Shah-Kan-Daw: Anthropogenic Simplification of Semi-arid Vegetation Structure

David A. Charlet

Abstract—Semi-arid shrublands and woodlands of Nevada are changing in the face of many daunting challenges. I compare Nevada to Iran to understand these challenges better, because Iran and Nevada have similar climate, geology, physiography, and latitude. Floristically, Iran and Nevada share many dominant genera, and many of Nevada's troubling invasive species are native to Iran. Yet, Iran is different in its long history of civilization and concomitant human exploitation of the landscape. Thus, we can look to Iran to gain insight into possible outcomes of our management actions in our remaining wild shrublands. The structure of Iranian vegetation is simple compared to that of Nevada. It usually possesses only a single canopy layer and has low shrub species diversity, producing one-dimensional vegetation of low value for wildlife. The Iranian flora shows the mark of long-term grazing and fire disturbance. In spite of enormous mountains, woodlands and montane forests are virtually non-existent. Nevada's vegetation, in spite of the challenges it faces, is in far better condition than the vegetation of Iran. However, if we allow the processes that simplify vegetation to gain momentum, then we can look to Iran to see our monotonic future.

Threats to Our Nation, Threats to Our Shrublands

Today in the news we hear about many political challenges to our nation. At this time, three nations appear boldly in our newspapers. China's rapid economic development poses a great challenge to our economy. Conversely, a lack of economic opportunity in Mexico and other Latin American countries has led to a steady and substantial inflow of undocumented immigrants across our southern border. Prominent in the news is Iran. We read that our government is suspicious of Iran's nuclear ambitions, despite the stated intention of its leaders to harness the atom strictly for the peaceful production of energy. Moreover, our government has accused Iran's government of aiding the insurgency in Iraq and Hezbollah in Lebanon. Coincidentally, each of these nations poses not only political challenges to the United States but also introduced elements of their floras threaten the ecosystems of our semi-arid West.

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Our arid and semi-arid shrublands are also in the news. Alien species have invaded our shrublands and woodlands. These species are affecting fundamental changes in basic ecosystem processes. Wildfires burn everywhere with dramatically increasing frequency (Whisenant 1990). The changes in the vegetation are reflected in the status of formerly abundant vertebrates, and so the public learns from the news the threats to sage grouse in *Artemisia* shrublands and the desert tortoise in *Larrea* shrublands. Misinformation abounds; we read in scientific literature that native juniper trees are invasive (Ansley and Rasmussen 2006), pinyons are often regarded as such, and both are treated as if they were undocumented immigrants.

A bright young Ph.D. student at Beijing Forestry University challenged me after my talk on semi-arid forestry conservation when he asked: "Why do you want to save the deserts?" He clarified himself, "We want to improve the deserts." I was not yet fully aware of what their concerns were, but I quickly learned. His concern was desertification in China. He was interested in shrubs and trees from Nevada that could hold back expanding sand dunes and so conserve the soil and the productivity of the land. I suggested he try species native to China, such as *Tamarix*.

Why Conserve Deserts?

My idea of deserts was different from that fine Chinese student's idea of deserts. I have spent all my life in the American West, most of it in Nevada. I am used to shrublands in my deserts and woodlands and forests in my mountains, with sand dunes and spring-fed wetlands as occasional fascinating features of a landscape already rich in species. It is no wonder that we had difficulty understanding one another, as definitions of deserts vary greatly. For instance, McGinnies and others (1968) report that definitions of deserts based on precipitation alone vary from a maximum mean annual precipitation of 5 cm to as much as 38 cm! Whatever we call them, in much of China—and as I was soon to find out in Iran as well—basic ecosystem processes in semi-arid regions are failing. By comparison, in Nevada, these processes are merely threatened. But if human activities further destabilize Nevada's ecosystems, the ecosystems may collapse. Such a collapse inevitably leaves a burdensome economic wake, and potentially leads to tragic human consequences (Diamond 2005). Humans deliver a one-two punch to wild ecosystems: they disturb the ground and bring seeds that flourish in the disturbance.

Human activities in Nevada during the last 150 years have caused countless disturbances. They have accelerated the spread of alien weeds, such as cheatgrass (*Bromus tectorum*), that may lead to their dominance throughout much of the region (Billings 1990; Bradley and Mustard 2006; Knapp 1996). Groundwater pumping constitutes a major threat to valley bottom phreatophytic vegetation and unique spring ecosystems (Charlet 2006). Utility corridors cut large swaths throughout the state, fragmenting formerly continuous ecosystems, creating convenient migration corridors, and providing suitable ground for the establishment of these invasive species (Bradley and Mustard 2006; Lathrop and Archbold 1980). In Nevada, alien species are notoriously flammable and invasive. Cheatgrass provides unbroken patches between shrubs, dries early in the growing season of most native plants, and so provides fine fuels early in the season that carry fires throughout large areas (Young and Evans 1978). Once burned, the likelihood of another catastrophic fire returning is high, as fire return intervals are now shorter by as much as an order of magnitude from what they were before settlement (Whisenant 1990). Life history characteristics conspire to accelerate the ascendancy of these species, which can prevent the establishment of shrubs even in the absence of returning fires (Billings 1990). The prospect of increasing atmospheric CO_2 levels almost ensures that this and other opportunistic aliens such as *Bromus madritensis* (Smith and others 2000) will come to dominate the region. The net effect of alien brome grasses in Nevada is to impoverish biodiversity (Billings 1990) by converting shrublands and semi-arid woodlands to annual grasslands (Bradley and others 2006). Moreover, the consequences of grassland replacement of shrublands and woodlands in the global carbon budget are that Nevada semi-arid vegetation rapidly transforms from a carbon sink to a carbon source (Bradley and others 2006).

Twenty years ago, Young and Sparks (1985) made an ominous, and hopefully not prophetic, prediction about the sagebrush shrublands of the Great Basin:

> If the burned sagebrush ranges are not restored, the alien weeds will inherit the sagebrush/grasslands. The way is thus paved for repeated burnings and a continuing downward spiral of degradation.

Over the 35 years I have lived in Nevada, spending much of that time in its wild mountains and basins, I have witnessed a continuing and expanding degradation of its vegetation formations. I was troubled by these changes, and wanted to get closer to the source of these problems. So, when an opportunity presented itself for me to go to Iran, I pursued it with enthusiasm and diligence.

Why Iran?

While they may have arrived here via Europe, most of the invasive species that are destabilizing Nevada ecosystems are native to Iran or elsewhere in the Middle East. Cheatgrass (*Bromus tectorum*) is aggressively invading upland shrublands and semi-arid woodland formations. Although not spreading as rapidly, saltlove (*Halogeton glomeratus*) continues to expand in the halophytic zone; occasionally forming pure stands over large areas. Russian-olive (*Elaeagnus angustifolium*) is mainly a problem in riparian areas in central Nevada, but salt-cedar (*Tamarix ramosissima*) is rapidly gaining the upper hand along streams and at springs throughout Nevada. It makes sense to see the landscapes from where these alien elements are native, in order that we may better understand the threats to our region.

Latitude, physiography, and climate are shared by Iran and Nevada. Major genera, both in number of taxa and their importance on landscapes, are shared by Iran and Nevada (such as *Acer, Acacia, Amelanchier, Artemisia, Astragalus, Atriplex, Ephedra, Fraxinus, Juniperus, Prosopis, Prunus, Quercus, Salvia,* and *Suaeda*).

Interior Iran and Nevada Physiographic Settings

Iran is considerably larger than Nevada, occupying 1,648,000 km^2. This is roughly equivalent to the area of California, Nevada, Utah, Arizona, Colorado, and New Mexico combined (1,483,637 km^2). Because of its size, Iran occupies a wider latitudinal range than Nevada, but virtually all of Nevada lies within the latitudinal range of Iran. Iran lies from 39° 46' N to 25° N (fig.1), while Nevada occurs from 42° N to 35° N. A considerable amount of Iranian territory occupies coastal regions along the Persian Gulf, Indian Ocean, and Caspian Sea, environments that have no equivalent in Nevada. Nevertheless, the great interior of Iran is much larger than the Great Basin and Mojave combined, about half of which is in Nevada. My expedition to Iran traversed very nearly the latitudinal range of Nevada, from 32° 30' N near Esfahan in the south, to 39° 30' N at the Iranian-Turkish frontier northwest of Urumieh.

The physiography of Iran is similar to Nevada and the whole of the Basin and Range physiographic province (Hunt 1967), which includes the Great Basin, and the Mojave, Sonoran, and Chihuahuan Deserts . Iran is a land of large, parallel mountain ranges with large intermountain, internally drained basins (Zohary 1973). While the western boundary of the Basin and Range province drains to the Pacific Ocean, the western slopes of the Zagros Mountains of western Iran drain into the Persian Gulf. The northern boundary of the Great Basin drains into the Columbia River and thence to the Pacific, much as the northern slopes of the Alborz Mountains of Iran drain into the Caspian Sea.

The Alborz Mountains are large, equivalent in length and breadth to the Sierra Nevada (both are 650 km long), but considerably higher than the Sierra Nevada and the Zagros Mountains. Although not taller than the Alborz Mountains, the Zagros Mountains are more massive, spanning 1,630 km in length and 400 km in width. Mount Dena is the highest point in the Zagros Mountains at 5,098 m (16,998 ft), compared to the highest point in the Sierra Nevada, Mount Whitney (4,417 m; 14,494 ft). Nevada has two small, active "rock" glaciers in cirque basins below Wheeler Peak in the Snake Range (Orndorff and Van Hoesen 2001) and Cougar Peak in the Jarbidge Mountains (Coats 1964). Iran has four clusters of small glaciers: at Mount Damāvand and Takht-e-Suleiman in the Alborz, and at Kūhhā-ye Sabālan and Zard Kūh in the Zagros Mountains (Ferrigno 1990).

The non-coastal climates of Iran and Nevada are remarkably similar. Both have interior climates in the rain-shadow of enormous mountain ranges that intercept storms coming ashore and strip them of their moisture. Not only are the regions semiarid to arid, but they are also characterized by mainly winter precipitation and have cold winters in the north and hot summers in the south. For instance, the northern Nevada city of Reno occurs at the base of the Sierra Nevada, much like Tehran sits at the base of the Alborz Mountains. Las Vegas and Esfahan are southern cities in hot deserts amidst treeless, arid mountains. Paradise Valley and Urumieh are both high agricultural valleys situated between moderately sized mountains that develop large snow packs. Virginia City and Tabriz are located at about 39°N and 38°N, respectively. Both cities occur near high mountains and at moderately high elevations, with Virginia City at about 1890 m A.S.L while Tabriz is situated at 1430 m A.S.L. In each case, not only are average annual temperature and precipitation close (table 1), but the monthly distribution of precipitation and temperature is also comparable (fig. 2).

Figure 1—Iran, its neighboring nations, and geographic features named in the text. The Alborz Mountains extend across northern Iran from Turkey to Afghanistan, connecting the mountains of eastern Europe with the mountains of Central Asia. The Zagros Mountains run nearly the entire north-south dimension of Iran along its western border.

Table 1—Annual average temperature (T) and precipitation (P) for selected cities in Iran and Nevada. Iran data from the Iran Meteorological Organization (2006). Nevada data from the Western Regional Climate Center (2006).

Nevada City/Town	T (°C)	P (mm)	Iran City/Town	T (°C)	P (mm)
Paradise Valley	8.6	238.1	Urumieh	11.2	346.3
Reno	9.9	189.7	Tehran	9.5	240.7
Virginia City	8.8	337.0	Tabriz	13.7	348.0
Las Vegas	19.5	107.4	Esfahan	15.9	113.3

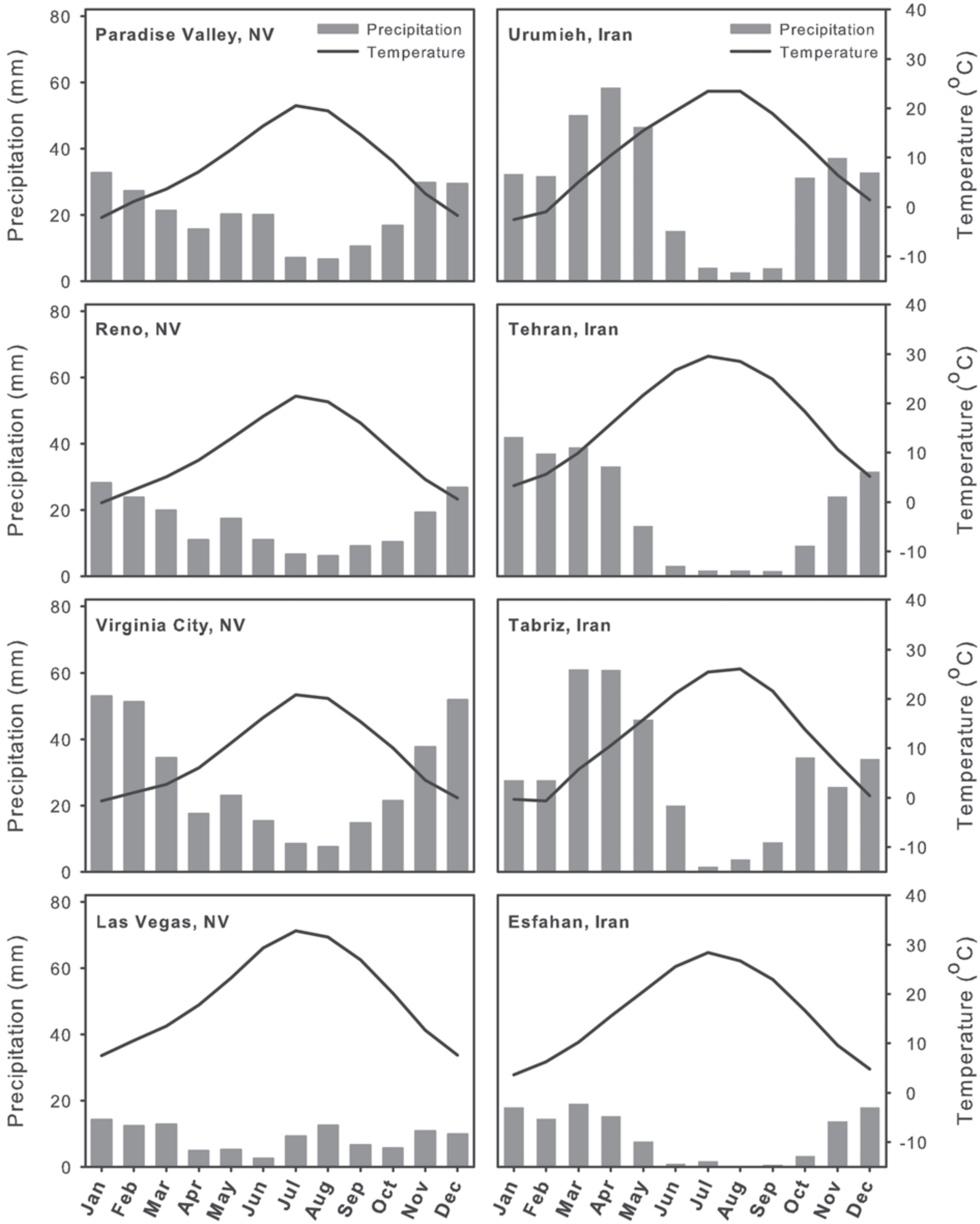

Figure 2—Climagraphs for selected city pairs from Nevada (left) and Iran (right), indicating monthly precipitation (mm) as bars and monthly average temperature (°C) as a line. From top to bottom the city pairs are Paradise Valley and Urumieh, Reno and Tehran, Virginia City and Tabriz, and Las Vegas and Esfahan.

The elevation range of Nevada is large, from 146 to 4005 m A.S.L (479 to 13,140 ft), but Iran has greater relief, rising from the Caspian Sea (–28 m A.S.L; [–92 ft]) to Mount Damāvand (5671 m A.S.L [18,600 ft]) in the Alborz Mountains. Two vast interior basins in Iran, the Dasht-e-Kavir and the Dasht-e-Lut are reminiscent of the Bonneville Basin of Utah, although far larger than Bonneville and not as dissected by mountain ranges as is the Lahontan Basin of Nevada, nor do they possess permanent lakes. However, Lake Urumieh in northwestern Iran, situated between the Alborz and Zagros Mountains, is very similar to the Great Salt Lake and the lakes even possess at the base of their food webs closely related brine shrimp (*Artemia urmiana* in Urumieh and *Artemia franciscana* in the Great Salt Lake) (D. Christopher Rogers, written communication 2006).

Today both Iran and Nevada are experiencing dramatic human population growth (fig. 3). And so at this time in both places, demands on water, minerals, and other natural resources, including the land itself, are escalating at an ever-increasing pace. Thus, comparing Nevada and Iran is like a "Natural Experiment" of Diamond (2005). The main difference between the two regions is that in Iran during the Holocene, the vegetation evolved in a context of agriculture, pastoralism, metallurgy, and denser human populations. Therefore, an investigation of the flora and vegetation of Iran should provide insights on management and conservation of the Great Basin and Mojave Desert of Nevada.

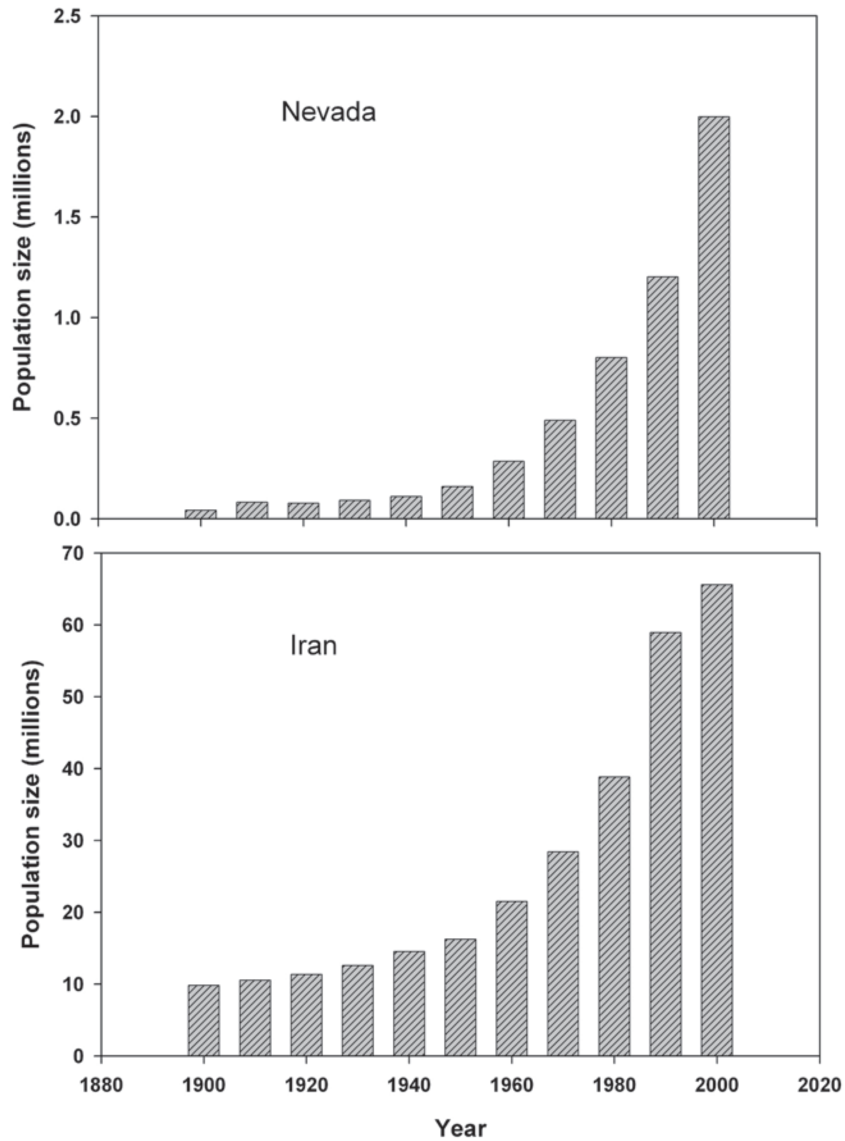

Figure 3—Human population growth in Nevada (top) and Iran (bottom), 1900 to 2000. Both experienced geometric population increases during the 20th century. The rate of growth slowed in Iran during 1990–2000 due to the Iran-Iraq war. Data for Nevada from US Census Bureau (2006), data for Iran from Lahmeyer (2006).

Vegetation in Iran

Hot, non-saline deserts are occupied by a *Zygophyllum* desert shrubland. These shrublands are reminiscent of the Mojave Desert's *Larrea* shrublands, our only native member of the Zygophyllaceae. However, unlike Nevada's *Larrea* shrublands, Iran's *Zygophyllum* is rarely accompanied by other shrub species. Instead, these monotonic shrublands extend across vast areas of the Turan Biosphere Preserve and vegetated portions of the Dasht-e-Kavir (Moore and Bhadresa 1978). Widely spaced chenopodiaceous shrubs, in genera such as *Atriplex*, *Suaeda*, and *Haloxylon*, dominate salt deserts in terminal basins. Upland xeric vegetation is largely dominated by short *Artemisia* shrublands, again with few other shrub species. Shrublands are omnipresent in the montane zone; these dominated largely by thorny members of the fabaceous genera *Astragalus* and *Onobrychis*. Similarly, subalpine habitats do not have multi-story, highly diverse shrublands. Instead, these are invariably dominated by a single low, shrubby *Astragalus* species. Inter-shrub spaces are dominated by a wide array of geophytes largely in the genera *Lilium*, *Allium*, and *Tulipa* whether in the subalpine, the montane, or the low deserts. Desert shrublands sometimes have grasses such as *Stipa barbata*, while montane shrublands are sometimes accompanied by bunchgrasses such as *Agropyron* spp.

As the expedition's conifer expert, I expected to find some of the 10 species that were on my list of native woody species of Iran. Curiously, most of the conifer specimens in the five herbaria we visited were not part of the native flora at all, but instead were collections made from the respective University's arboretum of non-native species such as *Sequoiadendron giganticum*.

As the expedition's vegetation expert, I was stunned: here were familiar landforms, familiar conditions, but major vegetation elements were missing. While the landscapes before me were familiar, they also were eerie in what was absent.

Questions arose like warriors from the dragon's teeth Jason planted in the Field of Ares. Where are the forests? Why is neither *Pinus* nor *Picea* even on my list? Where are the woodlands? I saw on my list that there were *Quercus*, *Juniperus*, *Cupressus*, *Acer*, and *Pistacia*. Of these, I ultimately found all but *Cupressus*, but the find was difficult in every case, and I never saw more than 10 individuals of any of them. Our planned trip to a relic *Quercus* forest in Kurdistan was turned away by military personnel, incredulous, as they were to find our permits and papers in order. Still, we went 100s of km through what appeared to be fine habitat for woodlands and montane forests, yet woodlands and forests were not there. Mountains like these abound in Nevada, yet Nevada's mountain bases are cloaked with pinyon-juniper woodlands and their highlands are sprinkled with subalpine forests.

Of the American invasives that I was seeking to find, I saw *Halogeton glomeratus, Bromus tectorum Elaeagnus angustifolium,* and *Tamarix ramosissima* in Iran, but were dominant nowhere. I found *Halogeton glomeratus* once, as a rare, diminutive plant in a fertile river valley in Kurdistan. In only one place did I see wild *Elaeagnus angustifolium*, as a stand of about six trees along a mountain stream. I observed a full, healthy stand of *Tamarix* only once, northwest of Esfahan. Otherwise, throughout Iran I encountered only a few small *Tamarix* trees that rarely occurred along streams.

Similarly, I found *Bromus tectorum* at many locations, but nowhere was it dominant. North of Lake Urumieh was a nearly shrubless piedmont slope leading up to tall cliffs. It was a familiar landscape. If in Nevada, I would have known that I was looking at a recent burn in sagebrush that had been replaced by cheatgrass. Here was the largest patch dominated by cheatgrass that I saw in Iran, but it was barely 1 m^2, and the reproductive individuals were no more than 10 cm tall. The annual grass that dominated the landscape was a long-awned, unpalatable *Aegilops* species. Cheatgrass does not dominate these landscapes. Other, more frightening weeds out compete the Iranian natives that wreak havoc in Nevada.

At the base of most mountains one can see a fascinating engineering feat (the *Qanât*) that allowed for the expansion of agriculture and urban areas into places otherwise able to sustain humans only in a nomadic lifestyle. Persian engineers invented the *Qanât* during the Achaemenid Empire by at least 2000 BP to extend agriculture into desert valleys to support the growing cities. A *Qanât* is a series of wells extending in a line from the base of the mountain out into the valley. The wells are all connected with a subterranean tunnel that collects the water and is tipped slightly out into the valley so that the water descends out near the piedmont base (Yazd Regional Water Authority 2003). From that point forward to the present, the phreatophytic halophytes such as *Tamarix* and the chenopodiaceous *Suaeda aegyptiaca*, *Haloxylon persicum*, and *H. recurvum* that occupy suitable areas of high water table must have been severely impacted over more than two millennia of this practice.

I left Iran richer, having gained many new colleagues, students, friends, and magnificent vistas permanently etched in my neurons. But I also left Iran with five disconcerting impressions concerning its vegetation: (1) the lack of trees on landscapes otherwise apparently well suited for them; (2) the "flat" nature of the native shrublands was puzzling; that is, the vertical structure of the shrublands was simplistic, typically dominated by a single shrub species at a single height, with very few other shrub species in the formations; (3) the replacement of shrublands by annual grasslands dominated by species that out compete cheatgrass; (4) the multitude of large, fresh, and active erosion features wherever we went; and (5) I observed the appearance of a heavy imprint of human use.

Archaeobotany of Iran

Upon my return to Nevada, I was compelled to find out how the vegetation came to be as it is. I examined the literature concerning the vegetation history of Iran. Here I found a wealth of information from archaeobotanical research supported by William Sumner and currently led by Naomi Miller (such as Miller 1996, 2001, 2002a,b, 2003a,b) at the University of Pennsylvania Museum.

Although the record is not geographically or temporally complete, the evidence allows a general picture of the development of civilization in a semi-arid, mountainous region.

Several critical developments occurred throughout the Middle East, including Iran, that led to one of the earliest developments of urbanized culture. The first permanent settlements appear in Iran at about 12000 BP (Miller 2004). By 10000 BP, the first crops were cultivated, and almost immediately the record shows the increase of weedy species. At about this same time, the ancient Persians began herding sheep, goats, and cattle. The introduction of pastoralism was coincident with the decline of palatable vegetation, and the ascendancy of armed and poisonous species. By 8000 BP, irrigation was applied to croplands in the Zagros Mountains (Miller 1992a). This allowed these early agricultural people some protection from annual variations in precipitation, providing communities with some insurance from drought-induced crop failure. This security allowed the successful communities to grow in size, requiring more land clearance for the structures, more land clearance for more agricultural fields, and more sheep and goats in the mountains to support them (Miller 1992b). By around 4500 BP, major erosional events appear in the record (Wilkinson 1990, cited in Miller 1992a).

One site where extensive work has been done is Malyan, located at about 1,700 m A.S.L. in the southern Zagros Mountains, about 50 km from Shiraz (Miller 1985). Although it is not the earliest of sites nor was it the first to employ these technologies, the archaeobotanical evidence is complete enough to suggest a sequence of vegetation change that was likely repeated at numerous locations in the Zagros Mountains. People lived in settlements on the plain near Malyan since about 9000 BP. Malyan was settled at about 5400 to 4800 BP and at its height (ca. 4200 to 3600 BP) the urban area of Malyan had from between 13,000 and 26,000 people, with a permanent population associated with the city of between 30,000 and 60,000 (Zohary 1973). Settlements like Malyan were usually associated with semi-arid woodlands ranging from *Pistacia* woodland-steppe at low elevations, through *Pistacia-Prunus* woodlands and forest, to *Quercus* forests, with *Juniperus* species occurring throughout (Miller 1985). Riparian areas were rich and possessed *Ficus*, *Fraxinus*, *Populus, Tamarix*, and *Elaeagnus* (Miller 1985).

Throughout this time, coastal forest resources were exploited for buildings, ships, and weapons of war (Kuniholm 1997; Wallinga 1993). About 5000 BP, the Persians used plaster and lined their homes and other buildings with it. Ancient production technology required burning two tons of limestone with two tons of wood to produce 1 ton of plaster (Miller 1992a). The development of metallurgy required fires much hotter than are produced by raw wood, straw, or dung. Charcoal was developed because it produces fires with sufficient heat and because direct contact of the ore with charcoal is required to produce pure copper (Rostoker and others 1988, cited in Miller 1992a). However, charcoal production is an extremely inefficient process, as most of the energy in the parent wood is lost in its burning to produce the charcoal (Horne 1982). Hence, the demands on the surrounding vegetation for the fuel necessary to support large urban areas were intensive and widespread (Miller 1992a). More rural landscapes were developed with agricultural, pastoral, mining, and other resource extraction activities to support the cities, casting a long shadow of human use on the landscape.

By 4500 BP, the woodlands were gone, *Juniperus* was virtually extinct, and the people were going high into the mountains to harvest oak at great cost in order to produce charcoal (Miller 1985). Residents of Malyan were burning dung as their domestic fuel (Miller 1985, 1996), as the high costs to ship wood from ever-farther distances reduced the use of wood for fuel (Miller 2002). Ultimately, Malyan was abandoned (Miller 1985). This pattern of settlement, development, and abandonment of small cities in the Zagros Mountains appears to be widespread throughout the region (Miller 2003c).

The Insurgency

We hear on the news that the government of Iran may be supporting insurgent activities in Iraq. I was interested to read the definition of this word:

> Insurgent: […present participle of *insurgere* to rise up, insurge] A person who rises in revolt against civil authority or constituted government: rebel; especially; a rebel who is not recognized as a belligerent. (Gove 1961:1173).

In a different context, then, we can consider "insurgents" to be people who wish to improve their living conditions in the natural world by creating a civilization; people who rise up against the authority of nature and the limitations it imposes. They do this by developing and producing the tools of civilization from the natural resources about them. In this sense, then, it is the "insurgents" who cut forests to build a civilization. Trees are cut and converted to charcoal to smelt metals and make plaster. The land cleared of forests is plowed and irrigated for agriculture. Forests and shrublands are burned to increase grazing productivity. Alien species are introduced and spread through the modified landscapes. Surface and ground water is moved for increased agriculture productivity that supports urbanization. An empire is made from wood.

The result of this "insurgent" activity is a destabilization of ecosystems. This destabilization ultimately disrupts ecosystem processes and leads to a rapid simplification of vegetation structure. This simplification is characterized by a type conversion that transforms multi-layered shrublands to annual grasslands and converts woodlands to monotypic, one-layered shrublands. The biodiversity is reduced, and conditions ultimately promote a reduction of the flora to geophytes and armed and poisonous plants that can withstand heavy grazing and fire. Ultimately, the shrublands are converted to even simpler annual grasslands. The simplification of the vegetation results in widespread and severe erosion that may forever prevent the return to the pre-civilization state. To understand what forces were behind the creation of the contemporary Iranian flora and its dominant associations, we have to look no further than ourselves as human beings creating civilization.

Nevada Prehistory and History

Humans have occupied Nevada for millennia. The earliest human records in Nevada are from Paleoindian populations termed "Paleoarchaic" (*sensu* Beck and Jones 1997) and are among the oldest in the continental United States. These earliest records date back to the Pleistocene/Holocene Epoch boundary about 11500 yr BP (Beck and Jones 1997), and Nevada has been inhabited ever since. The evidence indicates a rather abrupt change in tools around 7500 yr BP, suggesting a cultural response of the Paleoindians to climatically induced environmental change in the region (Grayson 1993). Perhaps as late as 1000 yr BP, the Numic-speaking Western Shoshone and Northern and Southern Paiute arrived, and successfully hunted and foraged in a nomadic lifestyle until the late 1800s (Elston 1986). Pinyon pine seeds were of particular importance for the survival of the Shoshone and Paiute (Fowler 1986).

While Native Americans elsewhere in the Southwest developed agriculture, pastoralism did not develop until after the arrival of the Europeans and their domestic herd animals. The oldest agriculture in Nevada is in the Moapa Valley in Clark County and Snake Valley in White Pine County, both near the eastern border, and both sites apparently developed by the Fremont culture around 1500 yr BP and occupied until about 900 yr BP (Fowler and Madsen 1986).

Shah-Kan-Daw in Nevada Pinyon-Juniper Woodlands: 1859-1899

Nevada changed forever in 1859 when gold was discovered near Virginia City (Angel 1881). The discovery helped bolster the western migration of people from the east to California and Nevada, while those already in California were also drawn to Nevada. Major anthropogenic changes to Nevada's environment were inevitable and imminent. Not long after its founding in 1860, Virginia City became the largest city west of the Mississippi, and the first with an elevator, electricity, and an opera house. Development in Virginia City and the other Nevada towns that were born suddenly (fig. 4) led to intense use of natural resources throughout the state.

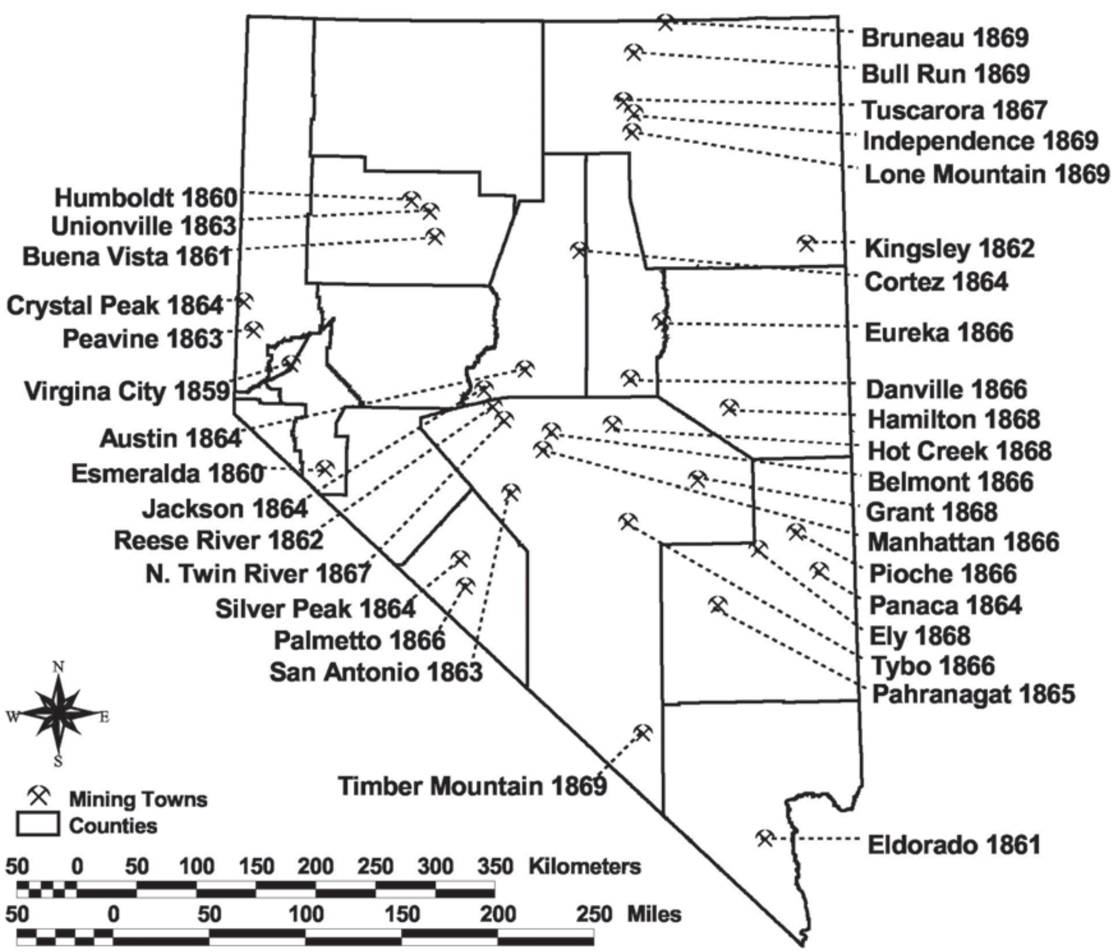

Figure 4—Thirty-five towns dispersed throughout Nevada were established at these locations from 1859–1869 (Angel 1881).

The early Nevada settlements and towns used singleleaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) woodlands extensively. The trees were used for structures and fuel, both as firewood and processed as charcoal. Firewood was employed as fuel for all Nevada railroads until 1885, except in the case of the Virginia and Truckee Railroad that burned firewood into the early 20th century (Wendell Huffman, Nevada State Museum, personal communication 2006). Firewood applications included heating all homes and businesses.

Virginia City required wood for structural lumber, both in the mines and for the city, especially in 1875 when the city needed rebuilding after the Great Fire destroyed most of it (Angel 1881). From 1874 to 1879, Virginia City consumed more than 300 million board feet of lumber from nearby Sierra Nevada old-growth forests that were fully stocked with yellow pines (*Pinus jeffreyi* and *P. ponderosa*) and western white pine (*Pinus monticola*) (Galloway 1947). This is a significant amount, considering that it is nearly equal to the total production of the Sierra Nevada (814,000 cubic m or 354 million bf) from 2000 through 2002 (USDA Forest Service 2004). The city and its industries could afford the high cost of transportation to bring lumber from the Lake Tahoe area, first by wagon and later by train (Galloway 1947). Towns that were located farther from the Sierra Nevada had no access to its timber, so they had to make due with what was available locally. For instance, 24 sawmills were operating in Nevada in 1868 (Lanner 1981). The locations of six sawmills are indicated on the 1908 USGS topographic map of the Las Vegas quadrangle alone.

Before trains bearing Sierra Nevada lumber could reach central Nevada, pinyon was milled producing "Reese River Lumber" (Angel 1881). Not until 1880 did the Nevada Central reach Austin, but even then, Reese River Lumber was used and sold for about half the price of Sierra Nevada lumber (Lanner 1981). The amount of pinyon that was produced was not trivial; in 1865, 5,660 cubic m (2.4 million bf) of Reese River Lumber was used in Austin alone (Lanner 1981). I am not certain how much Reese River Lumber was produced in the 1900s, nor do I know how to estimate how many board feet of pinyon can be produced in a single km^2, but these lumber operations clearly had a profound ecological impact on the native landscape.

Virginia City mining operations used pinyon and juniper fuel relatively sparingly because they had smelting options that other Nevada towns did not. Still, its 30,000 industrious residents had many needs that were met by the surrounding woodlands. The primary use of trees was for home heating, and this is likely to have taken a great toll on the surrounding vegetation in which they were immersed. From 1874 to 1879 Virginia City used 1,140,000 cords of wood for fuel (Galloway 1947). A high estimate of cordage per acre of old-growth pinyon-juniper woodlands in Nevada is 3,000 cords/km^2 (12 cords/acre) (Young and Budy 1979). Thus in these 6 years alone, Virginia City consumed 380 km^2 of pinyon-juniper woodland for fuel.

Railroads

Railroads were vital for the development of Nevada and the exploitation of its natural resources. The Central Pacific railroad was begun through Nevada in late 1867 after the line was built through the Sierra Nevada. The Atlantic-Pacific link was completed in May 1869, allowing other railroads to be constructed throughout the state before 1900. The most significant of these lines were the Eureka & Palisade, Nevada Central, Pioche-Bullionville, and the Virginia & Truckee. Nevada had no source of coal, and so Nevada railroads used wood-burning engines exclusively from 1868–1885, and the Virginia and Truckee did so into the 20th Century (Wendell Huffman, Nevada State Railroad Museum, written communication, 2006). Wood burning engines are easy to recognize due to their wide smokestacks fitted with spark arrestors. These railroads used a great deal of wood for fuel, and the ready source of fuel in Nevada was found in pinyon-juniper woodlands. A cord of wood was enough for powering a train an average of 6.4 km (4 mi) (Wendell Huffman, Nevada State Railroad Museum, written communication, 2006). By 1870, wood was so expensive that the Central Pacific began to buy coal from its archrival Union Pacific to supplement its wood use. Central Pacific paid $4.75/cord in Nevada (under $3/cord elsewhere in the West), but the Eureka & Palisade was paying $5.50/cord and Nevada Central was paying $7.00/cord (Angel 1881).

Summing the total length of track for each of the railroads, we find that in the 1800s there were 1,100 km (683 mi) of railroad in Nevada. If we assume that each railroad ran one train per day the length of its tracks in Nevada, then through the lifetime of wood burning for these railroads, 5,795,980 km (3,601,455 mi) were traveled over the 33 years (table 2). At 6.4 km/cord and 3000 cords/ km^2, we find that the total amount of pinyon-juniper woodlands consumed for railroad fuel was about 300 km^2.

Charcoal

Nevada residents needed tools and services dependent on charcoal-fired forges. As a result, an impressive amount of pinyon-juniper wood was used to produce the charcoal. In 1865, one Virginia City mill used 946 kg (21,500 bushels) of charcoal for fuel (Browne 1869). It took 100 cords of pinyon-juniper wood to make between 123,300–145,200 kg (2,800 to 3,300 bushels) of charcoal (Young and Budy 1979). Thus, it required about 715 cords of wood, or about 0.24 km^2 (60 acres) of pinyon-juniper forest to produce the charcoal for this one mill in Virginia City in one year. Virginia City's ore was more easily processed than other Nevada mines, because water was more available and the ore was better on the Comstock, allowing the Washoe Pan Process (Oberbillig 1967) to refine the ore. Thus, these Virginia City mills avoided the extreme charcoal needs of other early Nevada mining settlements, because the others lacked sufficient water and the nature of their "rebellious" ore (Oberbillig 1967) did not allow the pan process. Charcoal was the largest production expense (Lanner 1981).

Table 2—Nevada railroads, their length, and the years they operated while using wood for fuel. Distance traveled calculated by assuming one train travels the full length of the railroad every day during the life of the railroad. Fuel efficiency average was 2.48 cords per km (4 cords per mile) (Wendell Huffman, Nevada State Museum, personal communication).

Railroads	Length (km)	Wood as fuel (dates)	Number years	Distance traveled if one train/day (km)	Cords wood used
Central Pacific	723	1868-1880	13	3,428,715	532,626
Eureka & Palisade	135	1874-1889	16	789,479	122,640
Nevada Central	150	1880-1889	10	546,292	84,863
Pioche-Bullionville	8	1873-1881	8	23,496	3,650
Virginia and Truckee	84	1868-1900	33	1,007,997	156,585
Total					**900,364**

Outside of Virginia City, smelting required enormous amounts of charcoal, and this was produced locally from the pinyon-juniper forests. For instance, the central Nevada town of Eureka produced $60,000,000 of gold and silver and 200,000 metric tons of lead from 1869 to 1883 (Young and Budy 1979). Eureka was spectacular in its use of pinyon and juniper for charcoal and domestic and industrial fuel uses, ultimately sparking a "Charcoal Burners War," as the price and availability of fuel wood became a serious economic liability (Earl 1979). In 1880 alone, 55,000 metric tons (1.25 million bushels) of charcoal was consumed in Eureka. At 30 bushels of charcoal from one cord, 41,666 cords were used to produce the 1880 charcoal. At 3,000 cords per km^2 (Young and Budy 1979), the firewood used to make the charcoal resulted in 14 km^2 (3,472 acres) of pinyon-juniper woodland cut in this one year for Eureka alone. As early as 1874, a 32 km (20 mi) radius was cut, by 1878 the hauling distance was about 56 km (35 mi), and by 1880 this distance may have expanded to 80.5 km (50 mi) (Earl 1979). By 1900, 582 km^2 (600,000 acres) surrounding Eureka were denuded, of which about 24% was pinyon-juniper (Young and Budy 1979).

All other Nevada towns in the late 1800s had the same needs, but archaeologists have worked only in a few to establish the extent of deforestation. Using tree-ring cross-dating of living pinyon pines, stumps, and archaeological features, Hattori and Thompson (1987a,b) found evidence of three episodes of intense woodcutting in the Cortez Mining District in north-central Nevada from 1863 to 1904. Hattori and Thompson (1987a,b) do not provide an estimate of charcoal used or total area deforested, but they do have data on monthly wood consumption for the district. They concluded that the claim that a team of 200 woodcutters worked the area (Ashbaugh 1963) is an overstatement. Hattori and Thompson (1987a,b) found that a few trees were left standing, and so proposed that the area was not entirely deforested, but nevertheless seriously impacted.

Nathan D. Thomas, an archaeologist, has examined the record at Ward, in White Pine County (Thomas 2006). This short-lived mining town had 1,500 people, a post office, two newspapers, and even two breweries in 1877 (Thomas 2006). Thomas worked diligently to estimate how much wooded area was impacted to supply both the charcoal ovens and domestic uses. Thomas (2006), like Hattori and Thompson (1987a,b) in the Cortez Mining District, doubts that complete deforestation took place at Ward, and contends that modern White Pine County locals are incorrect in their claims of the woodlands being completely clear-cut in a 32 km (20 mi) radius around Ward. Notwithstanding the overstatement, Thomas (2006) concludes that woodcutting had a highly significant impact on the landscape, and provides data that allow an estimate of the areal extent of the wood removal operations.

Likewise, Zeier (1987) examined the archaeological record of charcoal production near Mt. Hope, about 32 km (20 mi) northwest of Eureka. Zeier (1987) studied temporary surface ovens, habitation and other working sites and concluded that the area was probably not completely deforested. The archaeologists all acknowledge the possibility of a known practice of stump removal for fuel, complicating interpretations of the available record. From the archaeological record so far assembled, it appears that the complete removal of trees in all areas where charcoal was produced probably did not occur. It is also clear that the woodlands that were originally cut consisted of much larger trees and were more widely spaced than the stands that have replaced them (Hattori and Thompson 1987a,b; Thomas 2006). We also know that a staggering amount of wood was used for a great many purposes. If the pinyon-juniper woodlands were not entirely cut, then I underestimate the area impacted by the woodcutting operations because the operations had to be carried out over a larger area to obtain the same amount of wood.

Ranches

Hundreds of ranches sprang up around Nevada to support the new towns that arose around the mines. Ranches also needed wood. Not only were pinyon and juniper wood the primary sources of household fuel, but also they were used to build fences, corrals, and homes (Young and Budy 1979). The impact on woodlands due to juniper cutting for fence posts was profound. For example, the corrals at Walti Hot Springs Ranch in central Nevada are made of 3,000 juniper poles. Most ranches built fences from juniper posts at 161 posts per km (260 posts per mi) (Young and Budy 1979). Railroads and ranching activities both contributed to an extremely high incidence of both intentional and accidental wildfires during the late 1800s, further shocking the vegetation formations (Lanner 1981).

Cumulative Impact on Pinyon-Juniper Woodlands

From the earliest settlement days, incoming Europeans valued the pinyon and juniper of Nevada only as fuel. To livestock operations, these woodlands had less available forage than the surrounding shrublands, and so were seen as worthless. These forests and woodlands had no value to either timber companies or the government, so if they were necessary to use for shafts in the mines, or reduced to charcoal for the smelting of ore, then they should be so used. This right was affirmed by the "Act of July 26, 1866" (Hattori and others 1984). The U.S. Senate (Committee on Mines and Mining 1889:I-II, cited in Hattori and others 1984) stated that "depriving or charging miners for worthless trees would, in effect, be un-American" (paraphrased by Hattori and others 1984:7).

Sargent (1879) and others opposed the wanton destruction of the pinyon-juniper forests and woodlands, but the Congressional Act of 1878 permitted the felling of any tree on public land with minerals for useful purposes by any U.S. citizen (Hattori and others 1984). This law was applied to stop Italian and Mexican woodcutters in 1888 (Hattori and others 1984), and numerous lawsuits were swiftly brought forward against non-Americans. American miners and charcoal makers had no such restrictions imposed on them. But miners and mills were in direct conflict once the "worthless" trees were in short supply. The miners' use of wood to shore up shafts and build structures depleted the forests gradually, but the cutting of trees for fuel had an immediate and devastating effect (W.A.J. Sparks correspondence, Committee on Mines and Mining 1889:31, cited in Hattori and others 1984). Not until 1907 was there any protection offered to pinyon and juniper on public land in Nevada, but this protection amounted to little more than a permit requirement, the marking of a U.S. stamp on the stump by federal rangers, and a fee of $1 per cord (Hattori and others 1984).

The problem of determining the areal extent of pinyon-juniper woodlands in 1859 is daunting. The current sum of all juniper, pinyon-juniper, and pinyon woodlands as mapped by Nevada GAP (Edwards and others 1996) is about 30,000 km^2. I have pinyon and juniper wood use data only for the towns of Virginia City (Galloway 1947), Eureka (Young and Budy 1979), Cortez (Hattori and others 1984), and Ward (Thomas 2006). Only the record for the smallest of these towns, Ward, is complete. I have derived an (under) estimate of total pinyon and juniper wood used by Nevada railroads by assuming that only one train ran the length of track each day of operation. Still, in compiling these scant data we find that more than 1,200 km^2 were clear-cut, or nearly so, which is more than 4% of the entire area covered by pinyon-juniper woodlands in the state today (table 3). If we extrapolate these uses out to the rest of the at least 35 towns in the state that arose from 1860–1869—and what was likely to be 100 by 1900—it is clear that while the pinyon-juniper forests were not wiped out, their range was significantly decreased, and the shock wave of the disturbance sharply resounded throughout the formation. Clearly, the view of the Western Shoshone was that this impact was devastating, as recounted here:

> The trees that bore pine-nuts were all cut down and burned in the quartz mills and other places… (Tsa-wie, Western Shoshone Headman, quoted by Indian Agent Levi Gheen [1876:521] in Hattori and others 1984).

Moreover, the impact was significant in the view of prominent foresters of the day:

> …in view of the vast importance of their [central Nevada mountain ranges] remaining wooded to serve as reservoirs of moisture…, it would seem wise … to check, or at least to regulate, that terrible destruction of forest, which follows…, every new discovery of the precious metals (Charles S. Sargent 1879, *The Forests of Central Nevada*, quoted in Hattori and others 1984).

Shah-Kan-Daw in the Shrublands: Early Nevada Ranching

The towns needed to be fed, and much of the food was produced locally. The conversion of valley meadows and sagebrush shrublands to agricultural production devastated

Table 3—Pinyon-juniper woodlands deforested in late 1800s to provide fuel for railroads and to support economic growth in the Nevada towns of Virginia City, Eureka, and Ward. The conservative estimates here derived from the railroad use and these four towns and years alone, deforested about 1218 km^2, or more than 4% of the current land occupied by pinyon-juniper woodlands in Nevada.

Area deforested (km^2)	Deforestation purpose	Location	Years of record or estimate	Reference
304.0	Railroad fuel	Throughout Nevada	1865-1899	Huffman, pers. comm. (2006)
768.9	Firewood & charcoal	Virginia City	1860-1885	Young and Svejcar (1999)
139.7	Charcoal	Eureka	1869-1889	Young and Budy (1979)
0.6	Charcoal	Cortez	1897	Hattori et al. (1984)
3.5	Charcoal	Ward	1872-1888	Thomas (2006)
1.3	Domestic use	Ward	1872-1888	Thomas (2006)
Total deforested: 1,218				

both plant formations wherever this occurred. However, a much greater areal-extent of Nevada landscapes were affected by beef and sheep production.

> …the Great Basin was the last natural grazing land to be exploited in western North America and, most probably, the world. (Young and Sparks 1985)

Nevada cattle and sheep ranches in the late 1800s were unregulated. They used no supplemental feeding of their herds, and so operated on enormous open ranges that possessed vegetation that could provide both winter and summer feed (Young and Sparks 1985). The operators rapidly increased their herds to supply the growing population. By 1888, there were more than 300,000 cattle on the range. This initial shock to the shrublands was turned back when two severe winters (1888–1889, 1889–1890) caused tens of thousands of cattle to freeze to death (Young and Sparks 1985). The ranchers responded well to the challenge by changing breeds, and by learning to grow alfalfa hay in the summer to provide over-wintering feed. Range practices evolved in the 1900s, allowing Nevada ranchers to maintain more than 500,000 cattle every year from 1951 through 2002 (fig. 5) (USDA Nevada Agricultural Statistics 2006).

Restoration in Iran Today

The problem facing Iranian resource scientists today is not advancing pygmy conifers replacing their shrublands. Instead, Iranian resource scientists and land managers are dealing with advancing sand deserts replacing shrublands. Iranian restoration biologists are working in collaboration with scientific teams from Germany to stabilize sand dunes in many parts of the nation. They irrigate *Tamarix* in plantations, and then out-plant them to sand dunes. The dunes are pre-treated by spraying them with oil to temporarily stabilize them until the *Tamarix* can hold them in place (Geisbauer 2004a,b; Khosroshahi and others 2006; Morell 2004; Pakparvar 2004).

Iranian soil scientists make recommendations for proper plowing and soil conservation, but the farmers and shepherds treat the recommendations as mere suggestions. I saw Iranian farmers in Kurdistan plowing native steppe on steep slopes for the first time with their tractors going up and down the slopes instead of following the contour. I queried the soil scientist with whom I witnessed this. Why were they doing that, and did they not know of the potential for an erosion disaster this could cause? He said they did tell them, but that the farmers explained it was easier on the tractors this way. Immediate practical matters overwhelm long-term concerns. That evening powerful thunderstorms caused massive flooding, nearly preventing our return to Urumieh because of several bridge washouts. The immediate practical matters suddenly became the crisis caused by that morning's practical, but ill-advised, decision.

Afforestation projects consist of monoculture plantations, generally of non-native Austrian pine (*Pinus nigra*) or Arizona cypress (*Cupressus arizonica*). They are seen as greenbelt production forests, evenly spaced in rows and with no understory. In the valley floor south of Tehran, these plantations are irrigated by wastewaters that flow through the city of

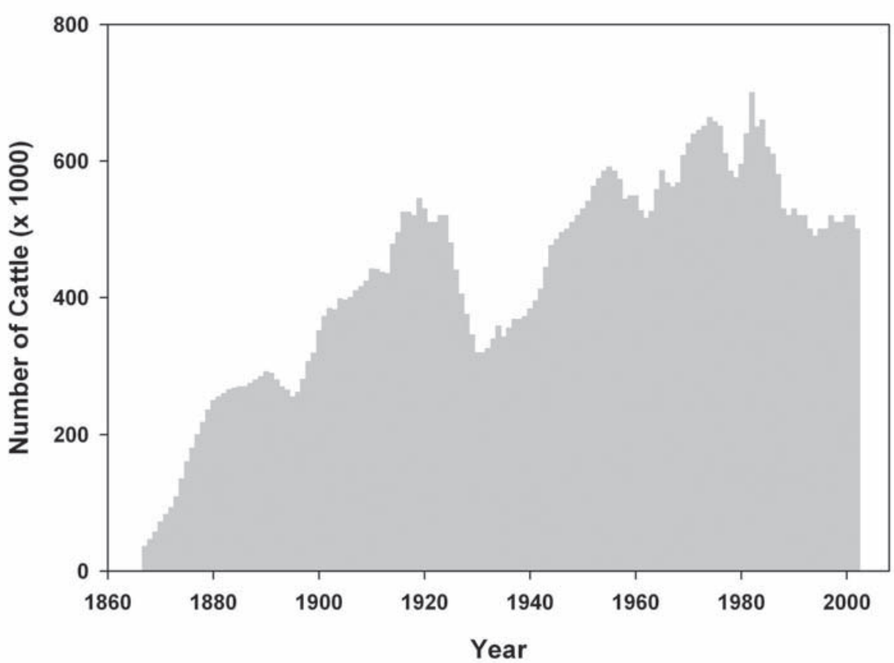

Figure 5—Number of cattle in Nevada, 1867–2002. Nevada Agricultural Statistics (2006). Note two periods of sharp decline, one following massive die-offs in the latter 1800s, and another prior to the Great Depression. Total number of cattle in Nevada has been at levels above 500,000 every year since 1951.

12 million people. Significant forest conservation efforts are rightfully placed in the Caspian Basin, with climate and vegetation that has no analogue in Nevada (Mooney 1956; Zohary 1973). Here, Hyrcanian forests, relics of the Tertiary, persist in a few locations (Zohary 1973). These forests are under tremendous pressure and are in dire need of conservation (Caspian Environment Program 2005). However, there seems to be no effort to restore woodlands or forests in the semi-arid interior of Iran. More than 30 years ago, Zohary (1973: 652) recognized that many areas formerly covered with woodlands had lost so much soil that they no longer even had the potential to become woodlands again:

> Large areas of the Middle East have lost their arboreal vegetation forever, especially those areas of woodland situated on the borders of steppes and deserts. Here conditions for tree growth are marginal and moisture deficiency and soil erosion are impeding regeneration of the destroyed vegetation. Living testimony in the form of relics, remnants, single shade trees, sacred forests, cemetery trees, etc., located amidst timberless lands tell the story of the lost forests and of the climax vegetation that did not come back centuries after destruction.

Nevada Today

What are we creating in Nevada? It seems that by following practices initiated in the Nineteenth Century ecologically we are turning Nevada into Iran. Who are the insurgents responsible for this change? They may be difficult to recognize, but we have met them, and they are we. As we take up arms (plows, drill rigs, bullhogs, and backhoes) against the established natural order of our landscapes, we fall into the same dilemmas that faced the amazing people that created the great Persian civilization.

When I moved to Nevada in 1971, the population of the state was nearly 500,000; now it exceeds 2,000,000, a fourfold increase in 35 years. The growth is not going to stop anytime soon because Clark County leaders are convinced that any cessation in growth will have immediate and dire consequences for the local economy (Hobbs and others 2004). Obviously, urbanization destroys and re-creates valley vegetation. Urban centers incidentally increase the fire frequency in a halo on their periphery, a periphery that is rapidly moving upslope out of the valleys and into the mountains (Brussard and others 1999).

To support our rapidly growing communities, we construct more utility corridors, further fragmenting the region and providing habitat and migration corridors for alien invasive species. These corridors, if left undisturbed after construction, will take centuries to recover (Lathrop and Archbold 1980). For instance, the Southern Nevada Water Authority (SNWA) is aggressively pursuing water rights from throughout Clark, Lincoln, Nye, and White Pine counties, in order to build a 2.13 m (84 in) pipeline, estimated in 1989 to cost \$2 billion for a 1.52 m (60 in) pipe, to bring enough water for 425,000 new homes in the Las Vegas and neighboring valleys (BLM 2004, 2005a).

Our activities replace forests with shrublands, and simplify the vertical dimension of these shrublands. Our activities replace shrublands with grasslands dominated by annual alien species from the Middle East. We are degrading riparian areas with alien species from the Middle East, and are reducing biodiversity of fauna and flora everywhere. Historically, mining activities laid waste to large tracts of pinyon-juniper woodlands for charcoal production, and the railroads contributed their own assault on these woodlands for the cordage they provided to the early trains. Today, mining destroys the land itself by crushing whole mountains and spraying the resulting piles of ore with cyanide solution.

We have had many conferences on the topic of our deteriorating shrublands and woodlands of the interior West. For instance, in my personal library, I have the following volumes of USDA Forest Service conferences on *Western Range Restoration: Pinyon-Juniper Conference* (1987), *Desired Future Conditions for Piñon-Juniper Ecosystems* (1994), *Wildland Shrub and Arid Land Restoration Symposium* (1995), *Ecology and Management of Pinyon-Juniper Communities Within the Interior West* (1999), *Restoring Western Ranges and Wildlands* (2004), and now I will soon be able to add *Shrublands Under Fire* (2006). Throughout these volumes, we find many ideas about how to control the expansion of pinyon and juniper woodlands. A lone voice of the Native Americans was present in these proceedings. Wassen (1987) felt that there was much talk about removing the pinyon and juniper, but little consideration for what was to replace them. Wassen (1987) eloquently expressed the view that all living things in the forest are "intertwined in the chain of life" and that to the Indian the pinyon is the grocery tree and the juniper the medicine tree. "Therefore, the cutting down of a single living tree is sacrilegious—the cutting down of a forest—UNTHINKABLE" (Wassen 1987:39).

Now we are looking to the pinyon and juniper to provide fuel again, calling it renewable energy (Fadali and others 2005; Harris and Dick 2005). We continue to manipulate the vegetation for preferred species. Instead of "range improvement" projects of the 1950s through 1970s that involved chaining of pinyon and juniper and planting with crested wheatgrass (Lanner 1977), we are now conducting "habitat restoration" projects—presumably for mule deer and sage grouse—that involve chaining of pinyon-juniper and planting of wheatgrass (BLM 2005b). Upon closer inspection, we find that this project (BLM 2005b) is designed to also provide benefit for the grazing permittee, as well as for the non-native wild horse herds. We also have a new mechanical "treatment" technology—the "bullhog"—that can chew up pinyon trees and spit out landscape mulch. This is seen as progress because the old chainings left many supple young pinyon and juniper saplings that actually increased their local dominance on the site over time. Now we can get rid of them once and for all.

We use the herbicide Spike 20P™ to kill big sagebrush (*Artemisia tridentata* ssp. *tridentata*), while Tordon 22K™ is used to kill rubber rabbitbrush (*Chrysothamnus nauseosus*) and greasewood (*Sarcobatus vermiculatus*) (Williamson and Parker 1996). I found the rationale fascinating: "Although livestock and wildlife will browse it, the plant [rabbitbrush] rates low in palatability. It is considered a problem because it tends to increase where soils have been disturbed, such as on overgrazed rangelands, at the expense of more desirable plants" (Williamson and Parker 1996:1). We need to poison the native plants that respond to overgrazing disturbance because those that overgraze will not eat it?

Similarly, greasewood is "undesirable" because "if eaten in large quantities by livestock it may be toxic" (Williamson and Parker 1996). If cattle overgraze to the point where there are only toxic plants left, they will eat the toxic plants. How do we conclude from this that we must poison the dominant native shrub? If the real interest was a healthy ecosystem, we could simply remove the source of the disturbance, which is overgrazing. Today we are using a new tractor-pulled mower to destroy sagebrush in eastern Nevada in the name of restoration (Eastern Nevada Landscape Coalition 2006). It seems to me that something is fundamentally wrong with activities that are designed to destroy the native, dominant species in the region.

Considerations of and For the Long Term

We know that the ranges of both pinyon and juniper have expanded and contracted greatly in the past (Miller and Wigand 1994; Tausch 1999a), and there is no reason to believe that this will change in the future. Moreover, while we have a good idea of the long-term changes throughout the past 50,000 years or so, we do not know exactly what those changes look like. I imagine that range shifts in pinyon and juniper did not occur slowly and evenly, but instead were dynamic; that is, there are pulses of recruitment and pulses of dieback. The organisms we are considering here live much longer than we do. Tausch and others (1993) remind us that it is extremely difficult to recognize natural or climatic vegetation change going on around us, much less know what direction it will be taking in the future.

It is difficult to interpret the snapshots of vegetation communities that we see on the ground. That is, what is the landscape like when pinyon and/or juniper woodlands expand their range? We should see recruitment both in the understory and beyond the limits of the existing forest or woodland. For a moment, there may be excellent establishment success of pinyons and junipers. That pulse may last for 5–10 years or 50 years, and at any time could be halted by a killing freeze that nails all the saplings. The climatic factor of cold winter low temperatures induced by cold-air drainage to valley bottoms, not repeating fires, is what appeared to Billings (1954) to prevent pinyon-juniper expansion onto valley floors, while a warm thermal belt allowed them to dominate lower mountain slopes.

Pinyon-juniper woodlands with closed canopies and no understories also represent a type of vegetation simplification. I know there is genuine concern over pinyon-juniper stands where canopy closure is complete and understory vegetation is absent or nearly so (Jameson 1987; Pellant 1999; Tausch 1999b). However, in Nevada this condition is the exception, not the norm. In the past 18 years, I have visited 285 of Nevada's 314 named mountain ranges (Charlet 1996 2007). I visited most of these ranges multiple times, often in the same year, and many for extended periods of time. Counting all visits to a mountain range in any year as one visit, I have averaged 5 visits per mountain range ($n = 285$) over these 18 years. I have made more than 1,300 collections of conifers in 183 of these ranges and keep track of vegetation wherever I go. I have seen canopy-closure with no understory only rarely in Nevada's pinyon and/or juniper woodlands. Stands that are approaching canopy closure I judge as being uncommon.

Are pinyon-juniper communities with canopy closure and no understory steady-state "pseudo-climax" communities with no change in their future, or, will they also change? I submit that these stands are already changing. The canopy closure we see in many stands of pinyon-juniper may simply be an early succession phenomenon that will be arrested by self-thinning services provided by the innumerable organisms of our biodiversity that are waiting in the wings to capitalize on the abundance of pinyons and junipers. Weber and others (1999) report that there are 16 pathogenic organisms responsible for mortality of pinyon, and 15 for Utah juniper. Most recently in my surveys, in closed stands and in stands approaching closure, I observe self-thinning in the form of beetle-kill, mistletoe-kill, and other pathogens. These events create the openings in the pinyon-juniper formation that the land managers seek. This is one way that old-growth pinyon-juniper forests are created. Alternatively, the pinyon-juniper expansion we think we see may simply be a minor interval of recruitment that will be quelled by a catastrophic event such as a deep freeze event that occurred in western juniper (*Juniperus occidentalis*) woodlands recently in eastern Oregon (Knapp and Soulé 2005). I am certain that events like this are commonplace in the timeline of pinyon and juniper woodland range shifts.

Jameson (1987) elegantly proposed that there are multiple pathways and potential states possible in vegetation change in pinyon-juniper woodlands. Tausch (1999b) expanded on transition and steady-state models, and discussed critical thresholds in the Great Basin pinyon-juniper woodlands, and how consideration of these models can inform our management decisions. How well do we understand these concepts, and how well have we tested the propositions and the unintended consequences of our actions? It seems that whenever pinyon and juniper are seen that they are now perceived as invading. We are over-generalizing and over-reacting by taking drastic actions.

I am concerned that as we proceed with our plans that the projects themselves will serve to introduce more disturbances and further destabilize our systems to the point where they may cross a threshold (*sensu* Tausch 1999b) that prevents the return to woodland formations. The power that we can wield on the region is awesome, and it may be that we effect a change as great as Zohary (1973: 654) senses has occurred in the Middle East.

> This change of the flora, vegetation and the animal world, has already reached dimensions never paralleled in the history of the region. In other words, man has introduced here floristic and distributional changes that in their magnitude exceed by far those caused by Pleistocene climatic changes.

Management Implications

I think we need to slow down with our restoration efforts. Eddleman (1999) offered five guidelines for the ecological management of pinyon-juniper woodlands. As enumerated by Pellant (1999), the first guideline for ecological management of pinyon-juniper woodlands is to establish clear goals and objectives. I am concerned that we have not yet accomplished this. We need to decide what we want our landscapes to be in accordance to their potential. We need to develop an honest, realistic vision of what our region will look like in 5, 20, 100, 1,000 years into the future. Are we managing for healthy ecosystems, or are we managing for the artifacts of our destruction of the system in the first place: the mines, cattle, and horses? Are we managing for fire because of the health of the ecosystem, or because of the danger such a fire may pose to utility corridors and expanding town limits? It is difficult to be aware of one's own bias, but it affects how we interpret what we see. A shepherd sees young pines on a shrub-steppe and says the pines are encroaching and should be removed. A forester looking upon the same scene may say instead that the pines are insurance for the future of his forester sons and should be pruned and thinned and allowed to grow to large size. A fireman sees a fuel model and wants to remove fuels. An ornithologist sees resource partitioning, and wants to construct a blind. A soil scientist sees a soil type and wants to dig a hole. A miner sees supports for shafts, while a charcoal maker sees starting material. A developer sees a new subdivision, and I see biodiversity (fig. 6). How much longer will our population increase? Will we occupy every valley with human development? The habitat conversion from shrubland to houses is going to have a much greater impact on sage grouse than does the current pinyon-juniper "encroachment." We need to engage in an open discussion about the future of the valleys and mountains of Nevada and the life that is teeming there, and see if we can hold a shared vision of our future in the midst of a landscape whose vegetation will constantly change.

Eddleman's (1999) third guideline for ecological management of pinyon-juniper woodlands is to develop baseline data by conducting an inventory to determine understory vegetation and functional status of stands. As far as I can tell, the baseline data of pinyon-juniper communities required to inform wise management has not been assembled. Since Eddleman (1999), other than my own cursory surveys (Charlet 1996, 2007), only Tausch (work in progress), McArthur and Sanderson (2006), and Greenwood and Weisberg (2006) have endeavored to obtain a sense of the breadth of variability in pinyon-juniper communities across the region, each using different methods. More efforts of this kind are desperately needed to inform us as to the real dynamics on the ground, rather than our impressions from a limited area of operations. Moreover, it would be superior to integrate the different approaches and develop a statewide vegetation inventory database. Analyses can be performed on the database to better understand the controlling factors of the variations in vegetation. Monitoring will be more informative so that statewide trends can be identified and quantified. But at present, our knowledge of the distribution and condition of shrublands and woodlands in Nevada is good in general but poor in the particulars.

For as much as we know, we still lack a great deal of basic research on these ecosystems. Our ignorance of the basic processes that are operating in the ecosystems of Nevada is so great that I am concerned when we take large-scale management actions based on what we assume we know. Instead, these actions exacerbate the problems by introducing more disturbances, creating more opportunities for alien weeds to colonize and ultimately dominate the landscapes of Nevada. We are reminded in our Environmental Assessment forms that we should consider the consequences of both action and no action. Tausch and others (1993) pointed out that "no action" is still a management action. I agree,

Figure 6—Biologically diverse shrublands with structural complexity are rare in Iran and are rapidly disappearing in Nevada. This complex Mojave shrubland remnant was spared from flattening at the new Coyote Springs Valley housing development, Clark County, Nevada, May 2006. Photograph by the author.

and I propose that "no action," in most cases, is superior to aggressive action in the absence of baseline data and experimental design. "No action" is superior to "experiments" with no replication and insufficient controls. It is the "no action" option that is enthusiastically embraced by Romme and others (2006) concerning the natural, "self-thinning" fire protection service provided by forest insect outbreaks in Colorado forests.

Currently state and federal agencies are conducting and planning dozens of high-impact manipulative projects on vegetation throughout Nevada. Each of these projects represents an opportunity for experimentation and thus learning from our actions. Instead, virtually none of the projects are designed with replication or even proper controls. Lacking such design, the projects keep us busy, but we learn nothing from them. Worse, we may create more harm than good. We act as if we know the role and history of fire in pinyon-juniper woodlands, when in fact our knowledge base of fire history in Nevada is very poor (Baker and Shinneman 2004).

For example, the ambitious restoration plan for Spruce Mountain (BLM 2005b:3) states in its introduction that "a study published in 1976 identified … improper livestock grazing, wild horse use and abuse, and pinyon-juniper encroachment into sagebrush/perennial grass communities" as the three major factors causing decline of mule deer winter habitat on Spruce Mountain. The plan seeks to remove pinyon and juniper, but addresses the other two causes of degradation (wild horses and cattle) only by changing the management levels in order to "attain multiple use objectives" for the allotments (BLM 2005b:3). It may be that the grazing enhances pinyon-juniper "encroachment" (Miller and Wigand 1994). Nevertheless, the pinyon-juniper woodland is demonized and removed but the cattle and horses will remain.

Later, the proposal continues by stating, as before without citation or reference, that "Studies show that the expansion of pinyon-juniper has more than tripled in the areas dominated by pinyon-juniper woodlands within the last 150 years" (BLM 2005b:5). I am unaware of any study that proposes a three-fold expansion of the range of pinyon-juniper woodlands in the past 150 years in Nevada, much less multiple studies as the proposal states. The proposal states that one of the contributing factors to this shock wave of pinyon-juniper expanding throughout Nevada was that the forests were cut for the mines. But how is that possible? Mining in Nevada began in 1860, more than 150 years ago, and the industry consumed large amounts of the woodlands for fuel. Surely the trend from 1860 to 1910 was a drastic decline in the distribution of the forests. I submit that we are, in most cases, witnessing a reoccupying of pinyon-juniper range as a response to prior human actions that included cutting many of the forests down to bare ground, or nearly so.

Every summer we have large-scale fires consuming pinyon-juniper forests and woodlands in Nevada. When the woodlands regrow, do we call this an "invasion"? It is a reoccupation. When they are burned, do we count it as a loss? Photographic time series studies such as Rogers (1982), fascinating and informative as they are, usually have photographs available at the earliest in the early1900s, long after most of the initial damage was done. If an area is clear-cut in 1880 and photographed in 1900, the site will not appear to be woodland. If the woodland recovers then we will see an increasing amount of trees and they will be getting bigger throughout the photographic history. The statement that pinyon-juniper woodlands have increased threefold in 150 years seems like an example of data distortion that occurs when one whispers something to a person who whispers it to the next and on the story goes around the room until at the end it is unrecognizable as the original statement. It is possible that the authors of this report had read this passage in Tausch (1999b:362) and misread "third threshold" as three-fold: "The outcome of this [third] threshold has been the dramatic increase in the area and dominance of pinyon-juniper woodlands that has been progressing largely unrestricted over the last 150 years." This "third threshold" for vegetation change that Tausch (1999b) proposed was crossed as we passed out of the Little Ice Age. This released certain potentials that before were inaccessible. "Abiotic conditions and associated patterns of disturbance and succession that prevented this [pinyon-juniper expansion] in the past are gone" (Tausch 1999b:362). But potential is one thing and reality is another. The *potential* for increase of pinyon-juniper woodlands to expand may have turned 150 years ago, but have they really been expanding all this time? I submit that, in light of the above discussion, in the first 50 of the past 150 years there was a dramatic decline in the extent and density of the pinyon-juniper woodlands. It may be that this is a phase of pinyon-juniper expansion because of a peculiar confluence of variables that turned to favor woodland development at the close of the Little Ice Age, but the climatic variables at least will once again turn to favor shrublands over woodlands. Given that both the potential and the reality of pinyon-juniper expansions and contractions have occurred many times in the past, we should have no expectation that their distributions and abundances should remain the same. I submit that a phase of expansion—if that is what we are seeing—is not necessarily a "bad" thing; it simply is what is happening. Getting in the way of the natural trend will be painful, expensive, and frustrating for us.

Likewise, successful management will work with, instead of against, the native elements of biodiversity within the system. As Tausch (1999b:363) stated (emphasis mine):

> These treatments should be done based on the conditions existing on the entire associated landscape to maintain the diversity of the community, its successional stages, and their interconnectedness, and to help avoid the establishment of new, unwanted thresholds. The treatments used must incorporate the biological, topographic, and edaphic heterogeneity of the sites involved into their application. *This is to preserve, and to take advantage of, the existing diversity— both biotic and abiotic.*

For instance, land managers should take advantage of self-thinning processes instead of fighting them. The Spruce Mountain restoration proposal expressed concern that bark beetles and mistletoe are killing pinyon and juniper trees, and so the work must go forward (BLM 2005b:6, 22, 23, 43). If the "No Action" alternative were taken, then "Dwarf mistle toe [sic] and bark beetle infestations would continue to spread" (BLM 2005b:6). The decision to take "Action" thus makes no sense to me. The fact is that these are but two of the at least 31 native organisms in our ecosystems that are taking action now to thin closing stands of pinyon-juniper. There is no reason to fight those elements of biodiversity in the systems that are actively creating the solution for the perceived problem, instead we should either work with them or get out of their way and watch them create the openings that we have as our objective.

Additionally, areas chained in Spruce Mountain in 1970 "are now in need of maintenance" because "young trees are threatening to compromise the value of the original projects for mule deer" and "the previously chained areas … most beneficial to mule deer will be retreated to restore the original value" (BLM 2005b:5). Treatments include prescribed fires, with or without seeding, but there is no experimental design for the treatments, so little can be learned from this exercise. The times for these fires will be from March through mid-May and October through November, times that historically and pre-historically were at low risk for fire. Naturally, if the federal agency wishes to set fires on public land, the fires are easier to manage during these months. The agency considers that there may be negative impacts for resident vertebrate populations, but does not consider the impacts of these out-of-season fires on resident invertebrate populations, many of which are crucial to the healthy functioning of the ecosystem. How many elements of biodiversity in this system will we unintentionally knock out with our actions?

I submit that the goals and objectives of our management actions should be designed to restore habitat for all the native species in the area. They have maintained a dynamic equilibrium with one another for millennia before we arrived with our giant footprint on the land. If management is conducted to promote species such as mule deer that in the pre-disturbance state were of incidental importance (Tanner and others 2003), or for wild horses that we protect because of sentiment and law, or for cattle that we protect because of tradition and short-term economics, then we are neglecting our responsibility of maintaining wild and semi-wild, fully functioning ecosystems, with all their native parts. For all of our knowledge, we may lack the wisdom to intervene on the ecosystem's behalf. I trust the wisdom of the ecosystems themselves rather than our own biased and short-term impressions. Management actions that oppose native dominants and that require constant vigilance on our part in order to sustain the original efforts are fundamentally flawed in their approach. Management actions that require constant or oft-repeated interventions by humans are doomed to fail, because they run contrary to the natural trend on the ground, whatever that may be.

We must incorporate long-term experimental approaches to vegetation management activities, with adequate replication and controls. We should experimentally assess specific treatments before we apply them at the landscape or regional scale. Toward this end, the work of Chambers and others (2006) is an excellent example of the experimental approach testing certain management actions that perhaps should be taken. The results can be assessed and analyzed, and compared to a control. Unfortunately, such studies are rarely undertaken, and more often we have large-scale management actions producing major effects that we cannot adequately evaluate. For short-term needs, we can consider low-intensity activities that minimize disturbance, such as thinning techniques suggested by Goodwin and Murchie (1980).

We need to establish more collaboration with archaeologists and historians. The historical investigations of Creque and others (1999) are excellent. The authors point out the method's shortcomings and provide fine recommendations for improvement and future studies. In Nevada we also need to conduct studies that reconstruct the recent fire and vegetation history, especially for the past 500 years such as that conducted by Kitchen and others (2006) in Utah. Such research can help us more precisely see the transition from the pre-settlement past through the present state of instability. We must collaborate with historians and archaeologists to develop the means whereby we can actually estimate the extent of the pinyon and juniper woodland formations throughout Nevada at settlement time. Only then can we get an accurate picture of the trend in pinyon-juniper distribution and abundance in the past 150 years.

Conclusions

The climate and physiography of Nevada and much of Iran are comparable. However, the vegetation of Iran is now greatly simplified from its pre-civilization state. Complex shrublands and woodlands have been reduced to simple shrublands and annual grasslands, dominated by weedy, armed, and poisonous species. The type conversion sequence during the Holocene in Iran was from forest and semi-arid woodlands, to shrublands, and ultimately annual grasslands.

In contrast, Great Basin vegetation remains complex and the Mojave Desert is exquisitely complex in its multi-dimensional structure. There are many types of shrub communities, the different species occupying different canopy levels, providing multi-canopy shrublands of high diversity and high wildlife value. Nevada's Great Basin and Mojave Desert semi-arid woodlands appear to be advancing at this time, but it is extremely difficult to determine how much is expansion beyond the historic range prior to widespread deforestation in the late 1800s. As a result, we tend to overestimate the expansion of the woodlands today. This could lead to overreaction in land management whereby we use invasive techniques that cause much disturbance and destabilize the communities even more. It may be that the greatest danger of type conversion to our shrublands is not from shrublands to woodlands, but rather from shrublands to annual grasslands of extremely low biodiversity and ecological value, as is the case in Iran. Nevada's Great Basin and Mojave Desert native vegetation are global treasures, and I believe it is our obligation to conserve them.

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