Great Basin–Mojave Desert Region

The Great Basin–Mojave Desert region is a land of striking contrasts. Forming an expansive wedge between the Sierra Nevada, the Transverse ranges, the Rocky Mountains, and the Columbia and Colorado plateaus, the region harbors great biological diversity. This high diversity is produced by a blending of the surrounding region's flora and fauna with the unique species of the Great Basin and Mojave Desert. The Great Basin–Mojave Desert region is home to the oldest living organisms on Earth, such as Great Basin bristlecone pines, which can live 4,900 years (Schmid and Schmid 1975), and the creosotebush clones in the Mojave Desert, which are an estimated 10,000–11,000 years old (Vasek et al. 1975).

Biologists easily distinguish the Mojave Desert and the Great Basin from other regions by their flora and fauna. However, the boundaries between them and the surrounding regions are often unclear. Various scientific disciplines define the Great Basin–Mojave Desert region somewhat differently (Grayson 1993). Anthropologists define the region by cultural attributes of the aboriginal inhabitants (d'Azavedo 1986), botanists by species composition of the vegetation (Billings 1951; Holmgren 1972; Vasek and Barbour 1990), and geologists by the structure of the land (Hunt 1967). The region includes nearly all of Nevada, much of eastern California, western Utah, southeastern Oregon, and portions of southern Idaho. Our descriptions include the hydrographic Great Basin, the floristic Mojave Desert, and the Muddy, Virgin, and White rivers, which are tributaries of the Colorado River with headwaters deep in the floristic Great Basin (Fig. 1).

Hydrographic Great Basin

The hydrographic Great Basin is the area of internal drainage between the Rocky Mountains and the Sierra Nevada. The waters of streams in this area never reach the ocean but are confined to closed basins. The hydrographic Great Basin includes most of the Mojave Desert and exceeds 500,000 square kilometers (Morrison 1991). When the explorer John C. Frémont realized that this region did not drain to the ocean, he coined the term Great Basin (Frémont 1845).

Physiographic Region

The landforms of the Great Basin and the Mojave Desert define the region as part of the Basin and Range Physiographic Province (Hunt 1967) that extends south to include the Sonoran and Chihuahuan deserts of Arizona and Mexico. The Basin and Range Physiographic Province is characterized by hundreds of long, narrow, and roughly parallel mountain ranges that are separated by deep valleys (Hunt 1967; King 1977; Fiero 1986). These features have evoked several colorful descriptions, including "an army of caterpillars crawling northward out of Mexico" (Dutton *in* King 1977:156) and "washboard topography" (Houghton 1978:vii).

The Great Basin mountains are geologically recent, and the landforms of the region are a product of the formation of the Rocky Mountains and the Sierra Nevada. The structures of the more than 400 mountain ranges in the region are similar, but their compositions are diverse. Many


© D. A. Charlet, University of Nevada

Contents Article Page

Fig. 1. The Great Basin–Mojave Desert region.

granite ranges occur in the west, basalt ranges occupy the northwest, rhyolite mountains form the center, and limestone mountains dominate the east and southwest. In addition to this diversity of substrates, there is great topographic relief throughout the region, the greatest of which is 4,494 meters in the 135 kilometers between Badwater in Death Valley and the summit of Mount Whitney, both in California. In a transect across the Great Basin at 39° north latitude, Grayson (1993) found that the difference in elevation between mountaintops and valley bottoms ranged from 1,158 to 2,316 meters, with an average relief of 1,768 meters.

The topographic relief in the region creates powerful elevation gradients to which all the organisms in the region respond. As elevation increases, air density decreases and solar radiation and precipitation increase. The interaction of these factors produces different temperature regimes at different elevations, which significantly affect the distribution of plants (Billings 1970) and the animals that depend on them (Hall 1946). This mountainous terrain thus provides many opportunities for a multitude of organisms with diverse life strategies.

Floristic Region

The Mojave Desert can be distinguished from the Great Basin by the presence and abundance of its different plant species. Again, the boundaries are imprecise. The principal distinguishing feature of the two floristic regions is the presence of creosotebush in the Mojave Desert and its absence from the Great Basin (Billings 1951; Holmgren 1972). Alternatively, big sagebrush dominates much of the Great Basin floristic region, but it is mostly absent from the Mojave Desert except at moderate to high elevations in the mountains. The separation of the Mojave from the Colorado and Sonoran deserts is less clear because creosotebush is also dominant in these deserts.

Climate

The climate of the Great Basin–Mojave Desert region is one of the most varied and extreme in the world (Hidy and Klieforth 1990). The Sierra Nevada is primarily responsible for creating this arid, continental climate by capturing moisture from Pacific storm fronts before the moisture reaches the desert (Houghton et al. 1975); similarly, the Rocky Mountains intercept storms from the Gulf of Mexico (Hidy and Klieforth 1990). Local weather patterns are complicated by the mountain ranges that uplift the dispersed moisture, creating mountain storms (Hidy and Klieforth 1990). Thus, precipitation increases with elevation (Billings 1951), and average annual precipitation can be highly variable over small distances.

The region can be separated climatically into hot and cold deserts. The lower, hot, Mojave Desert receives most of its precipitation as rain, and the higher, cold, Great Basin Desert receives most of its moisture as snow (MacMahon 1988a). This distinction is complicated by a strong east–west gradient that allows more summer rains from the Gulf of Mexico to reach the eastern regions of the Great Basin and Mojave than their western regions. This pattern changes around 40° north latitude, where seasonal precipitation regimes are nearly equal between the Warner Mountains in the west and the Jarbidge Mountains in the east (Charlet 1991).

Climatic History and Its Influence

The Pleistocene Epoch, in which several major glaciation and deglaciation events occurred, lasted from about 3 million to about 11,000 years before present (Flint 1971). During the Pleistocene Epoch, enormous lakes and marshes formed in many of the valleys (Mifflin and Wheat 1979; Williams 1982; Benson et al. 1990; Morrison 1991; Fig. 2), and glaciers spotted the high mountains (Blackwelder 1931, 1934; Flint 1971; Piegat 1980; Porter et al. 1983; Osborn 1989). The modern distribution and ecology (interactions of organisms with the environment) of the organisms of the Great Basin–Mojave Desert region largely reflect the effects of increased precipitation and cooler temperatures of the Pleistocene Epoch (Reveal 1979; Wharton et al. 1990).

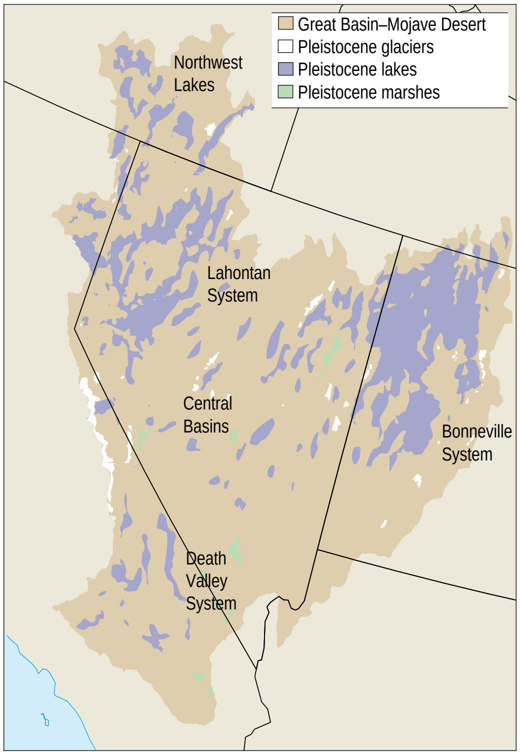


Fig. 2. Estimate of the maximum extent of marshes, pluvial lakes, and mountain glaciers during the Pleistocene Epoch in the Great Basin–Mojave Desert region. Data from Blackwelder (1931, 1934), Flint (1971), Piegat (1980), Williams (1982), Porter et al. (1983), and Osborn (1989).

Plants and animals of the region responded to the Pleistocene climate by changing their relative distributions and abundances (Brown 1971, 1978; Billings 1978; Harper et al. 1978; Wells 1983; Charlet 1991). Therefore, community composition changed as species moved in search of more congenial climates (C. L. Nowak 1991), adapted in place, or became either locally or globally extinct (Grayson 1993). Species were generally forced downslope and southward in response to Pleistocene conditions (Axelrod 1950, 1976, 1983; Van Devender and Spaulding 1979; Wells 1983; Mehringer and Wigand 1990; Wigand et al. 1994).

The Holocene Epoch of the last 11,000 years is characterized by the recession of mountain glaciers and a warmer and often drier climate than existed during the Pleistocene Epoch. Drought- and heat-tolerant species from southern deserts have moved northward into the Great Basin–Mojave Desert region during the Holocene Epoch (Reveal 1979), while drought- and heat-intolerant species have been forced farther north or higher into the cooler and wetter conditions of the mountains, or were extirpated (Billings 1978). This dry period has affected the animals (Brown 1978), the people (Bettinger 1991; Thomas 1997), and the plants (Billings 1978) of the region.

Gould (1991) maintains that the Holocene Epoch is simply another interglacial period before renewed glaciation. This view echoes that voiced earlier by Wright (1983:xi), "there is little doubt that another major glaciation will ensue." In the face of either a new glaciation period or human-induced global warming, how will the biota of the Great Basin–Mojave Desert region respond? To understand the answer, we must examine the spectacularly varied and numerous isolated communities of the region with history in mind.

Montane Islands in a Sea of Shrubs

The last 3 million years of climatic fluctuations left a biological legacy on the landscapes of the Great Basin–Mojave Desert region. Remnants of ancient pluvial lakes include Pyramid, Walker, Carson, Eagle, and Mono lakes; each has its unique plants and animals. The many mountaintops are refugia for species left behind from the Pleistocene Epoch in communities that are vastly different from the adjacent desert valleys. Within 10 kilometers, a single basin-range unit can host environments that range from treeless alpine bogs and rocky slopes to montane coniferous forests, diverse mountain shrublands, pygmy woodlands of pinyon pine or juniper, lower slopes of sagebrush and grasses, lake shores that support an entirely different array of shrubs and flowers, barren sand dunes, or playas (saline flats that sometimes form shallow lakes). Dozens of montane habitat islands in the region are now separated from each other by deserts.

Transition Zones

Contact between the flora and fauna of two regions creates transition zones (Meyer 1978; MacMahon 1988b). These zones have characteristics of both regions and constitute a unique type of habitat. Although transition zones may be important sites for plant evolution (G. L. Stebbins 1974), few researchers have examined the animals of these zones in detail (Pianka 1967, 1970; Parker and Pianka 1975; Robinson 1988; Wilson 1991).

The eastern boundary of the Great Basin–Mojave Desert region is sharply defined by the high elevations of the Wasatch Mountains and the Colorado Plateau. The western boundary along the Sierra Nevada is even sharper and has been called one of the world's sharpest boundaries between biological regions (Billings 1990). However, the northern and southern boundaries are subtler, and the transition zones there are much broader.

The most complex transition zone is about 115 kilometers wide and occurs between the Great Basin and the Mojave Desert (Beatley 1976; O'Farrell and Emery 1976; Fig. 3). This zone contains a mixture of smaller transition zones and sharp habitat edges (Billings 1949, 1951; Beatley 1974a,b, 1976; Meyer 1978; El-Ghonemy et al. 1980a,b; Turner 1982; Callison and Brotherson 1985; Young et al. 1986; MacMahon 1988b; West 1988; Tueller et al. 1991), which result from increasing elevation, decreasing temperatures, and a south–north shift in predominant precipitation from rain to snow (Billings 1951; MacMahon 1988a; Tueller et al. 1991).

Many terrestrial animals reach their northern or southern distribution limits in this zone (Hall 1946; Holmgren 1972; Stebbins 1985), and the boundaries of several subspecies occur here, such as the northern and southern desert horned lizards and the northern and desert side-blotched lizards (Stebbins 1985). The turnover of some bird and mammal species is also abrupt between the Great Basin and the Mojave Desert (Hall 1946; Behle 1978).

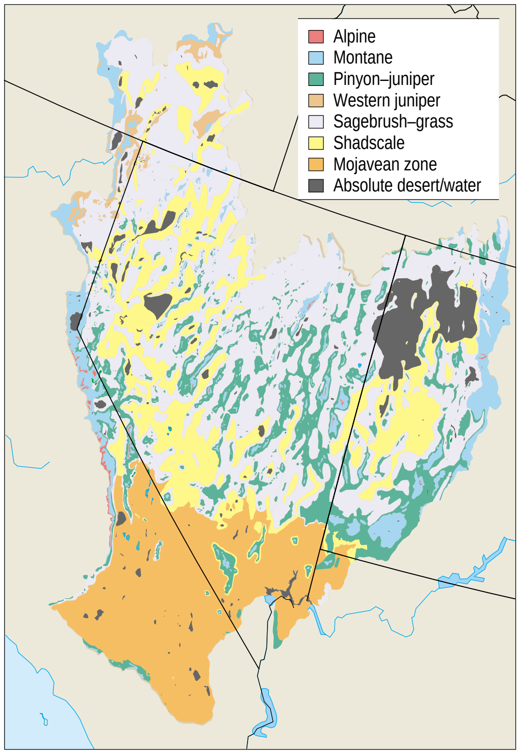


Fig. 3. Vegetation zones in the Great Basin–Mojave Desert region. Compiled from Shreve (1942), Billings (1951), Holmgren (1972), Ertter (1992), and D. A. Charlet (University of Nevada, unpublished data).

Another gradual transition zone occurs toward the northern edge of the region, where sagebrush declines in favor of perennial bunchgrasses. Pristine conditions in the north once included such a high grass component that these communities are commonly referred to as sagebrush–steppe or shrub–steppe. The gradation continues north until grasses dominate the steppe of the Columbia Plateau (West 1988).

Status of Major Communities

Aquatic Communities

Riparian Communities

Riparian communities occur along the major watercourses in most intermountain valleys of the Great Basin–Mojave Desert region and in association with isolated springs, seeps, and smaller streams. In the Great Basin, riparian communities are dominated by various mixtures of cottonwood, aspen, and willow species that are used by the native Humboldt beaver (Fig. 4). Thickets of chokecherry are common, and occasional patches of silver buffaloberry provide important overwintering sites for North American porcupines (Sweitzer 1990). Impressive groves of cottonwoods occur along the larger rivers (Fig. 5). In the low-lying Mojave Desert, these dominants are largely replaced by mesquite, cat-claw acacia, and velvet ash. Other riparian associations dominated by saltgrass and iodine bush occur on saline soils and along streams such as Salt Creek in Death Valley (Fig. 6).


© D. A. Charlet, University of Nevada

Fig. 4. Humboldt beaver at the headwaters of the Humboldt River, Jarbidge Mountains, Nevada.

Although extremely small in total area, riparian communities in this region are critical centers of biodiversity. More than 75% of the species in the region are strongly associated with riparian vegetation (U.S. General Accounting Office 1993), including 80% of the birds (Dobkin 1998) and 70% of the butterflies (Brussard and Austin 1993). Several butterflies are completely restricted to these habitats (for

© P. F. Brussard, University of Nevada

Fig. 5. Cottonwood groves along the Walker River in Antelope Valley, California.

© D. A. Charlet, University of Nevada

Fig. 6. A Mojave Desert riparian system at Salt Creek, Death Valley National Park, California.

example, the Apache nokomis fritillary butterfly and the Weidemeyer's admiral butterfly). Riparian corridors also provide migration pathways for many species, and subalpine and montane conifers descend to much lower elevations in riparian situations than in upland stands (Charlet 1996, 1997). Much of this vegetation has been destroyed or degraded by water diversions, agricultural development, and livestock grazing (U.S. General Accounting Office 1993), which is a major cause of riparian habitat degradation in the Great Basin (Platts 1990; Chaney et al. 1993; National Research Council 1994). Effects of grazing include a reduction of natural vegetation, stream channel widening and aggradation, and lowered water tables (Kauffman and Krueger 1984; Armour et al. 1991; Chaney et al. 1993; Fleischner 1994). A structurally diverse flora in riparian areas that has not been grazed supports a broad assemblage of wildlife species, whereas reductions of shrub and herbaceous cover following heavy cattle grazing modify many bird and small-mammal communities (Schulz and Leininger 1991; Dobkin 1994a). The effect of livestock on riparian habitats in the Great Basin is often so severe that those habitats no longer represent natural vegetation (Ehrlich and Murphy 1987; Chaney et al. 1993), and the associated faunal communities support largely widespread, ecological generalists that are adapted to such highly disturbed conditions (Dobkin 1998).

A striking example of generalist species in disturbed areas is found along the Virgin, Mojave (Lovich et al. 1994), Humboldt, and Walker rivers and in many other parts of the region, where riparian communities are now largely dominated by aggressive, nonindigenous tamarisks. These trees reduce the abundance of native riparian vegetation, and their rapid migration is profoundly altering species composition and community functions (Vitousek 1986). Tamarisks use water more efficiently than other trees do and tolerate saline conditions (Busch and Smith 1993). Tamarisks are fire-tolerant, thus increased fire frequency favors them over the native riparian vegetation (Anderson et al. 1977; Busch and Smith 1993). Tamarisks are also more tolerant of boron, a toxic element that concentrates in soil after fires (Busch and Smith 1993), than are native willow and cottonwood species. These postfire adaptations permit tamarisks to dominate riparian communities at the expense of the native trees (Anderson et al. 1977).

Stream flow also is altered by the encroachment of tamarisks into riparian communities. Tamarisks create narrower stream channels (Blackburn et al. 1982) and promote local flooding (Graf 1980). Although expensive (Graf 1980; Barrows 1993), the eradication of tamarisks has been shown to rejuvenate marshes, such as those along Eagle Borax Spring in Death Valley (Vitousek 1986).

Wet-Meadow Communities

Permanently wet meadows, like persistent streams, are scarce in this arid region, yet they contribute significantly to the region's plant diversity (Linsdale et al. 1952; Loope 1969; Charlet 1991). These habitats also are frequently destroyed by livestock grazing and water diversion (Hammond and McCorkle 1983). Several species at risk are characteristic of these communities. For example, many populations of the silver-bordered fritillary butterfly have been lost because springs were capped (Pyle et al. 1981).

Terminal-Wetland Communities

A distinguishing feature of most of the Great Basin–Mojave Desert region is the drainage of its waters to terminal basins rather than into the ocean. This feature creates isolated terminal lakes, marshes, and playas (Fig. 7), many of which support unique aquatic species. Although most are small and only seasonally filled with water, these wetlands are surprisingly numerous and critically important to the biological diversity and ecology of the region (Table 1).

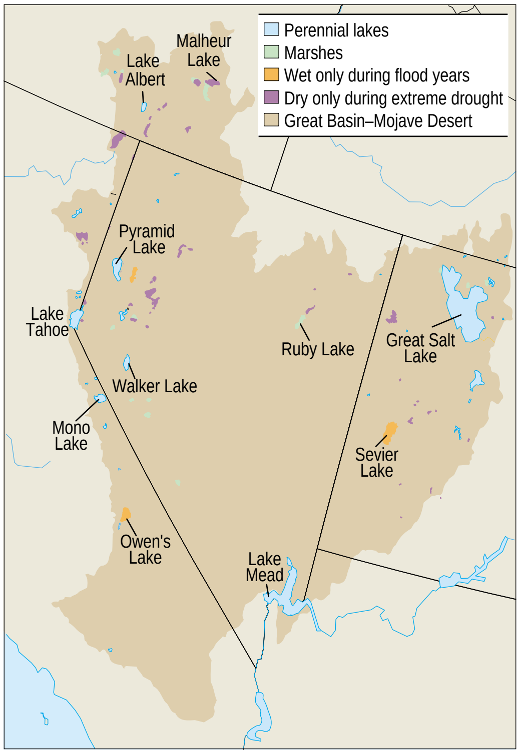


Fig. 7. Terminal wetland ecosystems in the Great Basin–Mojave Desert region.

Water levels in Great Basin–Mojave Desert wetlands are lowered by diversions for agriculture and urban growth; for example, Nevada lost 52% of its wetlands between 1780 and the mid-1980's (Dahl and Johnson 1991). Low water levels are accompanied by an increase in total dissolved solids (TDS) and increasing accumulations of heavy metals such as boron, selenium, arsenic, and mercury. Many of the region's wetlands, including some of the larger ones like Honey Lake, now go dry during low-water years.

All the wetlands of the region are important to waterbirds. Mono Lake and the Great Salt Lake already have high levels of TDS, and if TDS concentrations increase further, these lakes may lose their tremendous populations of brine shrimp and brine flies, which are key food sources for migrating waterbirds. Further increases in TDS levels at Walker Lake (associated with lower water levels) could prove fatal to fishes and eliminate them from the lake (Koch et al. 1979; C. A. Stockwell, Biological Resources Research Center, University of Nevada, Reno, unpublished manuscript).

Terrestrial Communities

Absolute Desert

Absolute desert communities (Table 2; Fig. 3) include playas, salt barrens, and sand dunes. When playas fill from rare rains or snow melt, an invertebrate fauna develops that consists of various crustaceans (for example, fairy shrimp) and insects, which in turn supports large populations of migratory waterbirds. This fauna has not been studied extensively and may include several undescribed species. The effects of off-highway vehicles on these organisms are unknown but are probably detrimental (R. C. Stebbins 1974).

Mojavean Zone

The Mojavean vegetation zone (Fig. 8) encompasses most of the geographic area of the Mojave Desert except the higher mountains. The flora and communities in this zone are characterized by great diversity, and only half of its 545 plant species also occur in the Sonoran Desert (Vasek and Barbour 1990). Several vegetation types are recognized in the Mojavean zone: creosotebush scrub, saltbush scrub, shadscale scrub, blackbrush scrub, Joshua-tree woodland, and annual vegetation (Vasek and Barbour 1990). The highest mountains within the boundaries of the Mojavean zone (the Sheep Range, and White, Spring, and Panamint mountains) exhibit most of the Great Basin vegetation zones and thus resemble high mountains in the Great Basin.

Las Vegas, the fastest growing city in the United States, lies in the northeastern part of the Mojave Desert. This growth and the lack of local persistent streams create an unprecedented demand on groundwater in the area. Exploitation of groundwater in the Pahranagat and Moapa valleys has significantly altered the hydrology of the area and has harmed riparian communities (Runeckles 1982; Franklin et al. 1987; Busch and Smith 1995). The fishes are restricted to springs and streams in the area. Tamarisk has invaded and now dominates many riparian areas, causing additional problems. Ironically, "Las Vegas" means "the meadows" in Spanish, but the inspiration for the name vanished early in the city's sprawling growth. This sprawl covers a large portion of the Mojavean zone vegetation with concrete and places at risk the desert tortoise, many other reptiles, and the California bearpaw poppy.

Shadscale Zone

The shadscale vegetation zone is named after its dominant plant species and is the third largest in total area in the region (Table 2; Fig. 3). In addition to shadscale, this area is populated by many other species of widely spaced, drought-tolerant shrubs that are usually thorny with small leaves. In the western Great Basin and in the Bonneville Basin, this zone occurs primarily on slightly saline soils on the periphery of ancient lake beds. In the Mojave Desert and in the mountains of southern Utah, it also occurs on rocky upland sites that are too dry to support sagebrush (Billings 1949). Greasewood is the

Table 1. Status of terminal wetlands in the Great Basin–Mojave Desert region.

Terminal wetland	Status
Nevada	
Artesia Lake	Dry during 1987–1994; currently refilling
Carson Lake	Selenium and boron are contaminants during low-water years; Public Law 101–618 should effect an increase of water levels and quality (U.S. Fish and Wildlife Service 1992)
Duck Flat	Episodically dries
Fallon National Wildlife Refuge	Dry during 1987–1994; currently refilling
Fernley Sink	Dry during 1987–1994; currently refilling
Humboldt Wildlife Management Area	Water levels were low from 1987 to 1994; total dissolved solids were high enough to kill duck chicks; high arsenic and selenium levels caused problems through bioaccumulation; current water levels are high
Mason Valley Wildlife Management Area	The hatchery outflow provides a reliable source of water; effects of a recent drought are being alleviated
Pyramid Lake	Very reduced lake levels; reduced inflows prevented spawning by the cui-ui and the Lahontan cutthrout trout until 1995
Ruby Lake and Ruby Marsh	Fed by 200 springs; water level in 1994 was 61 centimeters below targeted level; heavy metals were expected to become harmful
Soda Lake	Some effects from drought; high brine fly production; important to migrating red-necked phalaropes
Stillwater Wildlife Management Area	Water levels were low from 1987 to 1994; selenium, boron, and salinity levels were high; Public Law 101–618 should effect an increase of water levels and quality during drought years; water levels currently high
Washoe Lake	Dry during the 1930's and 1960's and during 1991–1994; currently high water level; historically very productive
Winnemucca Lake	Dry since 1938
Walker Lake	Rapidly decreasing water levels until 1994, when total dissolved solids approached levels that are fatal to fishes; water level currently stabilized
Southeastern Oregon	
Abert Lake	Lowest water level in past 18 years because of drought and water diversion; relatively clean; naturally high level of total dissolved solids; brine fly populations are low because of increased total dissolved solids
Alkali Lake	Chemical residue in water because of nearby disposal site
Alvord Hot Springs	Dry during recent drought
Bacus Lake	Water levels follow those of Malheur Lake
Malheur Lake	High precipitation in 1980–1986 increased the size of the lake; by fall 1992, lake size had been reduced to a historical low; in 1994, water levels continued to decline
Silver Lake	Dry since early 1980's from irrigation diversions
Stinking Lake	Dry during drought
Summer Lake	At 0.25 capacity as of fall 1994; relatively pesticide-free; wetlands are maintained regardless of lake level
Warner Wetlands	During 1983–1984, highest water level in recorded history; during 1985–1990, completely dry because of diversions and drought
Eastern California	
Clear Lake	Irrigation reservoir; turbid
Eagle Lake	Steady decline of water level from 1987 to 1994 because of drought; currently refilling
Goose Lake	No contamination; water diverted for farming
Honey Lake	Seasonally dry; possible chemical contamination; currently refilling
Lake Tahoe	1994 water level was below rim; in June 1995 water level was above rim; record high levels in January 1997
Modoc National Wildlife Refuge	Irrigation reservoir; no contamination
Mono Lake	High level of total dissolved solids; in accordance with legal settlements, water level will be raised
Owens Lake	Dry since 1957

common phreatophyte (plant requiring groundwater) in the zone (Holmgren 1972).

The rapid decline in the last 100 years of the important browse shrub, winterfat, and its replacement by nonindigenous annual species are clearly documented with photographs (Rogers 1982). This decline is due to heavy grazing by domestic livestock (Billings 1951; Holmgren 1972). An associated change of particular concern is the increase of the nonindigenous weed halogeton, which is often fatal to domestic stock (Holmgren 1972). Tamarisk is also rapidly invading and dominating riparian areas in this zone.

Sagebrush–Grass Zone

Although the principal shrub in this zone is big sagebrush, several other sagebrush species and subspecies also occur and can be locally dominant. Because precipitation is higher in the sagebrush–grass zone than in the shadscale zone (Billings 1949), this zone can support a surprisingly high richness of shrubs, grasses, and perennial forbs (Fig. 9). The sagebrush–grass zone is the largest (Table 2) and most contiguous vegetation zone in the region (Fig. 3).

One of the most significant changes in the sagebrush–grass zone has been the invasion of introduced plant species such as cheatgrass, halogeton, and other annuals, at the expense of the native bunchgrasses and forbs (Young et al. 1972; Rogers 1982). The sagebrush–grass zone

Table 2. Total area and percent of region occupied by the eight vegetation zones in the Great Basin–Mojave Desert region.

Vegetation zone	Total area in region (square kilometers)	Percent of region
Absolute desert	29,510	5.54
Mojavean	98,068	18.40
Shadscale	91,317	17.13
Sagebrush–grass	206,071	38.66
Pinyon–juniper	60,556	11.36
Western juniper	7,187	1.35
Montane	39,037	7.32
Alpine	1,224	0.23
Total	532,970	99.9[a]

[a] Does not total 100% because of rounding.

© D. A. Charlet, University of Nevada

Fig. 8. Mojavean vegetation zone, eastern base of the Spring Mountains, Nevada.

is contracting because of the downward expansion of the pinyon–juniper zone in the central portion of the region (Blackburn and Tueller 1970) and by western juniper woodlands in the north (Burkhardt and Tisdale 1976; Miller and Wigand 1994; Miller and Rose 1995). Sagebrush–grass communities are being fragmented by agriculture and human population increases, both of which increase the probability of invasion by nonindigenous plant species. This zonal contraction and fragmentation and the increase of nonindigenous plants are further aggravated by livestock grazing and fire suppression. The combination of these factors decreases grass density and increases shrub density (Rice and Westoby 1978; Young and Evans 1978; Anderson and Holte 1981). More than 99% of the sagebrush–grass zone has been negatively affected by livestock, with serious effects in about 30% of the zone (Noss et al. 1995).

© D. A. Charlet, University of Nevada

Fig. 9. Sagebrush–grass vegetation zone, Pueblo Valley, Oregon–Nevada border. The Pine Forest Range is in the distance.

Pinyon–Juniper and Western Juniper Zones

The pinyon–juniper zone was defined by Billings (1951) as the lowest in elevation of the montane zones. Here we follow Holmgren (1972) and map the unit as a separate zone because of its large size and ecological significance. Billings (1954a) found that thermal belts and higher precipitation on the mountain slopes contributed to the formation and maintenance of the zone, which is characterized by woodlands of pinyon pine and several species of juniper in various combinations. Understories are composed of grasses, perennial forbs, and shrubs (principally sagebrush and bitterbrush), and several gooseberry species are also common. By far the most abundant pinyon pine is singleleaf pinyon, but Colorado pinyon pine occurs in the Utah portion of the region (Lanner 1984). Utah juniper is the dominant juniper in the zone, but western juniper and Rocky Mountain juniper may enter the zone at its higher reaches or along streams. This zone is extensive throughout the Great Basin south of the Humboldt and Truckee river drainages and is sparse in the northern Lahontan River basin; it disappears altogether in Oregon. The zone barely extends into Idaho, east of the Humboldt River drainage. Many higher mountains in the Mojave Desert (for example, Providence, Panamint, Sheep, and Spring mountains) also support pinyon–juniper woodlands.

Higher precipitation and colder climate distinguish western juniper woodlands from those with pinyon or Utah juniper (Wigand and Nowak 1992). This zone dominates much of southeastern and central Oregon, northeastern California, and extreme northwestern Nevada (Fig. 3).

The pinyon–juniper and western juniper zones are spreading throughout the Great Basin. Tree densities increased dramatically in the last 100–150 years (Tausch et al. 1981; Rogers 1982). The abundance of Utah juniper clearly has increased in the Bonneville Basin since the late 1800's (Rogers 1982), and Utah juniper and singleleaf pinyon are also invading black sagebrush communities in east-central Nevada west of the Bonneville Basin (Blackburn and Tueller 1970). Increased tree density is accompanied by a decline in understory density and diversity, and in severely degraded juniper stands virtually all herb species can be excluded (Tausch and Tueller 1990; Charlet 1996, 1997). Such a landscape has little value as livestock forage or wildlife habitat.

Singleleaf pinyon also is spreading wherever it occurs in the Great Basin, particularly in western Nevada (Billings 1951). During the last 250 years, the species advanced north across the Truckee River into Peavine Mountain, the Virginia Mountains, the Junction House Range, and the Pah Rah Range (Charlet 1996). Western juniper is increasing its range and abundance in the northern part of the region in southern and central Oregon (Miller and Wigand 1994; Miller and Rose 1995) and in southwestern Idaho (Burkhardt and Tisdale 1976).

This woodland expansion is largely a result of a combination of fire suppression and overgrazing. These factors lead to a decline of browse and grass species that competitively exclude juniper and provide the fuels to carry fires that restrict junipers to rocky sites (Burkhardt and Tisdale 1976). Extreme measures, including chaining (Tidwell 1986), burning (Bunting 1986), and poisoning (Johnson 1986) have been used in attempts to control this expansion.

Montane Zone

Billings (1951) divided the mountain vegetation above the sagebrush–grass zone into several montane zones in three geographic series. We, however, followed Holmgren (1972) by mapping the pinyon–juniper zone and the alpine zone separately from the remainder of the montane series (Fig. 3). Smaller species of sagebrush (for example, Vasey's sagebrush and little sagebrush) are dominant plants above the pinyon–juniper zone and are associated with a different suite of shrubs and grasses than those in sagebrush–grass communities below the pinyon–juniper zone. These are productive communities that provide important forage for wildlife and livestock.

A common feature of the montane zone is the widespread occurrence of quaking aspens (Fig. 10). In many northern mountain ranges, aspens form extensive pure forest stands. Because these ranges usually contain few or no conifer (cone-bearing) species, aspens provide important habitats for birds and other wildlife. Curlleaf mountain-mahogany also provides important shelter and nesting sites and usually occurs in rocky, ridgeline situations. A close relative, the Mexican cliffrose, replaces it in the Mojave Desert mountains in similar but hotter and drier situations.

Forests of western juniper occur in the montane zone on the northern slope of Steens Mountain, Oregon (Holmgren 1972), and the species also extends into the montane zone of a few western Great Basin mountain ranges (Vasek 1966; Charlet 1996). High-diversity coniferous forests are abundant in the Carson Range, a spur of the Sierra Nevada along the western boundary of the region. Only 2 of the 15 conifer species in the Carson Range do not also inhabit western Great Basin mountain ranges (Charlet 1996).


© D. A. Charlet, University of Nevada

Fig. 10. Quaking aspens along Lye Creek in the Santa Rosa Range, Nevada. Granite Peak is in the distance.

Along the eastern boundary of the Great Basin region, forest fragments and extensive woodlands characteristic of the Rocky Mountains occur in the Wasatch Range (Billings 1951, 1990; Holmgren 1972). A few Great Basin–Mojave Desert mountain ranges (for example, Snake Range, Spring Mountains) support montane coniferous forests, but these are usually small and have few conifer species. However, subalpine woodlands (Fig. 11), with various mixtures of whitebark, bristlecone, limber, and lodgepole pines, and other conifers, occur in most of the higher mountains of the region (Charlet 1996).

Several forest trees have been extirpated during this century. For example, Douglas-fir has been lost from two mountain ranges in northern


© D. A. Charlet, University of Nevada

Fig. 11. Subalpine woodlands and meadows of the montane zone at Cougar and Prospect peaks, Jarbidge Mountains, Nevada.

Nevada since 1937 (Loope 1969; Charlet 1996), and California white fir probably was extirpated from Petersen Mountain, Nevada, by a fire in 1994 (Charlet 1996). Many conifer stands and their associates are susceptible to extirpation throughout the region, and fires may leave bald mountains (Billings and Mark 1957) in areas that can only marginally support trees. The loss of trees subsequently causes a rapid deterioration of conditions that are suitable to forest development (Billings and Mark 1957).

Increased success of subalpine conifer seedlings at higher elevations has been observed throughout the region. For example, whitebark pine and subalpine fir are moving toward the summits of the Jarbidge Mountains on the northern border of the region (Charlet 1996). Studies of tree rings revealed accelerated growth rates during the last 100 years in upper treeline trees such as limber pine in the Toquima Range and Great Basin bristlecone pine in the White Mountains (M. Rose, Desert Research Institute, Reno, Nevada, personal communication).

Alpine Zone

The alpine zone begins at the limit of the upper treeline. In the Great Basin–Mojave Desert region, the zone is tiny and restricted to only a few of the highest mountain ranges (Fig. 3). True alpine tundra is present in small local areas in the Ruby (Loope 1969), Sweetwater (Lavin 1981), White (Billings 1978), Toiyabe (Linsdale et al. 1952), and Toquima (Charlet 1997) mountain ranges. Alpinelike habitats also occur on many of the mountain ranges that do not have an upper treeline, such as the Spring Mountains and the Santa Rosa and Pine Forest ranges in Nevada and Steens Mountain in Oregon. In most of the mountains with an alpine zone, more alpine area is occupied by talus slopes, cliffs, rocky ridges, and peaks than by alpine tundra. Nevertheless, small patches of tundra, alpine bogs, and springs host many alpine plant species that occur nowhere else in that mountain range. The alpine flora of the Great Basin, with about 600 species, is as diverse as that of either the Rocky Mountains or the Sierra Nevada at equivalent latitudes (Charlet 1991). This richness of alpine species suggests that there was a greatly expanded alpine zone throughout much of the region during the Pleistocene Epoch.

Subnormal precipitation and higher temperatures during 1971–1994 (H. Klieforth, Desert Research Institute, University of Nevada System, Reno, personal communication) reduced snow cover and caused the demise of many perennial snowfields in the region. This allowed subalpine woodlands to encroach on the alpine zone, reducing its already tiny size. Reduced snow cover is detrimental for many plant species in alpine communities such as Eschscholtz's buttercup, which occurs around snowbanks; white bog-orchid, swamp laurel, and sphagnum moss, which are associated with bogs; and louseworts, shooting stars, and ladies' tresses, which are characteristic of springs (Charlet 1991).

Biodiversity Hot Spots

The Nevada Natural Heritage Program (1992) recognizes 101 locations in Nevada as areas with many rare species—biodiversity hot spots—based on the total number of sensitive species of all groups. Eighteen of these sites were identified and ranked on the basis of worldwide endangered subspecies and varieties, protection urgency, and management urgency (Nevada Natural Heritage Program 1992). Detailed maps of sensitive species of all taxonomic groups have been prepared for the Spring Mountains of southern Nevada (The Nature Conservancy 1994). The Spring Mountains are of particular concern for conservation because they are one of only two ranges (the other is the White Mountains) that contain all the vegetation zones in the Great Basin–Mojave Desert region. As a consequence, the Spring Mountains and the White Mountains have a great many species. The Spring Mountains are also unique because about 20% of the endemic plant species of Nevada—those found only in that state—occur there. In the exploratory study of the Spring Mountains, 23 areas of concern were mapped and described as biodiversity hot spots (The Nature Conservancy 1994).

Recognition of areas with particularly high biological diversity, regardless of the status of the taxa, is only at its beginning stages in the Great Basin–Mojave Desert region. Most of this exploratory work has focused on lists of species for local areas. Checklists for vascular plants were prepared for a few highly diverse mountain ranges, and 988 species were identified in the White Mountains (Morefield et al. 1988), more than 625 species in the Ruby and Sweetwater mountains (Charlet 1991), and many more than 500 species in other high ranges such as the Jarbidge, Warner, Toiyabe (Charlet 1991), Toquima, Santa Rosa, and Independence mountains (Charlet, unpublished data). Future mapping efforts of the Nevada Biodiversity Initiative are expected to reveal other areas of high biological diversity.

Montane Islands

Ecological islands of montane and alpine vegetation occur throughout the Great Basin–Mojave Desert region. These isolated, generally small communities have been known to exist for many years (Sudworth 1898, 1913) and have been the subject of serious inquiry for decades (Billings 1950, 1951, 1954b; Vasek 1966; Critchfield and Allenbaugh 1969; Loope 1969; Brown 1971, 1978; Little 1971; Johnson 1975, 1978; Axelrod 1976; Harper et al. 1978; Reveal 1979; Thompson and Mead 1982; Wells 1983; Critchfield 1984a,b; Axelrod and Raven 1985; Wilcox et al. 1986; Grayson 1987; Charlet 1991; Morefield 1992). The wide distribution of these habitats and the large number of species they support add greatly to the biological diversity of the region and to the potential resilience of the region in response to climatic change (Wharton et al. 1990; Charlet 1991).

Contemporary populations of 16 montane mammal species are presently isolated on mountains, and probably have been since the Pleistocene Epoch (Brown 1971, 1978; Grayson 1987; Mead 1987). Palmer's chipmunk is the only full species of mammal that is endemic to the Great Basin, while 15 endemic subspecies of 8 other species are montane isolates (Hall 1981; Table 3). Fossils indicate that populations of montane mammals occurred throughout the region during the Pleistocene Epoch (Grayson 1987). Exploratory research on the extinction of the region's montane mammals has included comparisons of current species assemblages above 2,300 meters in individual mountain ranges with species assemblages in the Rocky Mountains and Sierra Nevada (Brown 1971, 1978; Patterson 1984; Patterson and Atmar 1986; Belovsky 1987). The studies revealed that warm, dry periods during the Holocene Epoch reduced population sizes of montane mammals in the region and led to the extinction of many of their populations. If extirpated, relict mammal populations that are isolated on montane islands probably could not recolonize under current climatic conditions. Such extirpations may eliminate genetically unique populations; this threat has clear implications for the management of high-altitude environments in the Great Basin (Grayson 1987).

Table 3. Mammal taxa confined to montane habitats in the Great Basin–Mojave Desert region (Hall 1981).

Scientific name	Common name
Eutamias panamintinus panamintinus	Panamint chipmunk
E. panamintinus acrus	
E. umbrinus inyoensis	Uinta chipmunk
E. umbrinus nevadensis	
E. palmeri	Palmer's chipmunk
E. amoenus monoensis	Yellow-pine chipmunk
Spermophilus lateralis certus	Golden-mantled ground squirrel
S. lateralis bernardinus	
Neotoma cinerea lucida	Bushy-tailed woodrat
Marmota flaviventris parvula	Yellow-bellied marmot
M. flaviventris fortirostris	
Ochotona princeps nevadensis	Pika
O. princeps tutelata	
O. princeps sheltoni	
O. princeps albata	
Microtus longicaudus latus	Long-tailed vole
Zapus princeps curtatus	Western jumping mouse

Lowland Aquatic and Riparian Endemism

Fishes are the best-known native aquatic species in the region. Aquatic invertebrates may be equally diverse (Hershler and Pratt 1990), but relatively little is known about them. Riparian butterflies, however, have been well studied and show rather striking endemism in the region, far more so than in montane areas (Austin 1985, 1992). In the northern Great Basin, 27 species of butterflies are closely associated with lowland riparian vegetation. Of these, 9 (33%) have differentiated into 23 endemic subspecies. The most extensive subspeciation has occurred in the common wood nymph butterfly; nine subspecies are endemic to the Great Basin (Austin 1992). These butterflies evidently evolved in response to Holocene droughts that resulted in the isolation of remnant waters and their associated riparian communities.

Sand Dunes

At least 52 unconsolidated sand dunes occur in the region, 32 in Nevada (Fig. 12). These dunes were formed during the Holocene Epoch (Morrison 1964; Smith 1982; Lancaster 1988a,b; 1989; Dohrenwend et al. 1991) and are unique habitats because they are rare, small, of recent origin, and spatially dynamic. The dunes

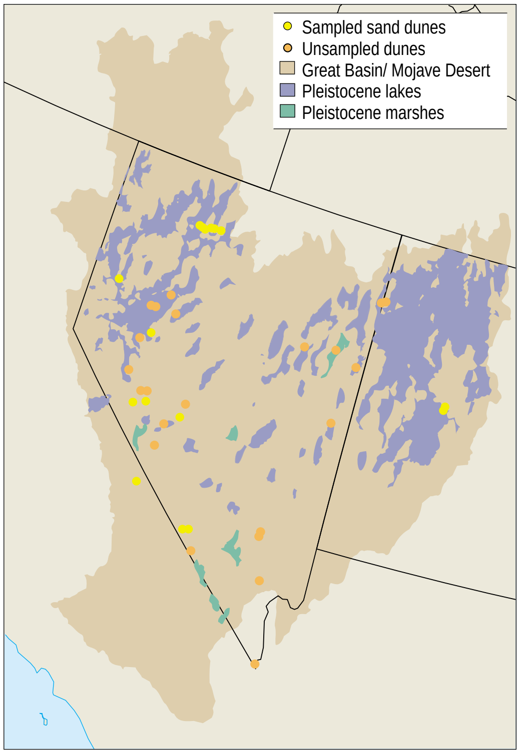


Fig. 12. Sand dunes of the Nevada portion of the Great Basin–Mojave Desert region.

support a diverse group of animals (Hall 1946; Brown 1973) and plants (Pavlik 1985, 1989) that have responded with special adaptations to the unique challenges of this harsh environment (Fig. 13).

Beetles are the best-studied group of sand dune invertebrates (Fig. 14). Most are either predators or are dependent as adults on fine organic debris, and the larvae of many species feed on plant roots. Most dune beetles depend on vegetation around the base of the dunes for adult or larval forage, mating sites, and protective cover. Ten Nevada sand dune beetle species are species of concern (U.S. Fish and Wildlife Service 1994a), including Giuliani's dune scarab from the Big Dune, the large aegialian scarab from the Big and Lava dunes, and several unnamed species of scarabs on the Big, Crescent, and Sand Mountain dunes. Additional sand dune insects that are species of concern from the region include the Sand Mountain pallid blue butterfly, Nelson's miloderes weevil, the Kelso giant sand treader cricket, and the Kelso Jerusalem cricket (U.S. Fish and Wildlife Service 1994a). Many of these species are highly endemic (confined to one or a few dunes). Small geographic distributions and habitat destruction by off-highway vehicles (Luckenbach and Bury 1983) are the greatest threats to their persistence.


Fig. 13. Eureka Dune in Eureka Valley, Death Valley National Park, California. Eureka Dune is the tallest sand dune in North America.

© D. A. Charlet, University of Nevada

Edaphic Communities

Communities that resemble the montane coniferous forest vegetation of the Sierra Nevada are scattered throughout much of the west-central Great Basin in a matrix of pinyon–juniper woodlands (DeLucia et al. 1988). More than 140 of these communities occur in edaphic sites (Billings 1950, 1990). These sites are well removed from the main body of Sierran forests and range from 1 to 15 hectares (DeLucia and Schlesinger 1990). The endemic altered buckwheat, a candidate for federal listing, occurs exclusively in these disjunct Sierran communities. The closest relative of this species, Lobb buckwheat, is restricted to high elevations in the Sierra Nevada. Seventy-four species of wild buckwheat and many more subspecies and varieties are native to Nevada (Reveal 1985, 1989; Kartesz 1988). One of the features of the buckwheat genus that contributes to its high diversity is its ability to occupy unusual soils. For example, Tiehm buckwheat is a candidate species that occurs in clays in the Silver Peak Range of western Nevada, Sulphur Springs buckwheat is from the Ruby Valley of northeastern Nevada, and the endangered Steamboat buckwheat grows at Steamboat Hot Springs in western Nevada.


Fig. 14. *Eusattus muricatus*, a darkling ground beetle at Sand Mountain, Nevada.

© R. W. Rust, University of Nevada

In the Mojave Desert, gypsum forms an unusual soil that supports many narrowly endemic plant species especially adapted to these conditions (Meyer 1986), including the endangered California bearpaw poppy. The Bureau of Land Management is currently mapping these edaphic units in detail (S. D. Smith, University of Nevada, Las Vegas, personal communication). Endemics that are restricted to limestone are important in canyons east of Death Valley (Raven 1988).

Status of the Biota

Fungi

Fungi are essential for community health because they decompose dead organic material, making nutrients again available for plants. Unfortunately, the fungi of the Great Basin–Mojave Desert region are virtually unknown. A survey of stalked puffballs was started in 1975 to help fill this void. About 700 collections of this group and all other encountered macrofungi have been made, but vast areas of the region have not yet been covered (Fig. 15).

Plants

Although large numbers of sensitive plant species are found in local areas, sensitive plants display no distinctive geographic or ecological patterns in the Great Basin–Mojave Desert region. Sensitive species occur in all areas and vegetation zones (J. Morefield, Nevada Natural Heritage Program, Reno, personal communication), and rare and endemic plant species occur in many types of habitats, from alpine summits to sand dunes. Many sensitive plants are restricted to edaphic habitat islands such as alkaline, limestone, or gypsum soils in the southern part of the region and soils derived from volcanic ash in the north. Throughout the

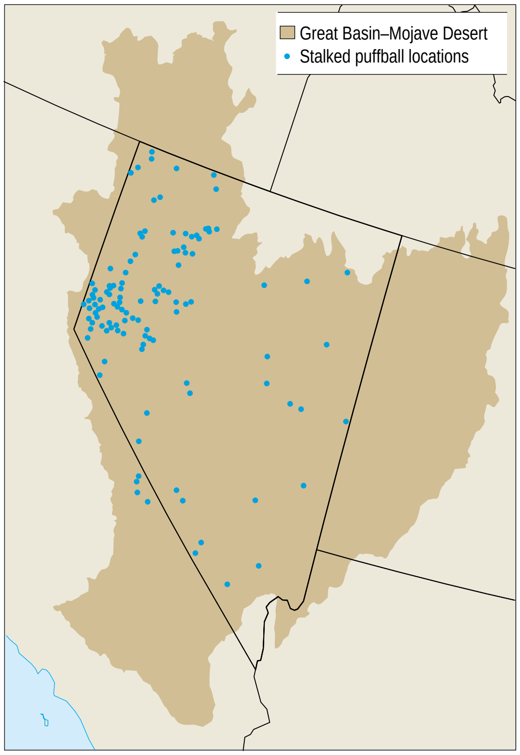


Fig. 15. Collection sites for stalked puffballs, a fungus, in Nevada and adjacent California.

region, hot springs often host narrowly restricted native species.

Populations of most sensitive plant species are presumably stable (Morefield, personal communication), but there are several exceptions. The California bearpaw poppy on gypsum soils in the Mojave Desert is seriously threatened by the expanding urbanization in the Las Vegas Valley. The persistence of the endangered Steamboat buckwheat, known only from ancient hot springs south of Reno, is of concern. This site is on private land that was recently developed for a geothermal power plant, and the species is therefore not protected by the Endangered Species Act of 1973. However, Nevada law (Nevada R.S. 527.260–527.300) prohibits the destruction of sensitive species listed by the state forester fire warden except by special permit. This statute was invoked to protect the species, and a cooperative venture was initiated between the developer, The Nature Conservancy, the State of Nevada Division of Forestry, and the Nevada Natural Heritage Program. As a result, the development proceeded, and a small portion of the Steamboat buckwheat population was transplanted to a nearby location. So far, the transplanted buckwheats are doing well, but a large portion of the plant's habitat is still on private lands that may be developed.

Assistance with the preservation of Grime's vetchling, a species of concern (U.S. Fish and Wildlife Service 1994a), was recently provided by a mining company in northeastern Nevada. This relative of the sweet pea was known only from a single population in the Independence Mountains (Barneby 1989). The mining company had proposed expansion of its exploration into the area occupied by Grime's vetchling and provided a helicopter to conduct aerial surveys of the species. Ground inspection of sites spotted from the air revealed 60 additional populations of the species (Morefield, personal communication).

Many plant species in alpine and montane habitat islands are uncommon in the region but are not candidates for listing because they are abundant outside of the Great Basin. Although the species are not globally threatened, the potential for dispersal and recolonization in the Great Basin and Mojave Desert in a different climatic regime is now small.

Invertebrates

Invertebrates make up 95% of the animals on Earth and are critical for ensuring community health (Mason 1995). Invertebrates generally experience the environment on much smaller spatial and shorter temporal scales than larger animals. As a result, invertebrates are extraordinarily susceptible to natural and human-caused habitat modifications (Mason 1995). Larvae and adults of the same species may rely on entirely different resources, including food plants, microhabitats, and solar insolation regimes (Weiss et al. 1988; New 1991). Consequently, many invertebrates are sensitive not only to habitat alterations that change vegetation structure but also to those that perturb microclimate (Thomas 1983, 1991; Dobkin 1985; Dobkin et al. 1987; Murphy et al. 1990). Therefore, land use patterns are important for the persistence of invertebrate populations at the regional scale and at the level of microhabitats (Hammond and McCorkle 1983; Dobkin et al. 1987; Weiss et al. 1988; Kremen 1992). Thomas (1984:337) noted that some invertebrates may be "extremely particular about the niches they occupy," and that "seemingly minor" modifications in land management or habitat structure may have major repercussions on the suitability of a given site for eggs and larvae. Land management is also critical to invertebrates that depend on a level of plant quality and abundance specific to a given successional stage (Scott 1986; Murphy et al. 1990; Thomas 1991).

The restricted mobility of many invertebrates that inhabit the diverse habitat islands in the Great Basin–Mojave Desert region renders them increasingly vulnerable to habitat disturbance. Many invertebrates have highly specialized adaptations, and the reestablishment of extirpated populations becomes less probable in degraded and fragmented habitats. Thus, invertebrates are of substantial conservation concern.

Terrestrial Invertebrates

Several groups of terrestrial invertebrates are well known in the region. The ants and butterflies are perhaps the most collected and studied groups of insects (Austin 1992; Wheeler and Wheeler 1986). The mosquitoes were studied by Chapman (1966), and the grasshoppers and crickets are well represented in collections of 179 known species and more than 3,000 identified specimens (J. B. Knight, Nevada Department of Agriculture, Reno, personal communication). However, most systematic entomologists consider collections of almost all other insect groups from the Great Basin to be insufficient, and most investigators report new, undescribed species (Rust 1986; Austin 1992) or geographic range extensions. Until the taxonomy of the region's insect fauna is better known, an assessment of species of concern is difficult.

Aquatic Invertebrates

The aquatic invertebrate fauna in the region shares species with the adjacent regions, especially the Rocky Mountains; species that also occur in the Sierra Nevada are not as widely distributed in the Great Basin (Nelson 1994). *Speciation* (the evolutionary formation of new species) in the region has probably occurred frequently because of recurring fragmentation and reconnection of the wetlands during the past million years. This pattern is now being documented for springsnails (Hershler and Sada 1987; Hershler 1989, 1994; Hershler and Pratt 1990). As with the terrestrial species, hundreds of native aquatic invertebrates probably exist in the Great Basin but have not been described (see Channel Islands and California Desert Snail Fauna box in California chapter).

General phenomena that affect aquatic invertebrates have been studied in other areas and probably also apply to the Great Basin. The composition of aquatic insect communities changes after the damming of waterways (Ward 1984; Williams and Feltmate 1992) and the release of mining waste (Ward 1984; Wiederholm 1984; Williams and Feltmate 1992). Furthermore, changes in water temperature after removal of vegetation, the presence of heavy metals in the water, and eutrophication of lakes are detrimental to aquatic insects (Ward 1984; Wiederholm 1984).

Kremen et al. (1993) suggested that terrestrial arthropods are appropriate indicators of the need for conservation, and aquatic insects are probably equally appropriate indicators of the need for conservation of aquatic communities. Aquatic invertebrate communities are useful for evaluating water quality because they respond to low-level disturbances, function as monitors (Chandler 1970; Erman 1991), and may be indicators of conditions for terrestrial plant communities (Erman 1991). Because the abundances of aquatic organisms are declining much more rapidly than those of their terrestrial counterparts (Moyle and Yoshiyama 1994), studies are clearly needed. Although aquatic invertebrates in other areas of the country have been used for evaluating alterations to stream communities, few studies have been done in the Great Basin–Mojave Desert region.

Vulnerable Invertebrates

Specific information on the conservation status of almost all sensitive invertebrates in the Great Basin–Mojave Desert region is completely lacking. For example, only the Ash Meadows naucorid is listed as threatened, and 1 grasshopper, 13 beetles, 27 moths and butterflies, 16 snails, 1 mussel, 1 stonefly, and 1 wasp in Nevada are species of concern (U.S. Fish and Wildlife Service 1994a; Table 4). As studies of invertebrates progress, this number will probably increase. A previously undescribed riffle beetle was recently discovered in Ash Spring in the Pahranagat Valley and will probably be recommended for federal listing (Schmude and Brown 1991).

Two examples of vulnerable invertebrates include the Apache nokomis fritillary and the Giuliani's dune scarab. The Apache nokomis fritillary is a showy, monarch-sized butterfly that is confined to wet areas, including riparian corridors, seeps, and damp meadows across the Great Basin. The species of violet on which the larvae feed and the thistles from which the adults take nectar are confined to these moist habitats. Although the butterfly is physically capable of dispersing over large distances, observations and genetic studies have revealed that it rarely ventures far from its small, insular patches of habitat. Thus, each colony is a semi-isolated population that is rarely recolonized after extirpation. Several colonies were

Table 4. Sensitive aquatic insects in the Great Basin–Mojave Desert region.

Common name	Scientific name	Category listing[a]
Lake Tahoe benthic stonefly	*Capnia lacustra*	S
Ash Meadows naucorid	*Ambrysus amargosus*	T
Death Valley agabus diving beetle	*Agabus rumppi*	S
Devil's Hole warm spring riffle beetle	*Stenelmis calida calida*	S
Moapa warm spring riffle beetle	*S. calida moapa*	S
Travertine bandthigh diving beetle	*Hygrotus fontinalis*	S
Amargosa naucorid	*Pelocoris shoshone amargosus*	S

[a] S = species of concern (previously treated as Category 2 species; U.S. Fish and Wildlife Service 1994a); T = threatened

destroyed by agricultural development in recent years. A related although still unnamed subspecies of the Apache nokomis fritillary from the Carson Valley is a species of concern (U.S. Fish and Wildlife Service 1994a).

Giuliani's dune scarab occurs only at Big Dune and Lava Dune in the southern Great Basin of Nevada and, because of its restricted geographic range and rarity, it became a candidate for federal listing in May 1984, although it is now considered a species of concern (U.S. Fish and Wildlife Service 1994a). Surveys of the beetle in 1993 and 1994 revealed the presence of fewer than 10 individuals at each survey site. This unique species is at high risk of extinction because it is present at only a few isolated sites and is abundant nowhere. No one knows how many other invertebrate species are in similar situations across the region.

Fishes

Fifty-six species and 75 subspecies of fishes occurred historically in the Great Basin–Mojave Desert region. Of these 131 taxa, 10 (8%) are now extinct. Of the remaining 121, 75 (62%) are listed, are candidates for federal listing, or are species of concern (U.S. Fish and Wildlife Service 1994a). More than 40% of the species and 90% of the subspecies are endemics. The causes of nearly all, if not all, declines in desert fish populations can be traced directly to human activities. Deacon (1979) recognized that habitat modification (including damming, diverting, and channelizing waterways; overgrazing; and other forms of human disturbance) was the largest contributor to the endangerment of desert fishes. Biotic interactions (including hybridization, competition, and predation), primarily with introduced fish species, are the second largest contributor to the endangerment of desert fishes. Given the pervasiveness of water development and introductions of nonindigenous fishes, probably few fish populations in the West remain unaffected. Minckley and Douglas (1991:15) succinctly summarize problems faced by desert fishes: "All major streams in the western United States are dammed, controlled, and overallocated. . . . Groundwaters are pumped at rates greatly exceeding those at which aquifers can be recharged." Clearly, this does not bode well for the future of the region's fishes or for its human inhabitants.

The entire fish fauna of the Virgin River in the southeastern part of the region is imperiled. The native fauna includes two endangered species (the woundfin and the Virgin River chub), one subspecies proposed as threatened (the Virgin spinedace), and at least one other candidate species. Despite management, the long-term persistence of native fish populations in the Virgin River continues to be doubtful. The recent use of rotenone to rid the system of nonindigenous red shiners severely harmed the native species and may have resulted in the loss of genetic variation in at least the Virgin River chub (Demarais et al. 1993).

The survival of native fishes in the Colorado River is also in doubt. The damming of this river drastically altered flow and temperature regimes, and many nonindigenous species have been introduced. Most of the larger native fishes such as the Colorado squawfish, the humpback and bonytail chubs, and the razorback sucker are endangered; it is unlikely that an effective preserve for these fishes can be established. Although dams could be regulated to maintain a more natural flow regime, this action is politically impossible on a river with overallocated water resources on which so many people depend.

The extensive isolation and close adaptation to specific circumstances by most desert fish species are illustrated by the six distinct subspecies of the Amargosa pupfish: the Amargosa, Tecopa, Ash Meadows, Saratoga Springs, Warm Springs, and Shoshone pupfishes. Each of these subspecies occurs in a single spring or small group of springs in the Amargosa Valley of southern Nevada and eastern California (Fig. 16). Two of the subspecies, the Ash Meadows and the Warm Springs pupfishes, are listed as endangered. Two more of the subspecies are species of concern (U.S. Fish and Wildlife Service 1994a). At least one subspecies, the Tecopa pupfish, is probably extinct (Sigler and Sigler 1994).

The problems of the Amargosa pupfish and all desert fishes can be summarized quite simply: water in the desert is scarce, humans want more than they require, and the fishes

© D. A. Charlet, University of Nevada

Fig. 16. The Amargosa Valley and Ash Meadows from Devils Hole Hills, Nevada. This area supports many endemic species.

must have it. Although desert fishes have a tenuous hold on survival under natural conditions, occurring only in the few permanent springs, rivers, and lakes of the region, their plight has been exacerbated greatly by human activities. The pumping of groundwater for agriculture nearly eliminated several Amargosa pupfish populations, including the Devils Hole pupfish and several other native endemic species (Deacon and Williams 1991). Grazing by cattle in riparian areas has increased sedimentation and siltation, reducing spawning of the threatened Lahontan cutthroat trout. Diversion of most of the flow of the Truckee River by the Newlands Project in 1906 to support agriculture in the Fallon area eliminated the largest known strain of cutthroat trout, the Pyramid Lake strain, and nearly wiped out another endemic fish, the endangered cui-ui. Anglers also pose a threat to desert fishes, not through direct take but by stocking waters with nonindigenous game fishes. Eighty-one species of nonindigenous fishes have been introduced in the region, and 28 species of nonindigenous game fishes have become naturalized or are currently released. Many of these have been implicated in the decline of native species.

One of the greatest concerns affecting survival of many fishes in the desert is the lack of available information on the status of these species. Few long-term studies or monitoring of any fishes other than those listed or proposed for federal listing have been made, and the distributions of many native fishes are poorly known. For example, many undescribed subspecies of the tui chub and speckled dace may exist, and the discovery and formal descriptions of other species or subspecies are possible.

Amphibians

Amphibians are one of the rarest animal groups in the Great Basin–Mojave Desert region because of their high water requirements. Only 22 native species and 2 introduced species occur, and the ranges of many of these barely extend into the region along the eastern Sierra–Cascades or along the western Colorado Plateau and the Wasatch Mountains in Utah. Four native species of frogs and toads are widely distributed throughout: the Great Basin spadefoot, western toad, Pacific chorus frog, and northern leopard frog. Three narrowly distributed natives also are residents: the relict leopard frog, Amargosa toad, and black toad. The introduced bullfrog occurs throughout the region. Of the 22 native amphibian species, 10 (45%) are species of concern or candidates for federal listing (U.S. Fish and Wildlife Service 1994a; Table 5), and several others seem to be declining. Surveys were conducted recently at several sites in northern Nevada where leopard frogs, spotted frogs (Fig. 17), western toads, chorus frogs, and spadefoots had been abundant earlier in this century. All species except the nonindigenous bullfrog are now difficult or impossible to find (P. Hovingh, University of Utah, personal communication).

Table 5. Amphibians of the Great Basin–Mojave Desert region, compiled from Stebbins (1985) and Zeiner et al. (1988).

Common name	Status [a]
Long-toed salamander	N
Tiger salamander	N
Inyo Mountains slender salamander	S
Western toad	N
Yosemite toad	S
Great Plains toad	N
Black toad	S
Southwestern toad	S
Amargosa toad	C
Red-spotted toad	N
Woodhouse's toad	N
Mount Lyell salamander	S
Owens Valley web-toed salamander	S
Boreal chorus frog	N
Pacific chorus frog	N
Canyon treefrog	N
California red-legged frog	PE
Bullfrog	I
Mountain yellow-legged frog	S
Relict leopard frog	N
Northern leopard frog	N
Spotted frog	C
Great Basin spadefoot toad	N

[a] C = Category 1 species; species for which there is adequate information on which to base a proposal to list as threatened or endangered under the Endangered Species Act; S = species of concern (previously treated as Category 2 species; U.S. Fish and Wildlife Service 1994a); I = introduced to the region; PE = proposed endangered; N = not listed.

The Amargosa toad, which is endemic to the Mojave Desert, is probably the most imperiled amphibian in this region. Thirty years ago, the estimated population size of this species was several thousand, but now as few as 15 breeding pairs and perhaps fewer than 100 adults may exist (G. Clemmer, Nevada Natural Heritage Program, Carson City, personal communication; K. Hoff, Biology Department, University of Nevada, Las Vegas, personal communication). Habitat loss and degradation—from grazing, off-highway vehicles, development, and introduced predators—are implicated in the decline of the Amargosa toad. The species is currently a candidate for federal listing (Table 5), although conservation at the local level may make such a listing unnecessary (Clemmer, personal communication).

The shortage of quantitative data on amphibian populations in this region is serious. Management of these species is difficult or impossible without data on current distributions, population trends, and species-specific ecological requirements. Amphibian populations may well disappear from the region even before they have been discovered.

© J. Reaser, Center for Conservation Biology, Stanford University

Fig. 17. Spotted frogs in the Great Basin.

Mojave Desert Reptiles

The Pet Trade and Mojave Desert Lizards

In 1993, 19 commercial pet collectors reported a harvest of 21,794 reptiles in Nevada at an estimated total value of $250,000 (S. Albert, Nevada Division of Wildlife, personal communication). Collectors took 308 chuckwallas (a species of concern; U.S. Fish and Wildlife Service 1994a) from Nevada in 1993 and may have collected more than 400 in 1994. This volume of collecting may harm chuckwalla populations and populations of other large, long-lived species such as desert iguanas and desert collared lizards. Commercially popular species such as California king snakes, Panamint rattlesnakes, long-nosed leopard lizards, Gila monsters, and Mojave Desert sidewinders are similarly at risk from pet-trade collecting.

States adjacent to Nevada eliminated the commercial take of reptiles for the pet trade through law enforcement. Because baseline data on reptile populations in Nevada are not available and the effect of unlimited harvesting of the state's reptiles has never been quantified, the Nevada Fish and Wildlife Commission has been reluctant to eliminate commercial harvesting. However, preliminary studies on several species of large-bodied lizards in southern Nevada revealed declines of lizard populations in areas that are affected by humans (U.S. Fish and Wildlife Service 1989). Leopard lizard abundances are much lower adjacent to roads and where off-highway vehicles are used than in areas that are removed from such effects.

Desert Tortoise

Declines of desert tortoise populations became a major concern of many biologists in the 1970's. The desert tortoise is a long-lived animal with a low reproduction rate, and population persistence depends on the long-term survival of adults (Fig. 18). High adult mortality seems to be the main cause of the population decline. Many factors are responsible for this mortality: direct take by humans (for example, collection for pets or food, shooting, killing and injuring with motor vehicles); habitat loss, degradation, and fragmentation (for example, from roads, agriculture, and residential development); trampling by livestock; predation by common ravens; diseases; and recent droughts (U.S. Fish and Wildlife Service 1994b).

The reversal of population declines in the desert tortoise is possible only if pressure from these factors is greatly alleviated. Protection of the desert tortoise began in 1980 when it was placed on the federal list of threatened species on the Beaver Dam Slope, Utah. In April 1990, the population in the Mojave Desert was listed as threatened (U.S. Fish and Wildlife Service 1990). Critical habitat was delineated in 1994 (U.S. Fish and Wildlife Service 1994c), following guidelines set by a desert tortoise recovery plan, which was released in the same year (U.S. Fish and Wildlife Service 1994b). The recovery plan recommended six recovery units based on genetic, ecological, and behavioral differences found in the species throughout the Mojave Desert. Several desert wildlife management areas on federal lands in these recovery units were proposed to provide protection for the tortoises.

© P. F. Brussard, University of Nevada

Fig. 18. A desert tortoise in the Mojave Desert.

More than 150,000 square kilometers of desert lands recently gained some additional protection under the California Desert Protection Act (Public Law 103–433), which created the Mojave Desert National Preserve. Although the preserve includes parts of two major desert tortoise populations, many activities that contribute to declines of desert tortoise populations—such as residential development and agriculture (U.S. Fish and Wildlife Service 1994b)—are to continue in the preserve. On the positive side, however, the Death Valley and Joshua Tree national monuments were expanded and gained full national park status.

In addition, 69 wilderness study areas were designated wilderness areas by the Bureau of Land Management and were thereby afforded additional protection. The same preserves may protect many other desert species whose populations have declined.

Birds

Vulnerable Birds

Although only three of the Great Basin–Mojave Desert region's bird species are accorded official status as endangered or threatened (bald eagle, peregrine falcon, and southwestern willow flycatcher), an additional 20 species that regularly breed here are candidates for federal listing or are considered sensitive species by either the U.S. Fish and Wildlife Service (1994a), the Bureau of Land Management, or the region's state wildlife agencies. The Columbian sharp-tailed grouse historically occurred in the region but has been extirpated in recent decades, and the western yellow-billed cuckoo's population has been reduced to only a few individuals. Most species of concern are jeopardized by the loss and degradation of habitats which they use during breeding, wintering, or migration.

Almost all of the region's bird species depend on wetland and riparian habitats during at least some phase of their annual cycle. Among the 134 species of migratory land birds that breed regularly in the Great Basin, more than half are associated primarily with riparian habitats (Dobkin 1998). Throughout the arid and semiarid West, an extraordinary diversity of bird species depends on these habitats (Carothers et al. 1974; Knopf et al. 1988a,b; Dobkin 1994a), and degradation and destruction of riparian areas are widely viewed as the most important causes of the decline of land bird populations in western North America (Bock et al. 1993; DeSante and George 1994; Ohmart 1994). Restoration of riparian habitats must become a top priority for land management agencies, many of which are now aware of the importance of protecting and restoring these habitats for birds and other wildlife (Thomas et al. 1979; Warner and Hendrix 1984; Johnson et al. 1985). However, information about the response of bird populations to riparian habitat restoration is scarce (Krueper 1993; Ohmart 1994).

In conjunction with the cessation of livestock grazing on the Hart Mountain and Sheldon national wildlife refuges in the northwestern Great Basin, a long-term study was initiated in 1991 to examine the relation of bird populations to riparian habitat recovery (Dobkin 1994b; Dobkin et al. 1995b). Although many species used riparian habitats during the breeding season (96 at Hart Mountain, 86 at Sheldon), most were represented by only a few individuals. The ten most abundant species accounted for more than half of the total abundance of breeding birds in riparian habitats on both refuges (Dobkin 1994b). The overall composition of birds in riparian habitats was characterized by low species richness and disproportionate representation of a small number of abundant, widespread species. The riparian habitats of the Sheldon National Wildlife Refuge (elevation 1,335–1,855 meters) supported less diverse avifaunas than comparable habitats on Hart Mountain (elevation 1,750–2,250 meters) and were quintessential examples of degraded, lower-elevation Great Basin riparian communities that are numerically dominated by blackbirds. Long-term studies are needed to determine whether recovery of quality riparian bird communities will be as slow and unpredictable in degraded Great Basin habitats as suggested thus far (Dobkin 1994b, 1998).

Nonriparian, shrub-dominated habitats support nearly 20% of the migratory land birds that breed in the Great Basin, and the number of breeding bird species there is second only to that in riparian habitats (Dobkin 1998). In addition, resident species of conservation importance, such as the sage grouse (Dobkin 1995), are linked inextricably to sagebrush-dominated steppe. Although abundances of migratory shrub–steppe birds often vary greatly in time and space (Wiens and Rotenberry 1981; Wiens 1989), DeSante and George (1994) detected widespread population declines of grassland and shrub–steppe birds throughout the western United States and attributed these declines to destruction of grasslands and livestock overgrazing in shrub–steppe habitats (Fleischner 1994). As indicated by Bock et al. (1993), almost all shrub–steppe-nesting birds are probably harmed by livestock grazing. The extreme modification of vegetation structure and plant species composition from overgrazing creates communities that are poor in both plant and bird species. To understand the dynamics of shrub–steppe birds, restored examples are urgently needed of the shrub–steppe communities that existed before livestock were introduced into the region. Such communities are dominated by native perennial grasses and forbs and have only moderate shrub densities (Bock et al. 1993; Dobkin 1995).

Population declines of many bird species that nest in forests in eastern North America have been linked to fragmentation of forest and woodland habitats (Robbins et al. 1989; Terborgh 1989; Ehrlich et al. 1992; Bohning-Gaese et al. 1993; Rich et al. 1994), but few studies have been conducted on the effects of habitat fragmentation on western birds (Dobkin 1994a). Habitat fragmentation, degradation, and loss are threats to birds in the riparian and shrub–steppe communities in the Great Basin. The distribution patterns of many riparian species are area-dependent, and many such species are lost from smaller riparian fragments, such as the Toiyabe Mountains of Nevada (Dobkin and Wilcox 1986). In shrub–steppe habitats of the Snake River Plains in southern Idaho, species such as the sage thrasher, Brewer's sparrow, and sage sparrow select nesting territories based on landscape-scale patterns of size and distribution of shrub habitat patches (Knick and Rotenberry 1995). Fragmentation of native shrub–steppe by major wildfires that now let nonindigenous plant species invade may be an important factor in the decline of bird populations of the shrub–steppe and grasslands in the region. The potential influence of habitat fragmentation in coniferous woodlands and forests of the Great Basin has not been examined.

The shrinking and disturbance of suitable habitat also present problems for many birds during migration. On their annual migration, large numbers of birds of prey and many shorebird species move through the Great Basin. The larger saline and alkaline lakes of the region are critical stopover points for waterbirds such as the eared grebe, Wilson's phalarope, and red-necked phalarope (Jehl 1994). The large concentrations of these and other birds depend on these lakes for rest and food and would be seriously threatened by the shrinkage or human-caused disturbance of this habitat.

Neotropical Migrant Birds

Recent interest in the management of Neotropical migrant land birds (Finch and Stangel 1993; Dobkin 1994a) arose when the declining abundance of many of these species in the eastern United States was recognized. Neotropical migrants depend on habitat in their North American nesting areas and on habitat in their wintering areas in the Neotropics, which include the Caribbean, Central America, and South America. In the Great Basin–Mojave Desert region, Neotropical migrants are a heterogeneous group that includes more than half of all nesting bird species.

To assess changes in the abundances of North American birds, the U.S. Fish and Wildlife Service established the Breeding Bird Survey. Annual surveys have been conducted in the western United States since 1968. Data from the survey have been used to determine trends in the population sizes of some western birds (Robbins et al. 1986), but the reliability of the data on most species in the Great Basin–Mojave Desert region is questionable because of limited sampling. To overcome these limitations, statistical analyses of Breeding Bird Survey data have become increasingly complex (Peterjohn and Sauer 1993; Peterjohn et al. 1994). Population sizes of some bird species in the Great Basin have fluctuated during a 23-year period, but no trend was statistically significant in the recent 10-year period (Fig. 19). However, population sizes and trends in population sizes have not been estimated for all species, and the reliability of the estimated trends for some species is not absolute.

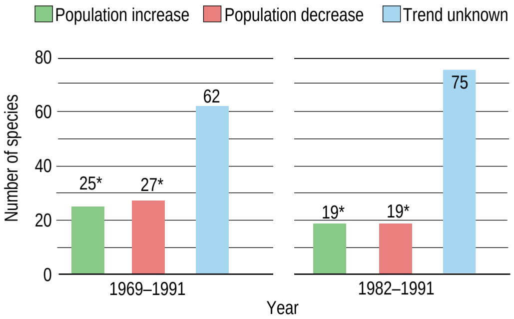


Fig. 19. Long-term population-size trends of 110 species of Neotropical migratory land birds in the Great Basin, based on rankings from population-trend indices developed with Breeding Bird Survey data (Dobkin 1998). Asterisks denote inclusion of species that exhibited upward and downward trends in two different portions of the region. For most species, data are insufficient to establish reliable trends.

Many species with downward trends in population size are associated primarily or exclusively with shrub–steppe or riparian habitats. In the shrub–steppe, such species include the northern harrier, mourning dove, horned lark, loggerhead shrike, green-tailed towhee, vesper sparrow, and sage sparrow. In pinyon–juniper woodlands with a sagebrush and bunchgrass understory, such species are the common nighthawk, northern flicker, gray flycatcher, northern mockingbird, chipping sparrow, and Scott's oriole. Trends in the population sizes of the rock wren, sage thrasher, Brewer's sparrow, black-throated sparrow, and western meadowlark were upward in one portion of the Great Basin and downward in another.

Species with downward population-size trends and associated most closely with riparian habitats include the killdeer, violet-green swallow, warbling vireo, yellow warbler, lazuli bunting, savannah sparrow, song sparrow, yellow-headed blackbird, and Brewer's blackbird. The population-size trend of the red-tailed hawk has been downward for 23 years.

Three riparian species with upward population-size trends are the broad-tailed hummingbird, red-winged blackbird, and Bullock's oriole. Other species with upward population-size trends are the American kestrel, house wren, mountain bluebird, American robin, and black-headed grosbeak—all of which frequently occur in riparian habitats and in pinyon–juniper or mountain-mahogany woodlands—and the northern rough-winged swallow, cliff swallow, and barn swallow, which are aerial insectivores and feed over riparian meadows and other open habitats. More species with upward population-size trends are the brown-headed cowbird, a nest parasite of many Neotropical migrants, and several wide-ranging birds of prey such as the turkey vulture, Swainson’s hawk, golden eagle, and prairie falcon. The lark sparrow was the only songbird species with an upward population-size trend in the shrub–steppe.

Data have been largely insufficient to determine population-size trends of nearly any of the 80 species of Neotropical migrant land birds that occur in the Mojave Desert (Fig. 20). The population sizes of the mourning dove and the loggerhead shrike, whose abundances are declining widely in western North America (DeSante and George 1994), are decreasing in the Great Basin. Upward population-size trends were found for the red-tailed hawk, ash-throated flycatcher, northern mockingbird, and black-throated sparrow.

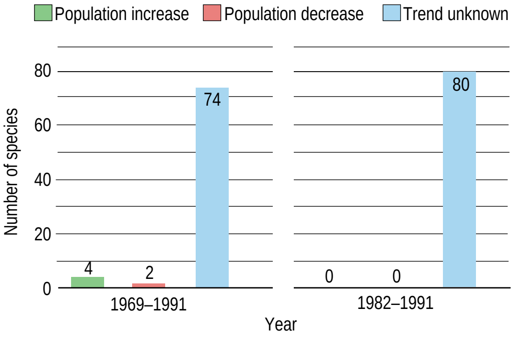


Fig. 20. Long-term population-size trends of 80 Neotropical migratory land birds in the Mojave Desert, based on rankings from population-size trend indices developed with Breeding Bird Survey data (Dobkin 1998). Because of inadequate data, reliable trends could be determined for only 6 of 80 species.

The preponderance of downward population-size trends of birds of the shrub–steppe indicates continuing problems with the health of these communities. As noted elsewhere (DeSante and George 1994), declining abundances of several of these species may also be linked to habitat degradation on wintering grounds in the southwestern United States and northern Mexico. The population-size trends were downward for several riparian specialists and upward for only two riparian specialists (broad-tailed hummingbird and Bullock’s oriole). These trends are further evidence of the continuing deterioration of the riparian habitats of the Great Basin.

Although more than 90% of the region’s Neotropical migrant land bird species were seen during Breeding Bird Surveys, inadequate sample sizes precluded the determination of population-size trends of almost all species, especially those in the Mojave Desert. Some species cannot be sampled adequately with the standard techniques of the Breeding Bird Survey, regardless of sampling effort. The monitoring of such species requires specialized techniques.

Waterbirds

Because of the tremendous past and continuing loss of wetlands, many waterbird species in the Great Basin–Mojave Desert region should be considered sensitive. Data on waterfowl are available from long-term surveys, but few data are available on other species.

Long-term surveys of waterfowl indicate that none seems to be in immediate danger of extirpation. The only waterfowl species that are considered sensitive in North America and occur in the Great Basin–Mojave Desert region are the trumpeter swan and the canvasback. Swans have a relatively stable, small population (about 25; Alcorn 1988), and canvasback populations seem to be stable.

Common loons and several species of grebes migrate through Nevada. Their primary stopover site, Walker Lake, is in danger of becoming too saline to support fishes, their primary food. The largest breeding colony of American white pelicans in the United States is on Anaho Island in Pyramid Lake, and the size of this population is believed to be decreasing. Survey records from the 1960’s and 1970’s showed that the population sizes of double-crested cormorants also were declining.

Population-size trends in wading birds are largely unknown. Population sizes of the great blue heron declined in the late 1980’s in association with an extended drought, but white-faced ibis populations seem to be increasing. No information is available on population-size trends of two species of concern, the American bittern and the western least bittern.

Surveys of shorebirds in western North America are inadequate, and a determination of the importance of habitats in the Great Basin for many of these species is difficult. Most data are provided by surveys in staging areas, and little is known about species that migrate in small groups. Wetlands of the Great Basin–Mojave Desert provide critical stopover habitat during migration for great numbers of the Wilson’s and red-necked phalaropes, long-billed dowitcher, and American avocet, and for smaller numbers of the least and western sandpipers. Significant numbers of the breeding snowy plover, long-billed curlew, American avocet, black-necked stilt, spotted sandpiper, and common snipe occur in the western Great Basin. Of these, the snowy plover is probably of greatest concern. The western snowy plover has been declining in abundance throughout its range, including Nevada (from 878 in 1980 to 349 in 1988 and 139 in 1991; see box on Western Snowy Plovers in California chapter) and in southeastern Oregon. The Franklin’s gull and the black tern occur in the Great Basin, and their numbers are declining in many parts of their ranges. No data are available on which to base population-size trends of either species in the region, but both seem to warrant concern.

Mammals

One hundred fifty species of mammals occur in the Great Basin–Mojave Desert region (Zeveloff 1988). Thirty (20%) of these species are either species of concern, candidates for listing as endangered under the Endangered Species Act of 1973, or are already listed as endangered (U.S. Fish and Wildlife Service 1994a,d; Table 6). The Mojave ground squirrel, Tehachapi pocket mouse, and Owens Valley vole are small rodents whose entire geographic ranges are in the Mojave Desert. The Mojave ground squirrel occupies a restricted range in the northwestern Mojave Desert in California (Hafner and Yates 1983), and the Owens Valley vole is restricted to the Owens Valley of southeastern California. The flora and fauna of the northwestern portion of the Mojave Desert were isolated in a wet relict habitat during the last glaciation and consequently became an ecologically unique area (Hafner 1992). This corner of the Mojave Desert borders on the expanding Los Angeles metropolitan area, and encroaching urban development is believed responsible for the declining abundance of the Mojave ground squirrel. Little is known about the ecology, the current population size, or the distribution of the Owens Valley vole.

The Sierra Nevada red fox, Pacific fisher, California wolverine, and Sierra Nevada snowshoe hare are montane mammals whose distributions in the Great Basin are confined to the east slope of the Sierra Nevada. The declining abundances of the Pacific fisher and California wolverine are attributed to trapping in the late nineteenth and early twentieth centuries (Ingles 1947; Hall 1981; Jameson and Peeters 1988; R. M. Nowak 1991). Humans perceived the wolverine as a nuisance and eliminated the species (Ingles 1947; R. M. Nowak 1991).

The California bighorn sheep is a species of concern (U.S. Fish and Wildlife Service 1994a). The historical distribution of this subspecies extended from northeastern California into northern Nevada and eastern Oregon (Hall 1981), but by the early part of the twentieth century, sheep populations were declining because of hunting (Zeveloff 1988). Bighorn sheep were reintroduced into the Great Basin by Nevada and Oregon wildlife agencies in an attempt to reestablish them as a game species. California bighorn sheep from populations in British Columbia are thriving at the Hart Mountain National Wildlife Refuge where the current population exceeds 450 individuals. Forty-two hunting tags were issued in 1994 (R. Cole, Hart Mountain National Wildlife Refuge, Oregon, personal communication).

Table 6. Mammal species of concern, previously treated as Category 2 status of the U.S. Fish and Wildlife Service, in the Great Basin–Mojave Desert region. “States present” refers to the occurrence of the species in this region.

Species	States present
Amargosa vole	California
Pygmy rabbit	Nevada, Oregon, Idaho, Utah
Spotted bat	Nevada, Idaho, Utah, California, Arizona
Greater western mastiff-bat	Nevada, California, Arizona
Palmer’s chipmunk	Nevada
Hidden Forest Uinta chipmunk	Nevada
North American lynx	Nevada, Oregon, California
North American wolverine	Nevada, Idaho, Utah, California
California wolverine	Nevada, California
Allen’s big-eared bat	Nevada, Utah, California, Arizona
Sierra Nevada snowshoe hare	Nevada, California
Southwestern otter	Nevada, Utah, Arizona
California leaf-nosed bat	California?, Nevada?
Desert Valley kangaroo mouse	Nevada
Fletcher dark kangaroo mouse	Nevada
Pahranagat Valley montane vole	Nevada
Ash Meadows montane vole	Nevada
Small-footed myotis	Nevada?
Long-eared myotis	Nevada, California, Utah, Arizona
Fringed myotis	Nevada, Oregon, Idaho, California
Cave myotis	Nevada, Arizona
Long-legged myotis	Nevada, Oregon, Idaho, California, Utah, Arizona
Yuma myotis	Nevada, Oregon, Idaho, California, Utah, Arizona
Big free-tailed bat	Nevada, California, Utah, Arizona
Pale Townsend’s big-eared bat	Nevada, Oregon, Idaho, Utah, Arizona
Preble’s shrew	Nevada, Oregon, California
Fish Spring pocket gopher	Nevada
San Antonio pocket gopher	Nevada
Mojave ground squirrel	California
Owens Valley vole	California
Sierra Nevada red fox	California
Pacific fisher	California
California bighorn sheep	Nevada, Oregon, California
Tehachapi white-eared pocket mouse	California

Gaps in Knowledge

Recent research in Nevada revealed significant extensions of the known distributions of 14 of 22 conifer species that are native to the state (Charlet 1996). For example, the range of the western juniper was extended to 43 additional mountain ranges (Fig. 21), and the range of white fir was extended to seven more mountain ranges (Fig. 22). Many of these stands in Nevada were unknown to scientists, although conifers are easy to see on the landscape even from long distances, and their visual prominence is mirrored by their ecological importance wherever they occur. If not even the locations of the trees are known, how much can be known about other floral and faunal distributions and community processes of the region? Conifer species represent only 0.07% of the more than 3,000 known plant species in Nevada (Kartesz 1988). Among the Nevada flora, 127 plants are listed, are candidates for federal listing, or are species of concern (U.S. Fish and Wildlife Service 1994a,d), but virtually nothing

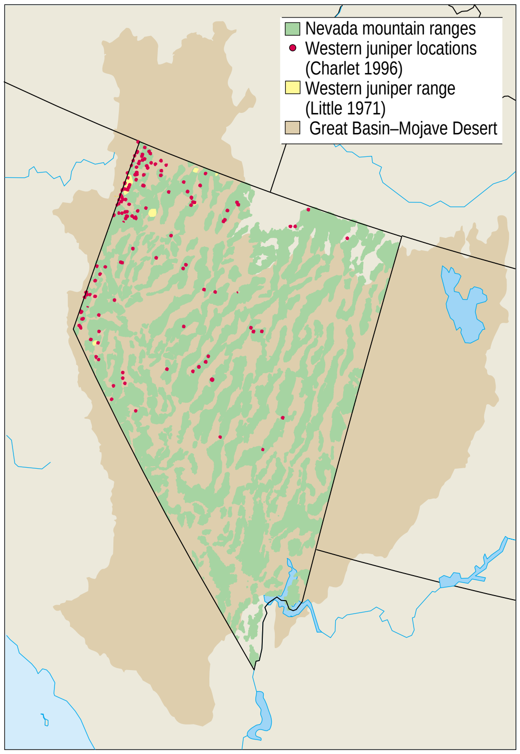


Fig. 21. Distribution of western juniper in Nevada. Red dots indicate known distributions based on collections (Charlet 1996). Yellow polygons are distributions as reported by Little (1971).

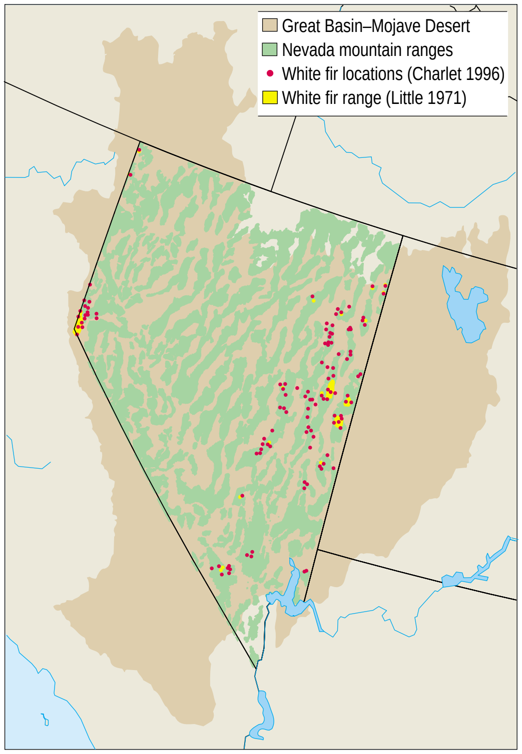


Fig. 22. Distribution of white fir in Nevada. Red dots indicate known distributions based on collections (Charlet 1996). Yellow polygons are distributions as reported by Little (1971).

is known about them except that they are probably rare. The basic information about plant distributions is skeletal at best, yet plants are the primary producers in communities, and all organisms ultimately depend on them. Information about the ecology and evolution of most organisms has not been gathered, although such information would greatly assist managers of public lands with balancing mandates for the conservation of biological diversity and for multiple use by humans.

Habitats

Caves

Most of the 300 described caves in the Great Basin are in limestone mountains (McLane 1975; Fiero 1986). Anthropological information has been a major focus of cave explorations in the region because of the long history of cave use by Native Americans (Thomas 1985). Woodrat middens, in which many important fossils have been found, are an additional rich resource in cave habitats throughout the region (Betancourt et al. 1990; C. L. Nowak 1991; Wigand and Nowak 1992; Nowak et al. 1994).

The Lehman Caves in Nevada and the Timpanagos Cave National Monument in Utah were developed for tourism (Fiero 1986). The Lehman Caves receive 46,000 visitors yearly, and changes in the cave community resulting from such heavy use are a source of concern (Great Basin National Park 1988). Invertebrates in caves are rarely surveyed (Desert Research Institute 1968), so it is difficult to determine if any invertebrate groups are at risk. Large colonies of bats in caves were killed or extirpated when the caves were mined for guano; bats that hibernate or raise young in caves are especially susceptible to disturbance (Pierson and Brown 1992; Dobkin et al. 1995a; Fig. 23).

Mines

Tunnel mines that were excavated since the mid-1800's provide potential roosting sites for 19 of the 22 bat species in the region (Burt and Grossenheider 1976; Pierson et al. 1991). In Nevada, most of the more than 50,000 known inactive mines are unsuitable roosts, although a few may house significant colonies. Inactive mines in California provide most known colony sites for the cave myotis and Townsend's big-eared bat. This situation is probably mirrored in

© D. A. Charlet, University of Nevada

Fig. 23. Long-eared myotis, a species of concern, at Emerald Lake, Jarbidge Mountains, Nevada.

the Great Basin (Pierson et al. 1991), although these species make extensive use of natural caves in forested lava flows adjacent to the region in Oregon and Idaho (Genter 1986; Dobkin et al. 1995b). The loss of mines as colony sites for rearing young and for hibernation is magnified by the degradation of natural roosts in caves through human disturbances such as recreation or guano mining (Pierson and Brown 1992). In addition, cyanide ponds used for gold extraction at active gold mines have been implicated in the deaths of many bats who drink the contaminated water (Clark and Hothem 1991).

The Abandoned Mines Program of the Nevada Division of Minerals identifies and secures abandoned mines that pose a hazard to human safety. Approximately half of the 3,000 mines that were closed in Nevada since 1987 were not inspected for wildlife and became unusable to bats and other wildlife after they were filled (D. Driesner, Bureau of Abandoned Mine Lands, Nevada Division of Minerals, Reno, personal communication). Since October 1993, however, mines have instead been closed by fencing and signs where possible, to retain wildlife habitat. Education of land management agencies about the use of inactive mines by bats in Nevada increased the frequency of bat surveys and proactive management. The Bureau of Land Management entered a cooperative agreement with the Nevada Division of Mines about management of orphaned mine sites on Bureau of Land Management land (Bureau of Land Management 1994). Population and natural history data of the region’s bats will become increasingly important as managers focus on the 11 bat species in the region that recently became species of concern (Burt and Grossenheider 1976; U.S. Fish and Wildlife Service 1994a).

Bogs

Although eagles were believed to require only the water they obtained from their prey (Brown and Amadon 1968), Charlet and Rust (1991) observed golden eagles drinking, bathing, and preening at high mountain bogs and springs in the northern Great Basin (Fig. 24). Five eagles at one time were seen on the ground on three occasions (Charlet and Rust 1991), and more than 45 landings at one bog occurred in an 8-hour period (Charlet, unpublished data). To date, golden eagles have been observed drinking at high mountain springs in 15 mountain ranges in the northern and central Great Basin (Charlet and Rust, unpublished data). Several of these bogs are in areas that attract many visitors or are claimed for mining. Trails pass near some of the bogs, and people camp at others to use the water. Golden eagles will not come to the sites if they detect humans (Charlet and Rust 1991); however, it is unclear how these birds are affected when they are displaced by humans.


© D. A. Charlet, University of Nevada

Fig. 24. Golden eagle leaving a bog after drinking and bathing at the headwaters of the Humboldt River, Jarbidge Mountains, Nevada.

Sand Dunes

Despite the uniqueness of the flora and fauna of sand dunes across the Great Basin–Mojave Desert region, little is known about these island-like habitats or the organisms that inhabit them. The locations of some dunes in the region are not even portrayed on U.S. Geological Survey maps. Virtually nothing is known about the spatial dynamics of these dunes and how these dynamics affect the biological communities. Biological inventories exist only from the most heavily used dunes, often from only one survey (Rust 1994). Popular dunes in the region (for example, Sand Mountain and Nevada and Little Sahara dunes, Utah) may receive several thousand visitors during one holiday weekend, but the ecological effects of this heavy recreational use have been assessed in only a few cases. Hardy and Andrews (1979) and Luckenbach and Bury (1983) linked the effects of off-highway vehicles to the loss of vertebrate and invertebrate species richness, a reduction in vertebrate and invertebrate populations, and a disruption of mating behaviors in insects that depend on dune-margin vegetation for mating habitat. More information is needed on the effects of off-highway vehicles on the dune biota and on how these effects can be minimized or mitigated. Nearly all sand dunes in the region are on land that is administered by the Bureau of Land Management, and this agency should take the lead on conserving the unique biota.

A good start to conservation of sand dune biota was made with the Sand Mountain pallid blue butterfly. This species was originally discovered in a small patch of Kearney buckwheat—the plant on which its caterpillars feed—near the parking lot at the base of Sand Mountain, Nevada. Sand Mountain is a large dune used extensively for recreational use of off-highway vehicles and was officially designated by the Bureau of Land Management for that purpose. Because the distribution of the butterfly at Sand Mountain was not known and because trampling and traffic seemed to threaten the species, it became a species of concern (U.S. Fish and Wildlife Service 1994a).

When biologists visited the site in summer 1994, they found that much of the Kearney buckwheat at the parking lot site had been beaten down by vehicles. At this point the options seemed to be fencing off the remaining plants or closing part of this popular recreational area, and recreationists feared the whole dune would then be closed. However, a recreationist overheard the agency biologists and took on the task of finding additional food plants. And indeed he found them—the plants were widely distributed all around the base of the dune. Thus, considerable potential habitat for the butterfly existed in areas that are rarely visited by off-highway vehicles. The question remained whether the butterfly also existed in these areas. Their presence at these sites was verified later by biologists during the butterfly's flight season. The Bureau of Land Management developed a management plan that includes monitoring the butterfly and its food plant and directing off-highway vehicle traffic away from the vegetated dune fringes, which are rarely used for recreation anyway. As long as the off-highway-vehicle community cooperates, the butterfly and its food plant should be secure without a federal listing.

Potential Ecological Crises

Invasion by Nonindigenous Plants

Europeans brought to the Great Basin–Mojave Desert region their farming techniques, plants, and animals; these created different disturbance patterns than the native biota of the region had previously experienced (Mack 1986). The newly disturbed environments created excellent seedbeds for highly invasive species like the Russian thistle, tumble mustard, cheatgrass, halogeton (Holmgren 1972), filaree (Mack 1986), and tamarisk (Robinson 1965).

The total effect of nonindigenous plant species in the region is unknown, but in North America invasions of nonindigenous grasses are most severe in the arid western United States (D'Antonio and Vitousek 1992). In Nevada alone, at least 315 nonindigenous plant species (about 10% of the state flora) are now established (J. Kartesz, Department of Biology, University of North Carolina at Chapel Hill, personal communication), and their biomass sometimes exceeds that of native species (Hunter 1990). Although most of the effect of nonindigenous plant species in the region occurs in sagebrush–grass, pinyon–juniper, and wetland zones, it is apparent to some extent in every community.

Several highly invasive nonindigenous species are recent introductions, and others, such as the yellow star-thistle, are poised on its edges. The medusahead is considered a particular threat because of its ability to invade undisturbed sites (R. J. Tausch, U.S. Forest Service, Intermountain Research Station, Reno, Nevada, and J. A. Young, Agricultural Research Service, University of Nevada, Reno, personal communication). Red brome continues to spread in the Mojave Desert (Beatley 1966; Hunter 1990, 1991). The barbwire thistle resembles and hybridizes with the Russian thistle, thus the barbwire thistle's introduction and dispersal during the past 20 years went virtually unnoticed until recently (J. A. Young, U.S. Forest Service Intermountain Research Station, personal communication).

The invasion of cheatgrass caused drastic changes in fire regimes and secondary plant succession (Piemeisel 1951) across at least a million hectares. Species composition (Piemeisel 1951) and competitive interactions in the affected plant communities are greatly modified by this invasion (Melgoza et al. 1990; D'Antonio and Vitousek 1992). Because of the rapid accumulation of flammable fuels from stalks, cheatgrass-infested areas experience more frequent fires (Pickford 1932; Whisenant 1990) and a longer fire season (Roberts 1990) than areas without grass or with sparse grass cover. The pattern of fire damage was altered: smaller, patchier burns that were typical before European settlement were replaced by fires that tend to destroy vegetation over large, more continuous stretches of land (Whisenant 1990; D'Antonio and Vitousek 1992). When fire-intolerant native plant species are burned, the resident fungi necessary for their establishment and growth also are lost, favoring the establishment of nonindigenous species such as the Russian thistle, tumble mustard (Goodwin 1992), and cheatgrass (Yensen 1981).

Although some areas that are dominated by cheatgrass can be reclaimed by native species if left undisturbed (Hironka and Tisdale 1963), the vulnerability of these sites to burning and susceptibility to midsummer erosion nearly ensures the continued persistence of cheatgrass (Yensen 1981). Thus, the naturalization of cheatgrass in sagebrush–grass communities is a

Contents ◀ Article ▶ ◀ Page ▶

Human-Induced Changes in the Mojave and Colorado Desert Ecosystems: Recovery and Restoration Potential

Large parts of the Mojave and Colorado desert (see chapter on Southwest) ecosystems have been affected by humans and their activities, especially in the last 100 years. Urbanization, agriculture, off-highway vehicle use, construction of roads and utility corridors, livestock grazing, and military training activities have all created measurable changes in the structure and stability of the ecosystem. Air pollution, although difficult to measure accurately (Reible et al. 1982), has noticeably damaged plants in the Mojave and Colorado deserts (Fisher 1978). The effects of mining have been limited to specific sites in the region. Like all ecosystems, the Mojave and Colorado deserts are resilient to some stresses but not to others. Unfortunately, the weakly defined, thin soil layers that characterize the region are easily disturbed. This vulnerability, coupled with the extreme aridity and temperature ranges of the region, means that conditions necessary for germination and survival of many plants occur only infrequently, and recovery of plant populations to predisturbance conditions is very slow (Table).

Understanding the changes that any system has undergone requires baseline information on conditions that existed before disturbance. The creosotebush-dominated shrub–steppe ecosystem that many recognize as characteristic of the Mojave and Colorado deserts (Burk 1977; Vasek and Barbour 1977) may have existed only for the last 10,000 years or so (Grayson 1993). Before the arrival of Europeans, this vast area was characterized by communities of widely spaced, long-lived, fire-sensitive shrubs, including creosotebush, burro-weed, Joshua-trees, various cacti, and other less familiar associates. Since then, the combined effects of human activities have increased erosion, the destruction of soil-stabilizing microorganisms, soil compaction, fire frequency, habitat destruction and fragmentation, the number of nonindigenous species, and the number of threatened and endangered species.

Much of what is known about ecological succession in the Mojave and Colorado deserts comes from research on recovery from human disturbances in the region. The rate of change in plant communities over time, or succession, is a function of the type of disturbance, its magnitude and frequency, and, to a lesser extent, the type of plant community affected. Short-term, partial recovery of Mojave and Colorado Desert plant communities may take place in a span of 9 to 78 years (Vasek 1979; Prose et al. 1987; Webb et al. 1987), but 1,000 or more years may be required for disturbed sites to recover to predisturbance vegetation structure and species composition (Webb and Newman 1982), though cover of colonizing plants may equal predisturbance cover values within 20–50 years.

Table. Estimated natural recovery times (years) for California desert plant communities subjected to various human-induced disturbances.

Disturbance	Location	Recovery time (years)	Reference
Tank tracks (military)	Eastern Mojave	65,[a] 76[b]	Lathrop (1983a)
Tent areas (military)	Eastern Mojave	45,[a] 58[b]	Lathrop (1983a)
Dirt roadways (military)	Eastern Mojave	112,[a] 212[b]	Lathrop (1983a)
Tent sites (military)	Eastern Mojave	8–112[c]	Prose and Metzger (1985)
Tent roads (military)	Eastern Mojave	57–440[c]	Prose and Metzger (1985)
Parking lots (military)	Eastern Mojave	35–440[c]	Prose and Metzger (1985)
Main roads (military)	Eastern Mojave	100–infinity[c]	Prose and Metzger (1985)
Military	Eastern Mojave	1,500–3,000[d]	Prose and Metzger (1985)
Town sites	Northern Mojave	80–110,[e] 20–50,[b] 1,000+[f]	Webb and Newman (1982)
Pipeline	Southern Mojave	Centuries[g]	Vasek et al. (1975b)
Power line	Southern Mojave	33[h]	Vasek et al. (1975a)
Fire	Western Colorado Desert	5[b,i]	O'Leary and Minnich (1981)
Off-road vehicle use	Western Mojave	Probably centuries	Webb et al. (1983)
Pipeline (berm and trench)	Mojave Desert	100[j]	Lathrop and Archbold (1980a)
Pipeline (road edge)	Mojave Desert	98[j]	Lathrop and Archbold (1980a)
Power line pylons and road edges	Mojave Desert	100[j]	Lathrop and Archbold (1980a)
Under power line wires	Mojave Desert	20[j]	Lathrop and Archbold (1980a)

[a] Recovery time to reach control density.
[b] Recovery time to reach control cover.
[c] Estimated recovery time for creosotebush to reach control densities.
[d] Estimated recovery time (if at all) to reach original vegetative structure, assuming establishment of control densities.
[e] Compaction recovery time.
[f] Total estimated recovery time.
[g] 30–40 years assuming linear rates of succession; 3,000 years until formation of large creosote bush clonal rings.
[h] Incomplete recovery time in areas of high impact.
[i] Time for appearance of perennial seedlings.
[j] Biomass recovery assuming that successional vegetative growth is approximated by a straight line. Recovery of long-lived species is estimated to take at least three times longer than indicated.

Construction of Utility Corridors

In the Mojave and Colorado deserts, the rates of increase and composition of colonizing plant species vary considerably following construction of utility corridors for power lines and pipelines, demonstrating how difficult it is to predict succession relative to adjacent undisturbed areas. Ground cover of short-lived perennial species actually increases in areas of severe disturbance, under the central wires, and along the edges of maintenance roads. After 33 years, there is a noticeable but incomplete recovery of vegetation (Vasek et al. 1975a). Natural revegetation (to 41% ground cover) by long-lived perennials was observed 12 years after construction of a pipeline by trenching, piling, and refilling (Vasek et al. 1975b). Disturbed and control areas appear to have similar cover, biomass, and densities of plants following partial recovery; however, long-lived species are poorly represented on disturbed sites (Lathrop and Archbold 1980a,b).

Impacts of Military Activities

Large areas of the Mojave and Colorado deserts have been, and continue to be, affected by military training activities. The recovery of such areas of the eastern Mojave Desert was studied almost 36 years after the region was first subjected to military activities (Lathrop 1983a). Disturbed areas included tent sites, roads, and tank tracks. All of these areas exhibited reduced plant density and cover relative to control areas. Reductions of cover and density were greatest in tank tracks and least in tent areas. Recovery to predisturbance levels of cover and density varied according to disturbance type. Tent areas showed the greatest recovery, and roadways showed the least, reflecting the intensity of disturbance. Recovery in tank tracks was intermediate. Diversity of

Contents ◀ Article ▶ ◀ Page ▶

dominant perennials also varied between disturbed and nondisturbed areas, but results were clouded by low species richness at the study sites and few individuals of subdominant species. However, diversity in disturbed transects at the Camp Ibis study site was low relative to control sites. The more intense or frequent the use of the site, the less similar the species composition was to that of undisturbed control sites.

Overall, recovery of plant density is slow relative to increases in cover: the number of individuals present at a site changes little following recovery from disturbance, but surviving individuals cover larger areas. Lathrop (1983a,b) concluded that recovery of the disturbed eastern Mojave sites to some original level of community composition and stability may not occur in the foreseeable future. Similar observations and conclusions were reached by Prose and Metzger (1985) and Prose et al. (1987) at abandoned military camps in the eastern Mojave. Long-lived species such as creosotebush were dominant in all control areas, but their cover and density were reduced in disturbed areas. Dominant plants in disturbed areas included pioneer species such as burro-weed and burrobrush. Ground cover by pioneer species in disturbed areas was equal to or greater than their cover in control sites.

Differences in vegetative structure between control and disturbed plots were due to soil compaction, removal of the top layer of soil, and alteration of drainage channel density at the military sites (Prose et al. 1987). Penetrometer measurements show that the compaction caused by a single pass by a "medium" tank can increase average resistance values in the upper 20 centimeters of soil by 50% relative to adjacent untracked soil; values of up to 73% were recorded. Dirt roadways could not be penetrated below 5–10 centimeters because of extreme compaction. Physical modifications to the soil beneath tank tracks extended to a depth of 25 centimeters and outward from the track edge to 50 centimeters (Prose 1985).

Effects of Off-Highway Vehicles

Off-highway vehicles have also disturbed large areas of the Mojave and Colorado deserts. The effects of these vehicles have been well documented and include destruction of soil stabilizers, soil compaction, increased wind and water erosion, noise, decreased abundance of lizard populations (Busack and Bury 1974), and destruction of vegetation (Webb and Wilshire 1983). Susceptibility of soils to damage is generally high in all areas except barren sand dunes (but see Bury and Luckenbach 1983) and the clay flats of playas (Dregne 1983). Soil damage caused by off-highway vehicles is environmentally significant because desert soils may take 10,000 years to develop. From this estimate, Dregne (1983) concluded that it was futile to speak of disturbed soil recovery in time periods related to human occupancy of the affected areas (Fig. 1).

A major effect of off-highway vehicles is the physical destruction of plants. Plants are destroyed when their stems and foliage, root systems, and germinating seeds are crushed. Lathrop (1983b) examined aerial photographs of nine disturbed and undisturbed areas in the Mojave Desert to assess the effects of off-highway vehicle use. Perennial plant density and cover were dramatically reduced in areas disturbed by vehicles, and total plant cover and density were less than 15% of that in three undisturbed control sites examined.

Weeds and Fire

Like the rest of the western United States, the Mojave and Colorado deserts have been hit hard in the last century by invasive nonindigenous plants. Nonindigenous annual grasses have become the dominant understory plants in areas formerly occupied by native perennial grasses (D'Antonio and Vitousek 1992). Large areas of the Mojave and Colorado deserts are infested with Mediterranean grasses, cheatgrass, and other exotics (Beatley 1969; Bowers 1987; Hunter 1991).

The proliferation of nonindigenous annual plants has dramatically increased the fuel load and frequency of fires in parts of the Colorado Desert in recent years (O'Leary and Minnich 1981; Brown and Minnich 1986). The frequency of fires in the Colorado Desert of California is further enhanced by the proximity of previously burned areas (Chou et al. 1990). Native perennial shrubs are poorly adapted to fire, as evident in their low rates of recovery. In the upper Coachella Valley on the east scarp of the San Jacinto Mountains near Palm Springs, California, burned creosotebush scrub is replaced by open stands of brittlebush, native ephemerals, and nonindigenous annual grasses (Brown and Minnich 1986).

Although fire had a role in the evolution of the desert plant community, it was probably minor, with limited effect and long intervals between fires. With the invasion of species that serve as fine fuels, like nonindigenous annual grasses, the fire cycle has been significantly shortened and fires are more likely to spread. The result has been the conversion of desert scrub landscapes to "weedscapes" dominated by nonindigenous plants.

Livestock Grazing

The effects of livestock grazing in the Mojave and Colorado deserts, while controversial, have been locally significant (General Accounting Office 1992). No published studies have yet fully documented the impact of grazing by livestock or estimated the time required by heavily grazed areas of the desert to recover to

Courtesy Bureau of Land Management

Fig. 1. Large areas of the Mojave and Colorado desert ecosystems have been affected by off-highway vehicles. The road scars shown in this photograph will be clearly visible for decades or longer.

pregrazing levels of plant diversity, density, and cover (Oldemeyer 1994).

Webb and Stielstra (1979) observed that, relative to ungrazed control areas, soils in the Mojave Desert exhibited greater compaction in areas where sheep bedded and grazed. Compaction was greatest in the upper 10 centimeters of soil but was also observed at lower depths. Surface soils trampled by grazing animals lose stabilizers composed of microorganisms, which increases erosion potential (Fig. 2).

The Role of Restoration

Establishment and growth of native plants are naturally slow processes under the extreme conditions of the desert, and disturbance makes these conditions even more severe. Natural recovery is thus extremely slow (Table) and does not necessarily result in communities that resemble predisturbance conditions. Revegetation and restoration can help mitigate many of these negative impacts and speed recovery.

Unfortunately, our ability to restore degraded habitats relies on current technologies that are sharply constrained by the harsh conditions imposed by the desert environment. Furthermore, the costs of large-scale restoration are prohibitive, and the chances of long-term success are low or unknown. Brum et al. (1983) estimated that power line corridors in the Mojave Desert could be restored for $9,221 per hectare by using seeding and irrigation. Estimates of costs involved in restoring degraded land at the Yucca Mountain site in Nevada were much higher, ranging from $73,969 to $115,754 per hectare, depending on the nature of the disturbance (Malone 1991). However, recent advances in desert restoration technology offer hope for the success of localized restoration efforts (Bainbridge and Virginia 1990; Bainbridge et al. 1995). Given the sensitivity of desert habitats and their slow rate of natural recovery, the best management option is to limit the extent and intensity of disturbances as much as possible.

Courtesy J. Lovich, USGS

Fig. 2. Grazing can have locally significant effects in the Mojave Desert, particularly around watering tanks. Notice the almost complete absence of perennial plants in the immediate vicinity of the tank. Soil compaction in these areas is very high relative to undisturbed areas.

See end of chapter for references

Author

Jeff Lovich
U.S. Geological Survey
Biological Resources Division
Department of Biology
University of California
Riverside, California 92521-0427

“catastrophic change to a new system” (Turner et al. 1993:223). The conversion of sagebrush–steppe to annual grasslands makes these rangelands virtually worthless (Yensen 1981; Morrow and Stahlman 1984; Roberts 1990), and the cost of rehabilitation is often higher than the value of the land on the open market (Roberts 1990).

Degradation of Springs

Isolation and small size render many spring communities in the Great Basin–Mojave Desert region particularly vulnerable to disturbance and loss. Groundwater pumping in Mojave Desert areas, such as Pahrump Valley, caused the drying of springs, complete loss of habitat, and extinction of subspecies of native fishes. Pumping in Ash Meadows nearly led to the loss of springs in the 1970’s, but the first intervention of the Endangered Species Act of 1973 prevented these losses (Soltz and Naiman 1978). Continuing development of hot springs for electric power in the Great Basin also poses questions about the persistence of spring habitats. Presently, pumping of groundwater from gold mines is one of the greatest threats to spring communities. In the north-central region of Nevada in particular, large open-pit gold mines are rapidly altering groundwater conditions in many areas, and many spring communities there are at risk. Although relatively few fish populations may be lost by these practices, the invertebrate faunas of the affected areas are poorly known, thus the effects on these organisms cannot be determined.

On a smaller scale, the continuing development of springs for livestock by ranchers and state and federal agencies also poses a threat to the continued existence of spring biota. These actions typically involve fencing of the area immediately adjacent to springs, placing a springbox over the water source, and piping most or all of the water off the site into livestock tanks. Although some of the riparian vegetation may be retained with such practices, the essential flowing character of the spring is lost, and often no exposed water remains on the surface. Populations of endemic species of springsnails have been lost under such circumstances (G. L. Vingard, University of Nevada, Reno, personal observation), and the consequences for other invertebrates must also be severe.

Livestock grazing continues to pose another serious threat to spring communities. Heavy trampling by livestock often reduces the substrate to mud, can completely eliminate riparian vegetation, and alters flow characteristics. Although the magnitude of these effects on the spring biota is largely unknown, it is probably great because of the complete alteration of the vegetation and substrate structure.

In springs throughout the region, introductions of nonindigenous organisms—particularly fishes, snails, crayfishes, and frogs—also have had adverse effects. Fish species have been lost in some springs, and changes in the invertebrate fauna have been substantial in others (Soltz and Naiman 1978). It is difficult to assess the magnitude of the effects from introduced nonindigenous species on spring biota because data on native organisms are lacking. Many populations and species will probably be destroyed before their presence has even been documented.

Development in the Las Vegas Valley

Future losses of species and decreased biological diversity attributable to water diversions seem inevitable in light of estimated human population growth throughout the Great Basin–Mojave Desert region and particularly in Clark County, southern Nevada. Water supplies in Clark County today include the Colorado River (300,000 acre-feet or 365.9 million cubic meters per year), groundwater in Las Vegas Valley (35,000 acre-feet or 42.7 million cubic meters per year net), and wastewater reuse. Forecasts indicate that at current rates of use, existing supplies will meet local needs until the year 2013; however, by the year 2020, the population of Clark County is expected to increase by 63%, from 919,388 in 1993 to an estimated 1,450,409 (Clark County 1994). To meet the water needs of this population, the Las Vegas Valley Water District filed applications to obtain surface water from the Virgin River and groundwater diversions from approximately 20 basins (Table 7); this includes all of the unappropriated perennial yield that would otherwise be lost to evaporation (Las Vegas Valley Water District 1992, 1993). Although hydrologic models are used to predict steady-state groundwater flow and to ascertain the effects of groundwater withdrawals, no one knows the level of success reached by predictions of the magnitude of these effects over the long term and on a regional scale.

Table 7. Sources and amounts of water currently consumed by Clark County and those sources in the permit application process with the Nevada Division of Water Resources (Las Vegas Valley Water District 1992; Clark County 1994; Nevada Division of Water Resources 1995, personal communication).

Water sources	Acre-feet per year	(Cubic meters per year)
Currently consumed		
Colorado River	300,000	(369,900,000)
Groundwater (from Las Vegas Valley basin)	35,000	(43,155,000)
Total consumed	335,000	(413,055,000)
In permit application		
Virgin River	125,000	(154,130,000)
Groundwater (from approximately 20 basins)	180,000	(221,940,400)
Total in permit application	305,000	(376,070,000)

Developments on the Truckee and Carson Rivers

The Truckee River originates as overflow from Lake Tahoe (Fig. 25) in the Sierra Nevada, flows through the Truckee Meadows (now occupied by the Reno-Sparks metropolitan area), and terminates at Pyramid and Winnemucca lakes. In 1906, water was diverted from the Truckee River for the Newlands Project in the Fallon area, the first project in an effort to make the desert bloom in the United States. While an agricultural economy was created in Fallon, Pyramid Lake dropped 25 meters, the endemic cui-ui became endangered, the Pyramid Lake cutthroat trout went extinct, and Winnemucca Lake completely dried shortly after it was established as a national wildlife refuge for waterbirds. Because of the loss of Winnemucca Lake, the Stillwater National Wildlife Refuge near Fallon became one of the only resources for migrating shorebirds in the area. The Stillwater marshes were naturally fed by the Carson River, but most of those waters are also diverted for irrigation. Added to these complications are the demands on the Truckee River from the rapidly growing Reno–Sparks area. These demands conflict with those of the Pyramid Lake Paiute tribe, the Fallon farmers, and the Stillwater refuge.

Heroic water importation schemes to solve Reno's insatiable thirst have included draining groundwater from central and eastern Nevada mines, sending this water down the Humboldt River, and pumping it to Reno. Pumping groundwater from Honey Lake Valley in northeastern California for delivery to Reno was also proposed. Estimates on the yield of the aquifer were made by using the rate of water use by the greasewood in Honey Lake Valley (L. Crowe, Air Quality Management, County of Washoe, Nevada, personal communication). Water used by greasewood was considered wasted, but this water could support additional development in Reno. Yet, that water supports not only greasewood, but an entire natural community that includes at least six species of scale insects from four families (D. R. Miller, Agricultural Research Service, U.S. Department of Agriculture, Logan, Utah, personal communication) and several desert rodents (W. Longland, Agricultural Research Service, Reno, Nevada, personal communication).

Walker River Basin and Walker Lake

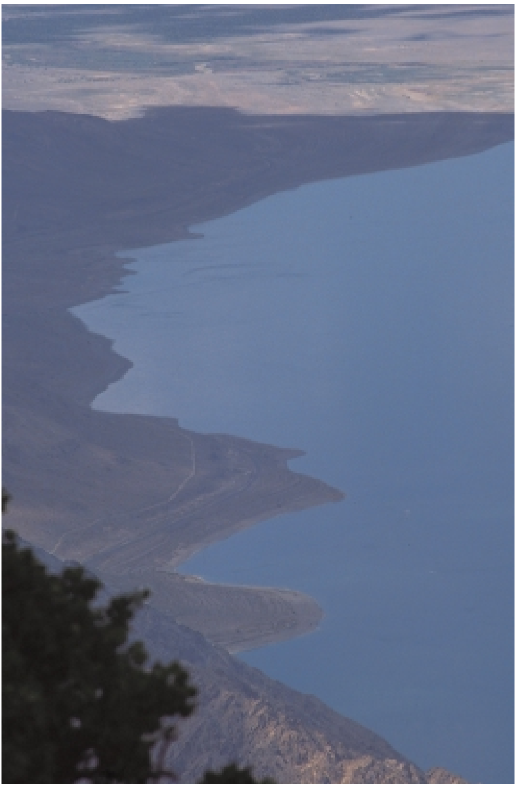
The Walker River basin is a medium-sized drainage in eastern California and western Nevada. The eastern and western forks of the Walker River originate on the eastern slope of the Sierra Nevada in California, flow into Nevada via the Smith and Mason valleys, merge, and eventually terminate in Walker Lake (Fig. 26). During the last 100 years or so, upstream water diversions for irrigation created a vigorous agricultural economy in the Smith and Mason valleys, but these diversions also diminished flows into Walker Lake. The lake's level has dropped considerably, and the concentration of total dissolved solids has increased to the extent that the lake will not be able to support fishes much longer (Koch et al. 1979; Horne et al. 1995; Stockwell, unpublished manuscript).

One hundred twenty percent of the average flow in the Walker River is allocated to upstream uses, primarily for agriculture in Smith and Mason valleys (California Department of Water Resources 1992). Thus, a runoff of 120% of normal—or about 420,000 acre-feet (512.2 million cubic meters)—is necessary for the righted allocations of all upstream users. Under drought conditions, flows are about 40%–60% of average, and only negligible amounts of water reached Walker Lake from 1986 to 1994. Under these conditions, the total dissolved solids in the lake will soon reach a level that will shift a fish-dominated community to one dominated by invertebrates (Stockwell, unpublished manuscript). One effect of this shift will be the disappearance of the fish-eating birds that depend on the lake's resources during migration; another will be the loss of a major recreational fishery that is important to the economy of Hawthorne, a town at the southern end of the lake.

The only feasible way to forestall these changes is to increase flows into Walker Lake. If 80,000–90,000 acre-feet (97.6–109.8 million cubic meters) of water were to reach the lake annually, the total dissolved solids would fluctuate around the present level, which is marginal for fish life. An annual inflow of more than 109.8 million cubic meters would result in a gradual reduction of the total dissolved solids (Stockwell, unpublished manuscript). However, providing about another 100,000 acre-feet (122 million cubic meters) of water annually for Walker Lake would require annual flows of 520,000 acre-feet (634.2 million cubic meters), or 157% of average. Because this amount of water probably will not become available in the basin unless it consistently receives much higher than average precipitation, various water redistribution schemes have been proposed by groups intent on preserving the current Walker Lake community. These schemes include the purchase of water rights from willing sellers, voluntary contributions to instream flow, or more draconian measures such as reallocation. However, the economy of the Smith and Mason valleys would probably suffer if substantial amounts of irrigation water were diverted into the lake.

© D. A. Charlet, University of Nevada

Fig. 25. Lake Tahoe, Nevada and California. Overflow from Lake Tahoe is the primary source of the Truckee River.



© D. A. Charlet, University of Nevada

Fig. 26. Walker Lake, Nevada, viewed from the summit of Mount Grant.

Authors

Peter F. Brussard
David A. Charlet*
Department of Biology
and Biological Resources
Research Center
University of Nevada
Reno, Nevada 89557

David S. Dobkin
High Desert Ecological Institute
15 SW Colorado, Suite 300
Bend, Oregon 97702

*current address:
Community College of
Southern Nevada
Department of Science S2B
3200 East Cheyenne Avenue
North Las Vegas, NV 89030

Contributing authors

Lianne C. Ball
Kathleen A. Bishop
Hugh B. Britten
Erica Fleishman
Scott A. Fleury
Tom Jenni*
Tom B. Kennedy
Christine O. Mullen
Mary M. Peacock
Don Prusso
Michael Reed
Lynn Riley
Richard W. Rust
Janice L. Simpkin
Gary Vinyard
Ulla G. Yandell
Biological Resources Research
Center
University of Nevada
Reno, Nevada 89557

Ron Marlow
Department of Biology
University of Nevada
Reno, Nevada 89557

*(currently employed by Nevada
Natural Heritage Program
Carson City, Nevada)

Furthermore, irrigation in these valleys may have created habitats that also support important elements of biological diversity. Upstream riparian and wetland habitats originally covered only a fraction of the land area in the Smith and Mason valleys, but they expanded considerably under irrigation. At present, modern irrigation practices (such as replacement of the original earthen ditches by concrete-lined ditches) and the recent drought have resulted in the degradation or loss of riparian segments. The extent to which these habitats support important elements of biological diversity must be quantified so that the overall effects of potential water redistribution can be predicted.

A second potential effect of water redistribution on upstream biological diversity may be the conversion of former grazing or agricultural lands into residential areas. If irrigation is no longer possible, the most profitable course for a landowner is to sell the land to a developer. Residential development creates habitat types that are not used by most native species, and pets (particularly house cats) have a substantial negative effect on bird, reptile, and small mammal populations. If the density of houses in a development is sufficiently high, most native animals disappear altogether.

The Walker River basin serves as an example for many others facing resource management dilemmas in the arid West. The land in the Walker River drainage basin has a variety of public and private ownership (Fig. 27), including two states with their respective fish and wildlife agencies, the U.S. Forest Service, the Bureau of Land Management, the Department of Defense, private landowners, and an Indian reservation. Resident organisms include a threatened species (the Lahontan cutthroat trout) and many migratory birds, and all vegetation zones of the Great Basin are represented in the Walker River basin. Will this area become the focus of yet another conflict over land and water use or an example of cooperative ecological restoration?

Conclusions

Biological diversity in the Great Basin and Mojave Desert region is concentrated in remnant waters, montane islands, and specialized habitats. Throughout the region, there is much endemism, mostly at the subspecies but also at the species level. However, the human population in Nevada is growing at one of the fastest rates in the nation (6.7% annually, which represents a doubling time of 10 years), and the portions of the region in adjacent states are growing nearly as fast. Most people who move into the region are from nondesert areas and do not understand the fragile ecology of the desert and the value of its biological heritage.

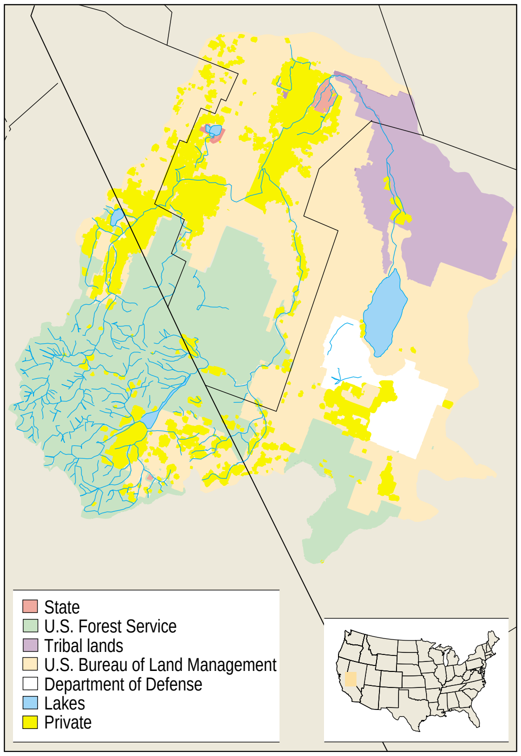


Fig. 27. Land ownership in the Walker River basin, California and Nevada.

In addition to being subjected to the new, severe effects brought on by population growth, the biota of the region already has been severely harmed by water development, mining, grazing, and the introduction of nonindigenous species. Many rare species are at risk in the Great Basin–Mojave Desert region, but even common species are now imperiled by human enterprises. All of these factors profoundly alter community structure, function, and integrity in many ways. In the face of these accelerating changes, it is difficult to be optimistic. Unless major changes are made in the interaction of people with natural communities in this region—one of the last large expanses of wild land in the nation—hope for the retention of the natural character and important ecological role of the Great Basin–Mojave Desert is small.

Acknowledgments

We gratefully acknowledge the assistance of the following individuals and their institutions: G. Clemmer, K. Cooper, and J. Morefield of the Nevada Natural Heritage Program, Carson City; R. Cole, Hart Mountain National Wildlife Refuge, Oregon; S. Bassett, T. Edwards, and C. Homer, U.S. Geological Survey, Utah Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, Utah State University, Logan; R. Hamlin, U.S. Fish and Wildlife Service, Nevada

State Office, Reno; J. Kartesz, Department of Biology, University of North Carolina, Chapel Hill; A. Launner and J. Reaser, Center for Conservation Biology, Stanford University, Stanford, California; Q. Ly and M. Rahn, Biological Resources Research Center, University of Nevada, Reno; T. Charlet, Department of Biochemistry, University of Nevada, Reno; K. Geluso, Department of Biology, University of Nevada, Reno; J. Nachlinger, The Nature Conservancy, Northern Nevada Project Office, Reno; P. Wigand and M. Rose, Quaternary Sciences, Desert Research Institute, Reno, Nevada; G. Stephens, Idaho Conservation Data Center, Idaho Department of Fish and Game, Boise; S. Smith, Department of Biology, University of Nevada, Las Vegas; and J. Young, U.S. Department of Agriculture, Agricultural Research Service, Reno, Nevada. The text was improved by the comments of four anonymous reviewers. Research at Hart Mountain and Sheldon National Wildlife Refuges was supported by the U.S. Fish and Wildlife Service and by the High Desert Ecological Research Institute of Bend, Oregon. Research in Nevada was supported by the Nevada Biodiversity Initiative and the Biological Resources Research Center and the Nevada Agricultural Experiment Station, University of Nevada, Reno.

Cited References

Alcorn, J. R. 1988. The birds of Nevada. Fairview West Publishing, Fallon, Nev. 418 pp.

Anderson, B. W., A. Higgins, and R. D. Ohmart. 1977. Avian use of saltcedar communities in the lower Colorado River Valley. Pages 128–136 *in* R. R. Johnson and D. A. Jones, editors. Importance, preservation and management of riparian habitat: a symposium. U.S. Forest Service General Technical Report RM-43.

Anderson, B. W., and K. E. Holte. 1981. Vegetation development over 25 years without grazing on sagebrush-dominated rangeland in southeastern Idaho. Journal of Range Management 34:25–29.

Armour, C. L., D. A. Duff, and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. Fisheries 16:7–11.

Austin, G. T. 1985. Lowland riparian butterflies of the Great Basin and associated areas. Journal of Research on the Lepidoptera 24:117–131.

Austin, G. T. 1992. *Cercyonis pegala* (Fabricius) (Nymphalidae: Satyrinae) in the Great Basin: new subspecies and biogeography. Bulletin of the Allyn Museum 135. 59 pp.

Axelrod, D. I. 1950. Evolution of desert vegetation in western North America. Contributions to Paleontology. Carnegie Institute of Washington Publication 590 VI. 306 pp.

Axelrod, D. I. 1976. History of the coniferous forests, California and Nevada. University of California Publications in Botany 70. 62 pp.

Axelrod, D. I. 1983. Paleobotanical history of the western deserts. Pages 113–129 *in* S. G. Wells and D. R. Haragan, editors. Origin and evolution of deserts. University of New Mexico Press, Albuquerque.

Axelrod, D. I., and P. H. Raven. 1985. Origins of the Cordilleran flora. Journal of Biogeography 12:21–47.

Barneby, R. C. 1989. Fabales. Volume 3, part B. *In* A. Cronquist, A. H. Holmgren, N. H. Holmgren, J. L. Reveal, and P. K. Holmgren, editors. Intermountain flora: vascular plants of the Intermountain West, U.S.A. New York Botanical Garden, New York.

Barrows, C. W. 1993. Tamarisk control II: a success study. Restoration and Management Notes 11:35–38.

Beatley, J. 1966. Ecological status of introduced brome grasses (*Bromus* spp.) in desert vegetation of southern Nevada. Ecology 47:548–554.

Beatley, J. C. 1974a. Effects of rainfall and temperature on distribution and behavior of *Larrea tridentata* (creosotebush) in the Mojave Desert of Nevada. Ecology 55:245–261.

Beatley, J. C. 1974b. Phenological events and their environmental triggers in Mojave Desert ecosystems. Ecology 55:856–863.

Beatley, J. C. 1976. Vascular plants of the Nevada Test Site and central-southern Nevada: ecologic and geographic distributions, TID-26881. Energy Research and Development Administration, National Technical Information Service, Springfield, Va.

Behle, W. H. 1978. Avian biogeography of the Great Basin and Intermountain Region. Intermountain biogeography: a symposium. Great Basin Naturalist Memoirs 2:55–80.

Belovsky, G. E. 1987. Extinction models and mammalian persistence. Pages 35–58 *in* M. E. Soulé, editor. Viable populations for conservation. Cambridge University Press, Cambridge, England.

Benson, L. V., D. R. Currey, R. I. Dorn, K. R. Lajoie, C. G. Oviatt, S. W. Robinson, G. I. Smith, and S. Stine. 1990. Chronology of expansion and contraction of four Great Basin lake systems during the past 35,000 years. Palaeogeography, Palaeoclimatology, Palaeoecology 78:241–286.

Betancourt, J. L., T. R. Van Devender, and P. S. Martin. 1990. Introduction. Pages 2–11 *in* J. L. Betancourt, T. R. Van Devender, and P. S. Martin, editors. Packrat middens: 40,000 years of biotic change. University of Arizona Press, Tucson.

Bettinger, R. L. 1991. Native land use: archaeology and anthropology. Pages 463–486 *in* C. A. Hall, Jr. Natural history of the White–Inyo Range, eastern California. University of California Press, Berkeley and Los Angeles.

Billings, W. D. 1949. The shadscale vegetation zone of Nevada and eastern California in relation to climate and soils. American Midland Naturalist 42:87–109.

Billings, W. D. 1950. Vegetation and plant growth as affected by chemically altered rocks in the western Great Basin. Ecology 67:62–74.

Billings, W. D. 1951. Vegetational zonation in the Great Basin of western North America. Les bases écologiques de la régénération de la végétation des zones arides. Pages 101–122 *in* International Union of Biological Sciences, Series B, No. 9.

Billings, W. D. 1954a. Temperature inversions in the pinyon–juniper zone of a Nevada mountain range. Butler University Botanical Studies 11:112–118.

Billings, W. D. 1954b. Nevada trees. University of Nevada, Reno, Agricultural Extension Service Bulletin 94. 125 pp.

Billings, W. D. 1970. Plants and the ecosystem. Wadsworth Publishing Company, Inc., Belmont, Calif. iv + 154 pp.

Billings, W. D. 1978. Alpine phytogeography across the Great Basin. Intermountain biogeography: a symposium. Great Basin Naturalist Memoirs 2:105–117.

Billings, W. D. 1990. The mountain forests of North America and their environments. Pages 47–86 *in* C. B. Osmond, L. F. Pitelka, and G. M. Hidy, editors. Plant biology of the Basin and Range. Springer-Verlag, New York.

Billings, W. D., and A. F. Mark. 1957. Factors involved in the persistence of montane treeless balds. Ecology 38:140–142.

Blackburn, W. H., R. W. Knight, and J. L. Schuster. 1982. Saltcedar influence on sedimentation in the Brazos River. Journal of Soil and Water Conservation 37:298–301.

Blackburn, W. H., and P. Tueller. 1970. Pinyon and juniper invasion in black sagebrush communities in east-central Nevada. Ecology 51:841–848.

Blackwelder, E. 1931. Pleistocene glaciation in the Sierra Nevada and basin ranges. Geological Society of America Bulletin 42:865–922.

Blackwelder, E. 1934. Supplementary notes on Pleistocene glaciation in the Great Basin. Journal of the Washington Academy of Sciences 24:212–222.

Bock, C. E., V. A. Saab, T. D. Rich, and D. S. Dobkin. 1993. Effects of livestock grazing on Neotropical migratory land birds in western North America. Pages 296–309 *in* D. M. Finch and P. W. Stangel, editors. Status and management of Neotropical migratory birds. U.S. Forest Service General Technical Report RM-229.

Bohning-Gaese, K., M. L. Taper, and J. H. Brown. 1993. Are declines in North American insectivorous songbirds due to causes on the breeding range? Conservation Biology 7:76–86.

Brown, J. H. 1971. Mammals on mountaintops: non-equilibrium insular biogeography. American Naturalist 105:467–478.

Brown, J. H. 1973. Species diversity of seed-eating rodents in sand dune habitats. Ecology 54:775–787.

Brown, J. H. 1978. The theory of insular biogeography and the distribution of boreal birds and mammals. Great Basin Naturalist Memoirs 2:209–227.

Brown, L. H., and D. Amadon. 1968. Eagles, hawks, and falcons of the world. McGraw-Hill, New York. 945 pp.

Brussard, P. F., and G. A. Austin. 1993. Nevada butterflies: check list and ecological distribution. Biological Resources Research Center, Reno. 5 pp.

Bunting, S. C. 1986. Use of prescribed burning in juniper and pinyon–juniper woodlands. Pages 141–144 *in* R. L. Everett, editor. Proceedings: pinyon–juniper conference. U.S. Forest Service General Technical Report INT-215.

Bureau of Land Management. 1994. Cooperative agreement with the Nevada Division of Minerals on Securing Mine Safety Standards. Instruction Memorandum NV-95-022. 14 pp.

Burkhardt, J. W., and E. W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. Ecology 76:472–484.

Burt, W. H., and R. P. Grossenheider. 1976. Field guide to the mammals. Peterson field guide series 5. Houghton Mifflin Company, Boston, Mass. xvii + 289 pp.

Busch, D. E., and S. D. Smith. 1993. Effects of fire on water and salinity relations of riparian woody taxa. Oecologia 94:186–194.

Busch, D. E., and S. D. Smith. 1995. Mechanisms associated with the decline of woody species in riparian ecosystems of the southwestern United States. Ecological Monographs 65(3):347–370.

California Department of Water Resources. 1992. Walker River atlas. State of California, The Resources Agency, Sacramento. ix + 99 pp.

Callison, J., and J. D. Brotherson. 1985. Habitat relationships of the blackbrush community (*Coleogyne ramosissima*) of southwestern Utah. Great Basin Naturalist 45:321–326.

Carothers, S. W., R. R. Johnson, and S. W. Aitchison. 1974. Population structure and social organization of southwestern riparian birds. American Zoologist 14:97–108.

Chandler, J. R. 1970. A biological approach to water quality management. Water Pollution Control 4:415–422.

Chaney, E., W. Elmore, and W. S. Platts. 1993. Livestock grazing on western riparian areas. U.S. Government Printing Office, Washington, D.C. 45 pp.

Chapman, H. C. 1966. The mosquitoes of Nevada. Entomology Research Division, Agriculture Research Service, U.S. Department of Agriculture and the Max C. Fleischmann College of Agriculture, University of Nevada, Reno. 41 pp.

Charlet, D. A. 1991. Relationships of the Great Basin alpine flora: a quantitative analysis. M.S. thesis, University of Nevada, Reno.

Charlet, D. A. 1996. Atlas of Nevada conifers: a phytogeographic reference. University of Nevada Press, Reno. xiv + 320 pp.

Charlet, D. A. 1997. Floristics of the Mt. Jefferson alpine flora. *In* D. H. Thomas, editor. The archaeology of Monitor Valley. 4. Alta Toquima and the Mount Jefferson Complex. American Museum of Natural History Anthropological Papers, New York. In press.

Charlet, D. A., and R. W. Rust. 1991. Visitation of high mountain bogs by golden eagles in the northern Great Basin. Journal of Field Ornithology 62:46–52.

Clark County. 1994. Clark County draft Desert Conservation Plan, August 1994, Clark County, Nevada. 123 pp. + appendixes.

Clark, D. R., Jr., and R. L. Hothem. 1991. Mammal mortality at Arizona, California, and Nevada gold mines using cyanide extraction. California Fish and Game 77:61–69.

Critchfield, W. B. 1984a. Crossability and relationships of Washoe pine. Madroño 31:144–170.

Critchfield, W. B. 1984b. Impact of the Pleistocene on the genetic structure of North American conifers. Pages 70–118 *in* R. L. Lanner, editor. Proceedings of the Eighth North American Forest Biology Workshop, 30 July–1 August 1984, Utah State University, Logan.

Critchfield, W. B., and G. L. Allenbaugh. 1969. The distribution of Pinaceae in and near northern Nevada. Madroño 20:12–26.

Dahl, T. E., and C. E. Johnson. 1991. Status and trends of wetlands in the conterminous United States, mid-1970's to mid-1980's. U.S. Fish and Wildlife Service. 28 pp.

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23:63–87.

d'Azavedo, W. 1986. Handbook of North American Indians, Volume 11: Great Basin. Smithsonian Institution, Washington, D.C. 852 pp.

Deacon, J. E. 1979. Endangered and threatened fishes of the West. Great Basin Naturalist Memoirs 3:41–64.

Deacon, J. E., and C. D. Williams. 1991. Ash Meadows and the legacy of the Devils Hole pupfish. Pages 69–87 *in* W. L. Minckley and J. E. Deacon, editors. Battle against extinction. The University of Arizona Press, Tucson.

DeLucia, E. H., and W. H. Schlesinger. 1990. Ecophysiology of Great Basin and Sierra Nevada vegetation on contrasting soils. Pages 143–178 *in* C. B. Osmond, L. F. Pitelka, and G. M. Hidy, editors. Plant biology of the Basin and Range. Springer-Verlag, Berlin, Germany.

DeLucia, E. H., W. H. Schlesinger, and W. D. Billings. 1988. Water relations and the maintenance of Sierran conifers on hydrothermally altered rock. Ecology 69:303–311.

Demarais, B. D., T. E. Dowling, and W. L. Minckley. 1993. Post-perturbation genetic changes in populations of endangered Virgin River chubs. Conservation Biology 7:334–341.

DeSante, D. F., and T. L. George. 1994. Population trends in the land birds of western North America. Pages 173–190 *in* J. R. Jehl, Jr., and N. K. Johnson, editors. A century of avifaunal change in western North America. Studies in Avian Biology, Volume 15.

Desert Research Institute. 1968. Final reports on the Lehman Caves studies to the Department of the Interior, National Park Service, Lehman Caves National Monument. The Laboratory of Desert Biology, Desert Research Institute, Reno, Nev. 57 pp.

Dobkin, D. S. 1985. Heterogeneity of tropical floral microclimates and the response of hummingbird flower mites. Ecology 66:536–543.

Dobkin, D. S. 1994a. Conservation and management of Neotropical migrant land birds in the northern Rockies and Great Plains. University of Idaho Press, Moscow. 220 pp.

Dobkin, D. S. 1994b. Community composition and habitat affinities of riparian birds on the Sheldon-Hart Mountain refuges, Nevada and Oregon, 1991–93. Final report. U.S. Fish and Wildlife Service, Lakeview, Oreg. 287 pp.

Dobkin, D. S. 1995. Management and conservation of sage grouse, denominative species for the ecological health of shrub–steppe ecosystems. Technical note. Bureau of Land Management, Portland, Oreg. 26 pp.

Dobkin, D. S. 1998. Conservation and management of Neotropical migrant land birds in the Great Basin. University of Idaho Press, Moscow. In press.

Dobkin, D. S., A. C. Rich, J. A. Pretare, and W. H. Pyle. 1995a. Nest-site relationships among cavity-nesting birds in riparian and snowpocket aspen woodlands in the northwestern Great Basin. Condor 97:694–707.

Dobkin, D. S., R. D. Gettinger, and M. G. Gerdes. 1995b. Springtime movements, roost use, and foraging activities of Townsend's big-eared bat (*Plecotus townsendii*) in central Oregon. Great Basin Naturalist 55:315–321.

Dobkin, D. S., I. Olivieri, and P. R. Ehrlich. 1987. Rainfall and the interaction of microclimate with larval resources in the population dynamics of checkerspot butterflies (*Euphydryas editha*) inhabiting serpentine grassland. Oecologia 71:161–166.

Dobkin, D. S., and B. A. Wilcox. 1986. Analysis of natural forest fragments: riparian birds in the Toiyabe Mountains, Nevada. Pages 293–299 *in* J. Verner, M. L. Morrison, and C. J. Ralph, editors. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison.

Dohrenwend, J. C., W. B. Bull, L. D. McFadden, G. I. Smith, R. S. U. Smith, and S. G. Wells. 1991. Quaternary geology of the Great Basin. Pages 321–352 *in* R. B. Morrison, editor. Quaternary nonglacial geology: conterminous U.S. Volume K-2. Geological Society of America, Boulder, Colo.

Ehrlich, P. R., D. S. Dobkin, and D. Wheye. 1992. Birds in jeopardy: the imperiled and extinct birds of the United States and Canada including Hawaii and Puerto Rico. Stanford University Press, Stanford, Calif. x + 259 pp.

Ehrlich, P. R., and D. D. Murphy. 1987. Monitoring populations on remnants of native vegetation. Pages 201–210 *in* D. A. Saunders, G. W. Arnold, A. A. Burbidge, and A. J. M. Hopkins, editors. Nature conservation: the role of remnants of native vegetation. Surrey Beatty and Sons Pty. Limited, Chipping Norton, New South Wales, Australia.

El-Ghonemy, A. A., A. Wallace, and E. M. Romney. 1980a. Multivariate analysis of the vegetation in a two-desert interface. Great Basin Naturalist Memoirs 4:42–58.

El-Ghonemy, A. A., A. Wallace, and E. M. Romney. 1980b. Socioecological and soil-plant studies of the natural vegetation in the northern Mojave Desert–Great Basin Desert interface. Great Basin Naturalist Memoirs 4:71–86.

Erman, N. A. 1991. Aquatic invertebrates as indicators of biodiversity. Proceedings of the symposium on biodiversity of northwestern California, 28–30 October 1991. Santa Rosa, Calif.

Ertter, B. 1992. Floristic regions of Idaho. Journal of the Idaho Academy of Science 28:57–70.

Fiero, B. 1986. Geology of the Great Basin. Max C. Fleischmann series in Great Basin natural history, University of Nevada Press, Reno. 197 pp.

Finch, D. M., and P. W. Stangel, editors. 1993. Status and management of Neotropical migratory birds. U.S. Forest Service General Technical Report RM-229. 422 pp.

Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology 8:629–644.

Flint, R. F. 1971. Glacial and quaternary geology. John Wiley & Sons, New York. 892 pp.

Franklin, J. F., H. H. Shugart, and M. E. Harmon. 1987. Tree death as an ecological process. BioScience 37:550–556.

Frémont, J. C. 1845. Report of the exploring expedition to the Rocky Mountains in the year 1842 and to Oregon and California in the years 1843–1844. Goles and Seaton, Washington, D.C. 693 pp.

Genter, D. L. 1986. Wintering bats of the upper Snake River plain: occurrence in lava-tube caves. Great Basin Naturalist 46:241–244.

Goodwin, J. 1992. The role of mycorrhizal fungi in competitive interactions among native bunchgrasses and alien weeds: a review and synthesis. Northwest Science 66:251–260.

Gould, S. J. 1991. Abolish the recent. Natural History 5(91):16–21.

Graf, W. L. 1980. Riparian management: a flood control perspective. Journal of Soil and Water Conservation 35:158–161.

Grayson, D. K. 1987. The biogeographic history of small mammals in the Great Basin: observation on the last 20,000 years. Journal of Mammalogy 68:359–375.

Grayson, D. K. 1993. The desert's past: a natural prehistory of the Great Basin. Smithsonian Institution Press, Washington, D.C. 356 pp.

Great Basin National Park. 1988. Resource baseline inventory of the Great Basin National Park. Cooperative National Park Resources Study Unit, University of Nevada, Las Vegas, and National Park Service. Great Basin National Park Special Publication 1, NPS/WRGR-BA/92-01. 56 pp.

Hafner, D. J. 1992. Speciation and persistence of a contact zone in Mojave Desert ground squirrel, subgenus *Xerospermophilus*. Journal of Mammalogy 73:770–778.

Hafner, D. J., and T. L. Yates. 1983. Systematic status of the Mojave ground squirrel, *Spermophilus mohavensis* (subgenus *Xerospermophilus*). Journal of Mammalogy 64:397–404.

Hall, E. R. 1946. Mammals of Nevada. University of California Press, Berkeley. xi + 710 pp.

Hall, E. R. 1981. Mammals of North America. John Wiley & Sons, New York. xv + 1,181 pp.

Hammond, P. C., and D. V. McCorkle. 1983. The decline and extinction of *Speyeria* populations resulting from human environmental disturbances (Nymphalidae: Argynninae). Journal of Research on the Lepidoptera 22:217–224.

Hardy, A. R., and F. G. Andrews. 1979. An inventory of selected Coleoptera from Algodones Dune. Bureau of Land Management contract report CA-060-CT-8-98:1–35.

Harper, K. T., D. L. Freeman, W. K. Ostler, and L. G. Klikoff. 1978. The flora of Great Basin mountain ranges: diversity, sources, and dispersal ecology. Pages 81–104 *in* K. T. Harper and J. L. Reveal, editors. Intermountain biogeography: a symposium. Great Basin Naturalist Memoirs 2.

Hershler, R. 1989. Springsnails (Gastropoda: Hydrobiidae) of Owens and Amargosa River (exclusive of Ash Meadows) drainages, Death Valley system, California–Nevada. Proceedings of the Biological Society of Washington 102:176–248.

Hershler, R. 1994. A review of the North American freshwater snail genus *Pyrgulopsis* (Hydrobiidae). Smithsonian Contribution to Zoology 554:1–115.

Hershler, R., and W. L. Pratt. 1990. A new *Pyrgulopsis* (Gastropoda: Hydrobiidae) from southeastern California, with a model for historical development of the Death Valley hydrographic system. Proceedings of the Biological Society of Washington 103:279–299.

Hershler, R., and D. Sada. 1987. Springsnails (Gastropoda: Hydrobiidae) of Ash Meadows, Amargosa basin, California–Nevada. Proceedings of the Biological Society of Washington 100:776–843.

Hidy, G. M., and H. E. Klieforth. 1990. Atmospheric processes affecting the climate of the Great Basin. Pages 17–45 *in* C. B. Osmond, L. F. Pitelka, and G. M. Hidy, editors. Plant biology of the Basin and Range. Springer-Verlag, New York.

Hironka, M., and E. W. Tisdale. 1963. Secondary succession in annual vegetation in southern Idaho. Ecology 44:810–812.

Holmgren, N. 1972. Plant geography in the Intermountain Region. Pages 77–161 *in* A. Cronquist, A. H. Holmgren, N. H. Holmgren, and J. L. Reveal, editors. Intermountain flora. Volume I. Hafner Publishing Company, New York.

Horne, A. J., J. C. Roth, and N. J. Barratt. 1995. Walker Lake, Nevada: state of the lake 1992–1994. Report to the Nevada Department of Environmental Protection. 83 pp. + appendixes.

Houghton, J. G. 1978. Foreword. Pages vii–viii *in* A. McLane. Silent cordilleras. Camp Nevada, Reno.

Houghton, J. G., C. M. Sakamoto, and R. O. Gifford. 1975. Nevada's weather and climate. Nevada Bureau of Mines and Geology, Special Publication 2, Reno. 78 pp.

Hunt, C. B. 1967. Physiography of the United States. W. H. Freeman, San Francisco, Calif. 480 pp.

Hunter, R. 1990. Recent increases in *Bromus* populations on the Nevada test site. Pages 22–25 *in* E. D. McArthur, E. M. Romney, S. D. Smith, and P. T. Tueller, editors. Proceedings of a symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. Las Vegas, Nevada, 5–7 April 1989. U.S. Forest Service Intermountain Research Station General Technical Report INT-276.

Ingles, L. G. 1947. Mammals of California. University of California Press, Berkeley. xix + 258 pp.

Jameson, E. W., Jr., and H. J. Peeters. 1988. California mammals. University of California Press, Berkeley. xi + 403.

Jehl, J. R., Jr. 1994. Changes in saline and alkaline lake avifaunas in western North America in the past 150 years. Pages 258–272 *in* J. R. Jehl, Jr., and N. K. Johnson, editors. A century of avifaunal change in western North America. Studies in Avian Biology, Volume 15.

Johnson, N. K. 1975. Controls of number of bird species on montane islands in the Great Basin. Evolution 29:545–567.

Johnson, N. K. 1978. Patterns of avian geography and speciation in the Great Basin. Pages 137–159 *in* K. T. Harper and J. L. Reveal, editors. Intermountain biogeography: a symposium. Great Basin Naturalist Memoirs 2.

Johnson, R. R., C. D. Ziebell, D. R. Patton, P. F. Ffolliott, and R. H. Hamre, technical editors. 1985. Riparian ecosystems and their management: reconciling conflicting uses. U.S. Forest Service General Technical Report RM-120. 523 pp.

Johnson, T. N. 1986. Using herbicides for pinyon–juniper control in the Southwest. Pages 330–334 *in* R. L. Everett, editor. Proceedings: pinyon–juniper conference. U.S. Forest Service General Technical Report INT-215.

Kartesz, J. T. 1988. A flora of Nevada. Ph.D. dissertation, University of Nevada, Reno. 1,729 pp.

Kauffman, J. B., and W. C. Krueger. 1984. Livestock impacts on riparian ecosystems and stream management implications: a review. Journal of Range Management 37:430–438.

King, P. B. 1977. The evolution of North America. Princeton University Press, Princeton, N. J. 197 pp.

Knick, S. T., and J. T. Rotenberry. 1995. Landscape characteristics of fragmented shrub–steppe habitats and breeding passerine birds. Conservation Biology. 9:1059–1071.

Knopf, F. L., R. R. Johnson, T. Rich, F. B. Samson, and R. C. Szaro. 1988a. Conservation of riparian ecosystems in the United States. Wilson Bulletin 100:272–284.

Knopf, F. L., J. A. Sedgwick, and R. W. Cannon. 1988b. Guild structure of a riparian avifauna relative to seasonal cattle grazing. Journal of Wildlife Management 52:280–290.

Koch, D. L., J. J. Cooper, E. L. Lider, R. L. Jacobson, and R. J. Spencer. 1979. Investigations of Walker Lake, Nevada: dynamic ecological relationships. Bioresources Center, Desert Research Institute, University of Nevada System, Reno. 189 pp.

Kremen, C. 1992. Assessing the indicator properties of species assemblages for natural areas monitoring. Ecological Applications 2:203–217.

Kremen, C., R. K. Colwell, T. L. Erwin, D. D. Murphy, R. F. Noss, and M. A. Sanjayan. 1993. Terrestrial arthropod assemblages: their use in conservation planning. Conservation Biology 7:796–808.

Krueper, D. J. 1993. Effects of land use practices on western riparian ecosystems. Pages 321–330 *in* D. M. Finch and P. W. Stangel, editors. Status and management of Neotropical migratory birds. U.S. Forest Service General Technical Report RM-229.

Lancaster, N. 1988a. Controls of eolian dune size and spacing. Geology 16:972–975.

Lancaster, N. 1988b. On desert sand seas. Episodes 11:12–17.

Lancaster, N. 1989. The dynamics of star dunes: an example from Gran Desierto, Mexico. Sedimentology 36:273–289.

Lanner, R. M. 1984. Trees of the Great Basin. University of Nevada Press, Reno. 215 pp.

Las Vegas Valley Water District. 1992. Environmental report of the Virgin River Water Resource Development Project, Clark County, Nevada. Cooperative Water Project, Report 2, Hydrographic Basin 222. 130 pp.

Las Vegas Valley Water District. 1993. Addendum to environmental report of the Virgin River Water Resource Development Project, Clark County, Nevada. Cooperative Water Project, Report 2, Hydrographic Basin 222. 27 pp.

Lavin, M. T. 1981. The floristics of the headwaters of the Walker River, California and Nevada. M.S. thesis, University of Nevada, Reno. 141 pp.

Linsdale, M. A., J. T. Howell, and J. M. Linsdale. 1952. Plants of the Toiyabe Mountains area, Nevada. Wasmann Journal of Biology 10:129–200.

Little, E. L., Jr. 1971. Atlas of United States trees. Volume 1. Conifers and important hardwoods. U.S. Forest Service Miscellaneous Publication 1146. 203 pp.

Loope, L. L. 1969. Subalpine and alpine vegetation of northeastern Nevada. Ph.D. dissertation, Duke University, Durham, N.C. 292 pp.

Lovich, J. E., T. B. Egan, and R. C. de Gouvenain. 1994. Tamarisk control on public lands in the desert of southern California: two case studies. Pages 166–177 *in* 46th Annual California Weed Conference, California Weed Science Society.

Luckenbach, R. A., and R. B. Bury. 1983. Effects of off-road vehicles on the biota of Algodones Dunes, Imperial County, California. Journal of Applied Ecology 20:265–286.

Mack, R. N. 1986. Alien plant invasion into the Intermountain West: a case history. Pages 191–213 *in* H. A. Mooney and J. A. Drake, editors. Ecology of biological invasions in North America and Hawaii. Springer-Verlag, New York.

MacMahon, J. A. 1988a. Warm deserts. Pages 231–264 *in* M. G. Barbour and W. D. Billings, editors. North American terrestrial vegetation. Cambridge University Press, New York.

MacMahon, J. A. 1988b. North American deserts: their floral and faunal components. Pages 21–81 *in* M. G. Barbour and W. D. Billings, editors. North American terrestrial vegetation. Cambridge University Press, New York.

Mason, W. T., Jr. 1995. Invertebrates. Pages 159–160 *in* E. T. LaRoe, G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, editors. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Biological Service, Washington, D.C.

McLane, A. R. 1975. A bibliography of Nevada's caves. Center for Water Resources Research, Desert Research Institute, Reno, Nev. 99 pp.

Mead, J. I. 1987. Quaternary records of pika, *Ochotona*, in North America. Boreas 16:165–171.

Mehringer, P. J., Jr., and P. E. Wigand. 1990. Comparison of late-Holocene environments from woodrat middens and pollen: Diamond Craters, Oregon. Pages 294–325 *in* J. L. Betancourt, T. R. Van Devender, and P. S. Martin, editors. Packrat middens—the last 40,000 years of biotic change. University of Arizona Press, Tucson.

Melgoza, G., R. S. Nowak, and R. J. Tausch. 1990. Soil water exploitation after fire: competition between *Bromus tectorum* (cheatgrass) and two native species. Oecologia 83:7–13.

Meyer, S. E. 1978. Some factors governing plant distributions in the Mojave–Intermountain transition zone. Intermountain biogeography: a symposium. Great Basin Naturalist Memoirs 2:197–207.

Meyer, S. E. 1986. The ecology of gypsum communities in the Mojave Desert. Ecology 67:1303–1313.

Mifflin, M. D., and M. M. Wheat. 1979. Pluvial lakes and estimated pluvial climates of Nevada. University of Nevada, Reno. Mackay School of Mines Bulletin 94. 57 pp.

Miller, R. F., and J. A. Rose. 1995. Historic expansion of *Juniperus occidentalis* (western juniper) in southeastern Oregon. Great Basin Naturalist 55:37–45.

Miller, R. F., and P. E. Wigand. 1994. Holocene changes in semiarid pinyon–juniper woodlands. BioScience 44:465–474.

Minckley, W. L., and M. E. Douglas. 1991. Discovery and extinction of western fishes: a blink of the eye in geologic time. Pages 7–17 *in* W. L. Minckley and J. E.

Deacon, editors. Battle against extinction. University of Arizona Press, Tucson.

Morefield, J. D. 1992. Spatial and ecologic segregation of phytogeographic elements in the White Mountains of California and Nevada. Journal of Biogeography 19:33–50.

Morefield, J. D., D. W. Taylor, and M. DeDecker. 1988. Vascular flora of the White Mountains of California and Nevada: an updated, synonymized working checklist. Appendix *in* C. A. Hall, Jr., and V. Doyle-Jones, editors. The Mary DeDecker Symposium: plant biology of eastern California. White Mountain Research Station, University of California, Los Angeles.

Morrison, R. B. 1964. Lake Lahontan: geology of southern Carson Desert, Nevada. U.S. Geological Survey Professional Paper 401. 156 pp.

Morrison, R. B. 1991. Quaternary stratigraphic, hydrologic, and climatic history of the Great Basin, with emphasis on Lakes Lahontan, Bonneville, and Tecopa. Pages 283–320 *in* R. B. Morrison, editor. Quaternary nonglacial geology: conterminous United States. The Geology of North America, Volume K-2.

Morrow, L. A., and P. W. Stahlman. 1984. The history and distribution of downy brome (*Bromus tectorum*) in North America. Weed Science 32, Supplement 1:2–7.

Moyle, P. B., and R. M. Yoshiyama. 1994. Protection of aquatic biodiversity in California: a five-tiered approach. Fisheries 19:6–18.

Murphy, D. D., K. E. Freas, and S. B. Weiss. 1990. An environment–metapopulation approach to population viability analysis for a threatened invertebrate. Conservation Biology 4:41–51.

National Research Council. 1994. Rangeland health: new methods to classify, inventory, and monitor rangelands. National Academy Press, Washington, D.C. xvi + 180 pp.

Nelson, C. R. 1994. Insects of the Great Basin and Colorado Plateau. Pages 211–238 *in* K. T. Harper, L. L. St. Clare, K. H. Thorne, and W. M. Hess, editors. Natural history of the Colorado Plateau and Great Basin. University Press of Colorado, Niwot.

Nevada Natural Heritage Program. 1992. Summary of elements that occur on the top priority conservation planning sites. Nevada Natural Heritage Program, Carson City.

New, T. R. 1991. Butterfly conservation. Oxford University Press, Melbourne, Australia. xi + 224 pp.

Noss, R. F., E. T. LaRoe, III, and J. M. Scott. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. National Biological Service Biological Report 28. 58 pp.

Nowak, C. L. 1991. Reconstruction of post-glacial vegetation and climate history in western Nevada: evidence from plant macrofossils in *Neotoma* middens. M.S. thesis, University of Nevada, Reno. viii + 69 pp.

Nowak, C. L., R. S. Nowak, R. J. Tausch, and P. E. Wigand. 1994. A 30,000 year record of vegetation dynamics at a semi-arid locale in the Great Basin. Journal of Vegetation Science 5:579–590.

Nowak, R. M. 1991. Walker's mammals of the world. Fifth edition. Johns Hopkins University Press, Baltimore, Md. Volumes 1 and 2.

O'Farrell, T. P., and L. A. Emery. 1976. Ecology of the Nevada test site: a narrative summary and annotated bibliography. Report NVO-167. U.S. Department of Energy, National Technical Information Services, U.S. Department of Commerce, Springfield, Va.

Ohmart, R. D. 1994. The effects of human-induced changes on the avifauna of western riparian habitats. Pages 273–285 *in* J. R. Jehl, Jr., and N. K. Johnson, editors. A century of avifaunal change in western North America. Studies in Avian Biology, Volume 15.

Osborn, G. 1989. Glacial deposits and tephra in the Toiyabe Range, Nevada, U.S.A. Arctic and Alpine Research 21:256–267.

Parker, W. S., and E. R. Pianka. 1975. Comparative ecology of populations of the lizard *Uta stansburiana*. Copeia 4:615–632.

Patterson, B. D. 1984. Mammalian extinction and biogeography in the southern Rocky Mountains. Pages 247–293 *in* M. H. Nitecke, editor. Extinctions. University of Chicago Press, Ill.

Patterson, B. D., and W. Atmar. 1986. Nested subsets and the structure of insular mammalian faunas and archipelagos. Biological Journal of the Linnaean Society 28:65–82.

Pavlik, B. M. 1985. Sand dune flora of the Great Basin and Mojave deserts of California, Nevada, and Oregon. Madroño 32:197–213.

Pavlik, B. M. 1989. Phytogeography of sand dunes in the Great Basin and Mojave deserts. Journal of Biogeography 16:227–238.

Peterjohn, B. G., and J. R. Sauer. 1993. North American Breeding Bird Survey annual summary 1990–1991. Bird Populations 1:1–15.

Peterjohn, B. G., J. R. Sauer, and W. A. Link. 1994. The 1992–1993 summary of the North American Breeding Bird Survey. Bird Populations. 2:246–261.

Pianka, E. R. 1967. On lizard species diversity: North American flatland deserts. Ecology 50:1012–1030.

Pianka, E. R. 1970. Comparative autecology of the lizard (*Cnemidophorus tigris*) in different parts of its geographic range. Ecology 51:703–720.

Pickford, G. D. 1932. The influence of continued heavy grazing and of promiscuous burning on spring–fall ranges in Utah. Ecology 13:159–171.

Piegat, J. J. 1980. Glacial geology of central Nevada. M.S. thesis, Purdue University, West Lafayette, Ind.

Piemeisel, R. L. 1951. Causes affecting change and rate of change in a vegetation of annuals in Idaho. Ecology 32:53–72.

Pierson, E. D., and P. E. Brown. 1992. Saving old mines for bats. Bats 10:11–13.

Pierson, E. D., W. E. Rainey, and D. M. Koontz. 1991. Bats and mines: experimental mitigation for Townsend's big-eared bat at the McLaughlin mine in California. Pages 31–42 *in* Proceedings V: issues and technology in the management of impacted wildlife. Thorne Ecological Institute, Snowmass Resort, Calif.

Platts, W. S. 1990. Managing fisheries and wildlife on rangelands grazed by livestock. Nevada Department of Wildlife, Reno.

Porter, S. C., K. L. Pierce, and T. D. Hamilton. 1983. Late Wisconsin mountain glaciation in the western United States. Page 71–111 *in* S. C. Porter, editor. Late-Quaternary environments of the United States. Volume 1. University of Minnesota Press, Minneapolis.

Pyle, R., M. Bentzien, and P. Opler. 1981. Insect conservation. Annual Review of Entomology 26:233–258.

Raven, P. H. 1988. The California flora. Pages 109–137 *in* M. G. Barbour and J. Major, editors. Terrestrial vegetation of California. California Native Plant Society, Special Publication 9.

Reveal, J. L. 1979. Biogeography of the Intermountain Region: a speculative appraisal. Mentzelia 4:1–92.

Reveal, J. L. 1985. Annotated key to *Eriogonum* (Polygonaceae) of Nevada. Great Basin Naturalist 45:495–519.

Reveal, J. L. 1989. A checklist of the Eriogonoideae (Polygonaceae). Phytologia 66:266–294.

Rice, B., and M. Westoby. 1978. Vegetative responses of some Great Basin shrub communities protected against jackrabbits or domestic stock. Journal of Range Management 31:28–34.

Rich, A. C., D. S. Dobkin, and L. J. Niles. 1994. Defining forest fragmentation by corridor width: the influence of narrow forest-dividing corridors on forest-nesting birds in southern New Jersey. Conservation Biology 8:1109–1121.

Robbins, C. S., D. Bystrak, and P. H. Geissler. 1986. The Breeding Bird Survey: its first 15 years, 1965–1979. U.S. Fish and Wildlife Service Research Publication 157. iii + 196 pp.

Robbins, C. S., D. K. Dawson, and B. A. Dowell. 1989. Habitat area requirements of breeding forest birds of the Middle Atlantic states. Wildlife Monographs 103. 34 pp.

Roberts, T. C., Jr. 1990. Cheatgrass: management implications in the '90's. Pages 9–21 *in* E. D. McArthur, E. M. Romney, S. D. Smith, and P. T. Tueller, editors. Proceedings: symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management. Las Vegas, Nevada, 5–7 April 1989. U.S. Forest Service Intermountain Research Station General Technical Report INT-276.

Robinson, S. K. 1988. Reappraisal of the costs and benefits of habitat heterogeneity for nongame wildlife. Pages 145–155 *in* Transactions of the 53rd North American Wildlife and Natural Resources Conference.

Robinson, T. W. 1965. Introduction, spread, and areal extent of saltcedar (*Tamarix*) in the western states. U.S. Geological Survey Professional Paper 491-A. 12 pp. + 1 plate.

Rogers, G. F. 1982. Then and now: a photographic history of vegetation change in the central Great Basin desert. University of Utah Press, Salt Lake City. 152 pp.

Runeckles, V. C. 1982. Relative death rate: a dynamic parameter describing plant response to stress. Journal of Applied Ecology 19:295–303.

Rust, R. W. 1986. New species of *Osmia* (Hymenoptera: Megachilidae) from the southwestern United States. Entomological News 97:147–155.

Rust, R. W. 1994. Survey and status of federal category 2 candidate beetle species from Big Dune and Lava Dune in the Amargosa Desert of Nevada. Bureau of Land Management Report for Proposal NV-0546631. 26 pp.

Schmid, R., and M. J. Schmid. 1975. Living links with the past. Natural History 84:38–45.

Schmude, K. L., and H. P. Brown. 1991. A new species of *Stenelmis* (Coleoptera: Elmidae) found west of the Mississippi River. Proceedings of the Entomological Society of Washington 93:51–61.

Schulz, T. T., and W. C. Leininger. 1991. Nongame wildlife communities in grazed and ungrazed montane riparian sites. Great Basin Naturalist 51:286–292.

Scott, J. A. 1986. The butterflies of North America. Stanford University Press, Stanford, Calif. xii + 583 pp.

Shreve, F. 1942. The desert vegetation of North America. Botanical Review 8:195–246.

Sigler, J. W., and W. F. Sigler. 1994. Fishes of the Great Basin and the Colorado Plateau: past and present forms. Pages 163–208 *in* K. T. Harper, L. L. St. Clair, K. H. Thorne, and W. M. Hess, editors. Natural history of the Colorado Plateau and Great Basin. University Press of Colorado, Niwot.

Smith, R. S. U. 1982. Sand dunes in the North American deserts. Page 481–524 *in* G. L. Bender, editor. Reference handbook of the deserts of North America. Greenwood Press, Westport, Conn.

Soltz, D. L., and R. J. Naiman. 1978. The natural history of native fishes in the Death Valley system. Natural History Museum of Los Angeles County in conjunction with the Death Valley Natural History Association, Science Series 30. Los Angeles, Calif. 76 pp.

Stebbins, G. L. 1974. Flowering plants. Belknap Press, Cambridge, Mass. 399 pp.

Stebbins, R. C. 1974. Off-road vehicles and the fragile desert. American Biology Teacher, National Association of Biology Teachers 36:203–208 and 294–304.

Stebbins, R. C. 1985. A field guide to western reptiles and amphibians. Petersen field guide series 16. Houghton Mifflin Company, Boston, Mass. xiv + 336 pp.

Sudworth, G. B. 1898. Check list of the forest trees of the United States, their names and ranges. U.S. Division of Forestry Bulletin 17. 144 pp.

Sudworth, G. B. 1913. Forest atlas. Geographic distribution of North American trees. Part I. Pines. U.S. Forest Service. 36 maps (folio).

Sweitzer, R. A. 1990. Winter ecology and predator avoidance in porcupines (*Erethizon dorsatum*) in the Great Basin Desert. M.S. thesis, University of Nevada, Reno. 64 pp.

Tausch, R. J., and P. T. Tueller. 1990. Foliage biomass and cover relationships between tree- and shrub-dominated communities in pinyon–juniper woodlands. Great Basin Naturalist 50:121–134.

Tausch, R. J., N. E. West, and A. A. Nabi. 1981. Tree age and dominance patterns in Great Basin pinyon–juniper woodlands. Journal of Range Management 34:259–264.

Terborgh, J. 1989. Where have all the birds gone? Princeton University Press, Princeton, N.J. xvi + 207 pp.

The Nature Conservancy. 1994. Spring Mountains National Recreation Area: biodiversity hot spots and management recommendations. Report to the Bureau of Land Management, U.S. Fish and Wildlife Service, and U.S. Forest Service. The Nature Conservancy, Reno, Nev. 52 pp. + 23 maps.

Thomas, D. H. 1985. The archaeology of Hidden Cave, Nevada. Anthropological papers of the American Museum of Natural History, New York. Volume 61, Part 1. 430 pp.

Thomas, D. H. 1997. The archaeology of Monitor Valley. 4. Alta Toquima and the Mount Jefferson Complex. American Museum of Natural History Anthropological Papers, New York. In press.

Thomas, J. A. 1983. A quick method for estimating butterfly numbers during surveys. Biological Conservation 27:195–211.

Thomas, J. A. 1984. The conservation of butterflies in temperate countries: past efforts and lessons for the future. Pages 333–353 *in* R. I. Vane-Wright and P. R. Ackery, editors. The biology of butterflies. Princeton University Press, Princeton, N.J.

Thomas, J. A. 1991. Rare species conservation: case studies of European butterflies. Pages 141–197 *in* I. F. Spellerberg, M. G. Morris, and F. B. Goldsmith, editors. The scientific management of temperate communities for conservation. 29th Symposium of the British Ecological Society, Blackwell Scientific Publications, Oxford, England.

Thomas, J. W., C. Maser, and J. E. Rodiek. 1979. Wildlife habitats in managed rangelands—the Great Basin of southeastern Oregon. Riparian zones. U.S. Forest Service General Technical Report PNW-80. 18 pp.

Thompson, R. S., and J. I. Mead. 1982. Late Quaternary environments and biogeography in the Great Basin. Quaternary Research 17:39–55.

Tidwell, D. P. 1986. Multi-resource management of pinyon–juniper woodlands: times have changed, but do we know it? Pages 5–8 *in* R. L. Everett, editor. Proceedings: pinyon–juniper conference. U.S. Forest Service General Technical Report INT-215.

Tueller, P. T., R. J. Tausch, and V. Bostick. 1991. Species and plant community distribution in a Mojave–Great Basin Desert transition. Vegetatio 92:133–150.

Turner, M. G., W. H. Romme, R. H. Gardner, R. V. O'Neill, and T. K. Kratz. 1993. A revised concept of landscape equilibrium: disturbance and stability on scaled landscapes. Landscape Ecology 8:213–227.

Turner, R. M. 1982. Cold-temperate desertlands. Pages 145–155 *in* D. E. Brown, editor. Biotic communities of the American Southwest—United States and Mexico. Volume 4: Desert plants.

U.S. Fish and Wildlife Service. 1989. Endangered and threatened wildlife and plants, emergency determination of endangered status for the Mojave population of the desert tortoise. Federal Register 54:32326.

U.S. Fish and Wildlife Service. 1990. Endangered and threatened wildlife and plants, determination of threatened status for the Mojave population of the desert tortoise. Federal Register 55:12178–12191.

U.S. Fish and Wildlife Service. 1992. Scoping report: proposed water acquisition program for Lahontan Valley wetlands under Public Law 101–618. September: i, 24, A1–A3, B1–B4.

U.S. Fish and Wildlife Service. 1994a. Endangered and threatened wildlife and plants; animal candidate review for listing as endangered or threatened species. Federal Register 59:58982–59028.

U.S. Fish and Wildlife Service. 1994b. Desert Tortoise (Mojave population) Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oreg. 73 pp. + appendixes.

U.S. Fish and Wildlife Service. 1994c. Endangered and threatened wildlife and plants: determination of critical habitat for the Mojave population of the desert tortoise: final rule. Federal Register 59:5820–5846.

U.S. Fish and Wildlife Service. 1994d. Endangered and threatened wildlife and plants: 50 CFR 17.11 and 17.12. 380–789/20165. Washington, D.C. 42 pp.

U.S. General Accounting Office. 1993. Livestock grazing on western riparian areas. Gaithersburg, Md. 44 pp.

Van Devender, T. R., and W. G. Spaulding. 1979. Development of vegetation and climate in the southwestern United States. Science 204:701–710.

Vasek, F. C. 1966. The distribution and taxonomy of three western junipers. Brittonia 18:350–372.

Vasek, F. C., and M. G. Barbour. 1990. Mojave Desert scrub vegetation. Pages 835–867 *in* M. G. Barbour and J. Major, editors. Terrestrial vegetation of California. California Native Plant Society, Special Publication 9.

Vasek, F. C., H. B. Johnson, and D. H. Elsinger. 1975. Effects of pipeline construction on creosotebush scrub vegetation of the Mojave Desert. Madroño 23:1–13.

Vitousek, P. M. 1986. Biological invasions and ecosystem properties: can species make a difference? Pages 163–176 *in* H. A. Mooney and J. A. Drake, editors. Ecology of biological invasions of North America and Hawaii. Springer-Verlag, New York.

Ward, J. V. 1984. Ecological perspectives in the management of aquatic insect habitat. Pages 558–577 *in* V. H. Resh and D. M. Rosenberg, editors. The ecology of aquatic insects. Prager Publishers, Westport, Conn.

Warner, R. E., and K. M. Hendrix. 1984. California riparian systems: ecology, conservation, and productive management. University of California Press, Berkeley. xxix + 1,035 pp.

Weiss, S. B., D. D. Murphy, and R. R. White. 1988. Sun, slope, and butterflies: topographic determinants of habitat quality for *Euphydryas editha*. Ecology 69:1486–1496.

Wells, P. V. 1983. Paleobiogeography of montane islands in the Great Basin since the last glaciopluvial. Ecological Monographs 53:341–382.

West, N. E. 1988. Intermountain deserts, shrub steppes, and woodlands. Pages 209–230 *in* M. G. Barbour and W. D. Billings, editors. North American terrestrial vegetation. Cambridge University Press, New York.

Wharton, R. A., P. E. Wigand, M. R. Rose, R. L. Reinhardt, D. A. Mouat, H. E. Klieforth, N. L. Ingraham, J. O. Davis, C. A. Fox, and J. T. Ball. 1990. The North American Great Basin: a sensitive indicator of climatic change. Pages 323–359 *in* C. B. Osmond, L. F. Pitelka, and G. M. Hidy, editors. Plant biology of the Basin and Range. Springer-Verlag, New York.

Wheeler, G. C., and J. N. Wheeler. 1986. The ants of Nevada. Natural History Museum of Los Angeles County, Los Angeles, Calif. vii + 138 pp.

Whisenant, S. J. 1990. Changing fire frequencies on Idaho's Snake River plains: ecological and management implications. Pages 4–10 *in* E. D. McArthur, E. M. Romney, S. D. Smith, and P. T. Tueller, editors. Proceedings: symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management, 5–7 April 1989, Las Vegas, Nevada. U.S. Forest Service Intermountain Research Station General Technical Report INT-276.

Wiederholm, T. 1984. Responses of aquatic insects to environmental pollution. Pages 508–557 *in* V. H. Resh and D. M. Rosenberg, editors. The ecology of aquatic insects. Prager Publishers, Westport, Conn.

Wiens, J. A. 1989. The ecology of bird communities. Volume 2. Processes and variations. Cambridge University Press, New York. xii + 316 pp.

Wiens, J. A., and J. T. Rotenberry. 1981. Habitat associations and community structure of shrub–steppe environments. Ecological Monographs 51:21–41.

Wigand, P. E., M. L. Hemphill, and S. M. Patra. 1994. Late Holocene climate derived from vegetation history and plant cellulose stable isotope records from the Great Basin of western North America. Pages 2574–2583 *in* Proceedings of the High-Level Radioactive Waste Management Conference and Exposition, 22–26 May 1994, Las Vegas, Nev.

Wigand, P. E., and C. L. Nowak. 1992. Dynamics of northwest Nevada plant communities during the last 30,000 years. Pages 40–61 *in* C. A. Hall, Jr., V. Doyle-Jones, and B. Widawski, editors. The history of water: eastern Sierra Nevada, Owens Valley, White-Inyo Mountains. White Mountain Research Station Symposium Volume 4.

Wilcox, B. A., D. D. Murphy, P. R. Ehrlich, and G. T. Austin. 1986. Insular biogeography of the montane butterfly faunas in the Great Basin: comparison with birds and mammals. Oecologia 69:188–194.

Williams, D. D., and B. W. Feltmate. 1992. Aquatic insects. Redwood Press Ltd., Melksham, England. xiii + 358 pp.

Williams, T. R. 1982. Late Pleistocene lake level maxima and shoreline deformation in the Basin and Range Province, western United States. M.S. thesis, Colorado State University, Fort Collins. 52 pp.

Wilson, B. S. 1991. Latitudinal variation in activity season mortality rates of the lizard *Uta stansburiana*. Ecological Monographs 61:393–414.

Wright, H. E., Jr. 1983. Introduction. Pages xi–xvii *in* H. E. Wright, Jr., editor. Late-Quaternary environments of the United States. Volume 2. The Holocene. University of Minnesota Press, Minneapolis.

Yensen, D. I. 1981. The 1900 invasion of alien plants into southern Idaho. Great Basin Naturalist 41:176–183.

Young, J. A., and R. A. Evans. 1978. Population dynamics after wildfires in sagebrush grasslands. Journal of Range Management 31:283–289.

Young, J. A., R. A. Evans, and J. Major. 1972. Alien plants in the Great Basin. Journal of Range Management 25:194–201.

Young, J. A., R. A. Evans, B. A. Roundy, and J. A. Brown. 1986. Dynamic landforms and plant communities in a pluvial lake basin. Great Basin Naturalist 46:1–21.

Zeiner, D. C., W. F. Laudenslayer, Jr., and K. E. Mayer, editors. 1988. California's wildlife. Volume I. Amphibians and reptiles. State of California Department of Fish and Game, Sacramento, Calif. ix + 272 pp.

Zeveloff, S. I. 1988. Mammals of the Intermountain West. University of Utah Press, Salt Lake City. xxiv + 365 pp.

Human-Induced Changes in the Mojave and Colorado Desert Ecosystems: Recovery and Restoration Potential

Bainbridge, D. A., M. Fidelibus, and R. MacAller. 1995. Techniques for plant establishment in arid ecosystems. Restoration and Management Notes 13:190–197.

Bainbridge, D. A., and R. A. Virginia. 1990. Restoration in the Sonoran Desert of California. Restoration and Management Notes 8:3–13.

Beatley, J. C. 1969. Biomass of desert winter annual plant populations in southern Nevada. Oikos 20:261–273.

Bowers, M. A. 1987. Precipitation and the relative abundances of desert winter annuals: a 6-year study in the northern Mojave Desert. Journal of Arid Environments 12:141–149.

Brown, D. E., and R. A. Minnich. 1986. Fire and changes in creosote bush scrub of the western Sonoran Desert, California. American Midland Naturalist 116:411–422.

Brum, G. D., R. S. Boyd, and S. M. Carter. 1983. Recovery rates and rehabilitation of powerline corridors. Pages 303–314 *in* R. H. Webb and H. G. Wilshire, editors. Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Burk, J. H. 1977. Sonoran Desert. Pages 869–889 *in* M. G. Barbour and J. Major, editors. Terrestrial vegetation of California. John Wiley & Sons, New York.

Bury, R. B., and R. A. Luckenbach. 1983. Vehicular recreation in arid land dunes: biotic responses and management alternatives. Pages 207–221 *in* R. H. Webb and H. G. Wilshire, editors. Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Busack, S. D., and R. B. Bury. 1974. Some effects of off-road vehicles and sheep grazing on lizard populations in the Mojave Desert. Biological Conservation 6:179–183.

Chou, Y. H., R. A. Minnich, L. A. Salazar, J. D. Power, and R. J. Dezzani. 1990. Spatial autocorrelation of wildfire distribution in the Idyllwild quadrangle, San Jacinto Mountains, California. Photogrammetric Engineering and Remote Sensing 56:1507–1513.

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23:63–87.

Dregne, H. E. 1983. Soil and soil formation in arid regions. Pages 15–30 *in* R. H. Webb and H. G. Wilshire, editors. Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Fisher, J. C., Jr. 1978. Studies relating to the accelerated mortality of *Atriplex hymenelytra* in Death Valley National Monument. M.S. thesis, University of California, Riverside. 81 pp.

General Accounting Office. 1992. Rangeland management: BLM's hot desert grazing program merits reconsideration. U.S. General Accounting Office. GAO/RCED-92-12. Washington, D.C.

Grayson, D. K. 1993. The desert's past: a natural prehistory of the Great Basin. Smithsonian Institution Press, Washington, D.C. 356 pp.

Hunter, R. 1991. *Bromus* invasions on the Nevada Test Site: present status of *B. rubens* and *B. tectorum* with notes on their relationships to disturbance and altitude. Great Basin Naturalist 51:176–182.

Lathrop, E. W. 1983a. Recovery of perennial vegetation in military maneuver areas. Pages 265–277 *in* R. H. Webb and H. G. Wilshire, editors. Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Lathrop, E. W. 1983b. The effect of vehicle use on desert vegetation. Pages 154–166 *in* R. H. Webb and H. G. Wilshire, editors. Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.

Lathrop, E. W., and E. F. Archbold. 1980a. Plant responses to utility right of way construction in the Mojave Desert. Environmental Management 4:215–226.

Lathrop, E. W., and E. F. Archbold. 1980b. Plant response to Los Angeles aqueduct construction in the Mojave Desert. Environmental Management 4:137–148.

Malone, C. R. 1991. The potential for ecological restoration at Yucca Mountain, Nevada. The Environmental Professional 13:216–224.

Oldemeyer, J. L. 1994. Livestock grazing and the desert tortoise in the Mojave Desert. Pages 95–103 *in* R. B. Bury and D. J. Germano, editors. Biology of North American tortoises. National Biological Service, Washington, D.C.

O'Leary, J. F., and R. A. Minnich. 1981. Postfire recovery of creosote bush scrub vegetation in the western Colorado Desert. Madroño 23:61–66.

Prose, D. V. 1985. Persisting effects of armored military maneuvers on some soils of the Mojave Desert. Environmental Geology and Water Science 7:163–170.

Prose, D. V., and S. K. Metzger. 1985. Recovery of soils and vegetation in World War II military base camps, Mojave Desert. U.S. Geological Survey Open-File Report 85-234. 114 pp.

Prose, D. V., S. K. Metzger, and H. G. Wilshire. 1987. Effects of substrate disturbance on secondary plant succession; Mojave Desert, California. Journal of Applied Ecology 24:305–313.

Reible, D. D., J. R. Ouimette, and F. H. Shair. 1982. Atmospheric transport of visibility degrading pollutants into California Mojave Desert. Atmospheric Environment 16(3): 599–613.

Vasek, F. C. 1979. Early successional stages in Mojave Desert scrub vegetation. Israel Journal of Botany 28:133–148.

Vasek, F. C., and M. G. Barbour. 1977. Mojave Desert scrub vegetation. Pages 835–867 *in* M. G. Barbour and J. Major, editors. Terrestrial vegetation of California. John Wiley & Sons, New York.

Vasek, F. C., H. B. Johnson, and G. D. Brum. 1975a. Effects of power transmission lines on vegetation of the Mojave Desert. Madroño 23:114–131.

Vasek, F. C., H. B. Johnson, and D. H. Eslinger. 1975b. Effects of pipeline construction on creosote bush scrub vegetation of the Mojave Desert. Madroño 23:1–13.

Webb, R. H., and E. B. Newman. 1982. Recovery of soil and vegetation in ghost-towns in the Mojave Desert, southwestern United States. Environmental Conservation 9:245–248.

Webb, R. H., J. W. Steiger, and R. M. Turner. 1987. Dynamics of Mojave Desert shrub assemblages in the Panamint Mountains, California. Ecology 68:478–490.

Webb, R. H., and S. S. Stielstra. 1979. Sheep grazing effects on Mojave Desert vegetation and soils. Environmental Management 3:517–529.

Webb, R. H., and H. G. Wilshire. 1983. Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York. 534 pp.

Webb, R. H., H. G. Wilshire, and M. A. Henry. 1983. Natural recovery of soils and vegetation following human disturbance. Pages 279–302 *in* R. H. Webb and H. G. Wilshire, editors. Environmental effects of off-road vehicles: impacts and management in arid regions. Springer-Verlag, New York.