (See Chapters 8 and 9 for a detailed discussion of information needs related to human interactions with the environment through time and preserving heritage resources in southern Nevada.)

Recreation Use on Federal Lands

The vast majority of lands are open to human use in southern Nevada. The burgeoning human population is increasing the use of these lands for recreational purposes, creating a very difficult challenge for Federal land managers (Chapter 10). Also, the human population is becoming more urban and multi-cultural, resulting in potential changes in recreational patterns that will require flexibility in current management approaches. To plan for these changes, land managers need information about how these changing demographics may affect the types and patterns of recreational use of public lands. (See Chapter 10 for a detailed discussion of information needs related to recreation use on Federal lands in southern Nevada.)

The Role of Science in Land Management

Management that balances public need and ecosystem sustainability is informed by the science information in this Synthesis Report. The goal of ecosystem sustainability has its origins in legislation mentioned at the beginning of this chapter, and subsequent national policies that call for natural resources, and by inference the ecosystem processes that sustain them, to be preserved unimpaired for future generations. However, land managers must balance the goal of ecosystem sustainability with other goals derived from other laws and national policies associated with recreation, resource extraction, and other land uses that collectively constitute the land management context of southern Nevada. Although science often plays a major role in the initial legislation and policy development and can form the foundation of initial planning goals and objectives, subsequent science produced through targeted research studies and monitoring for status and trend of resources has the greatest influence on deciding when a management response is warranted or when established management objectives may need to be modified (fig. 11.1).

Objectives should be written with specific science-based, objective, and measurable standards in mind, for example, allowing livestock grazing up to a limit of x percent vegetation biomass consumption based on a sliding scale that takes into account recent climatic conditions and other potential interacting stressors. Objective standards greatly simplify the process of monitoring and decision making because they are relatively unambiguous (fig. 11.1). The problem is that science is often insufficient to justify specific standards, and therefore standards are based on general scientific theory and are relatively subjective, for example, allowing grazing practices that do not negatively affect the health, productivity, and diversity of plant communities, which is subjective and hard to monitor. Subjective standards require more complicated monitoring and generally make decision making more difficult and controversial.

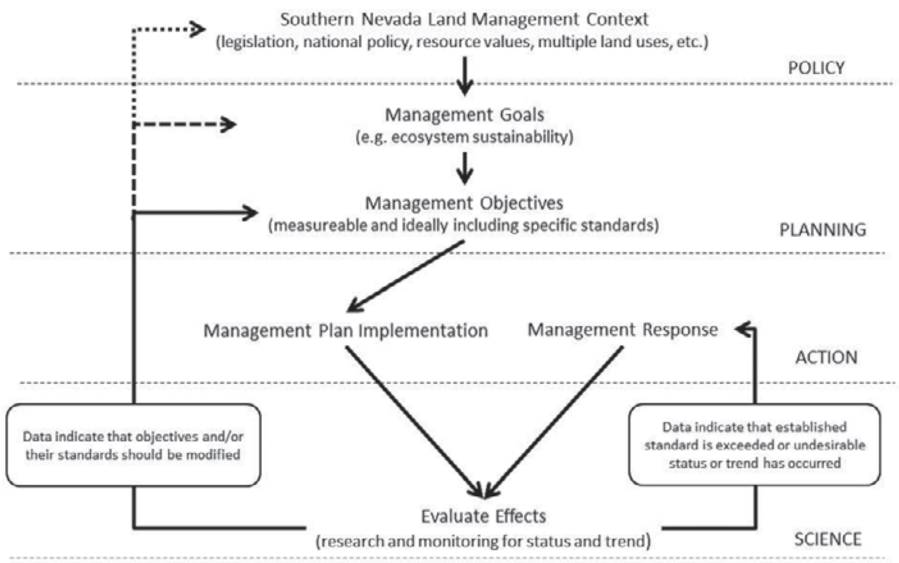

Figure 11.1—The role of science in the management of Federal lands in southern Nevada

Once management plans are implemented, monitoring plans that are specifically coupled with management objectives can help land managers monitor the status and trend of their ecosystem resources and determine if management responses or modifications of management objectives are warranted (fig. 11.1). With the advent of the information age and ability to archive and share data remotely, there has been a move towards more standardized monitoring methods to facilitate large scale analyses across multiple land management agency units. However, these standard methods are often not ideally suited for evaluating management objectives that are designed for smaller landscapes and their local land management contexts. Land managers must understand these potential limitations and choose their monitoring and data management methods carefully to ensure that they will give them the scientific information necessary to effectively evaluate their management objectives and management actions.

The Role of Science in Education

This Synthesis Report serves as an outreach document to inform stakeholders and the general public about the major ecosystem stressors, and natural, cultural, and recreational resources in southern Nevada. It also provides valuable information on management alternatives.

An educated populace makes it easier for land managers to communicate science-based management with the public, and should ultimately streamline the approval processes for land management plans. As mentioned above, science information is often written by scientists for scientists and science products are often not ideal for communication with the general public. There is, therefore, a need for science-based objective summaries of key land management topics that clearly distinguish between what is scientifically known and what is more generally derived from professional opinion and cultural influences. The mode of information delivery should also be varied to capture a wide range of audiences (e.g. print, radio, television, websites, and social media).

Reference

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