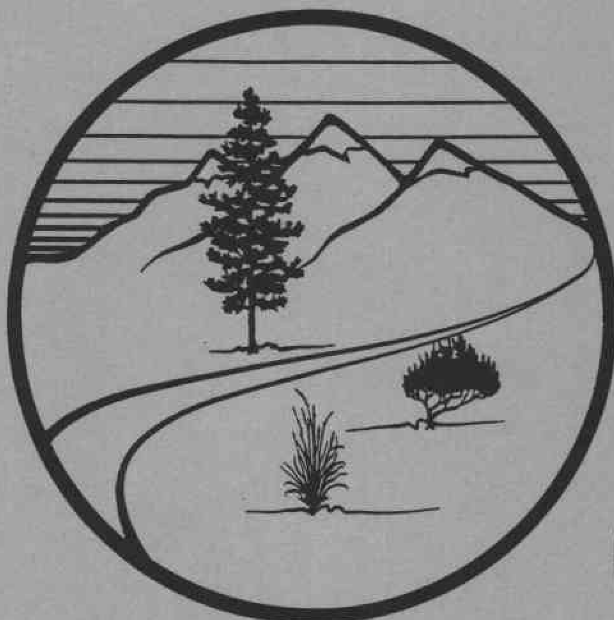
1989 Special Report

Oregon's High Desert: The Last 100 Years



Special Report 841 June 1989
Agricultural Experiment Station, Oregon State University Corvallis
in cooperation with
Agricultural Research Service, U.S. Department of Agriculture

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This special report is a cooperative effort of the Department of Rangeland Resources at Oregon State University and the Eastern Oregon Agricultural Research Center. The Eastern Oregon Agricultural Research Center, which includes the Squaw Butte Station and the Union Station, is jointly operated and financed by the Oregon Agricultural Experiment Station, Oregon State University and the U. S. Department of Agriculture, ARS. We wish to thank Carol Savonen for her help in preparing this report.

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FORWARD

Welcome to the 1989 Range Field Day. Traditionally, the format for Range Field Day has consisted of a series of presentations and a field tour detailing research projects currently being conducted by faculty of the Department of Rangeland Resources. Given the unprecedented interest in the ecology and management of the high desert by the people of Oregon, this year we are taking an approach to Range Field Days which differs from those of the past.

Today, we are going to explore changes to the vegetation of the high desert. From knowledge gained during several decades of research, it is apparent that dramatic changes since settlement have occurred in the high desert of Oregon. We will concern ourselves with several timely and important issues, including the increase of woody species such as sagebrush and juniper, the role of fire in this ecosystem, and the impacts of abusive grazing upon plant communities.

Though Oregon's high desert is unique and unparalleled in its rugged beauty, we are just now beginning to understand its ecology and functions. Our presentations will highlight some of the important ecological relationships in this unique ecosystem. We feel that you will leave the conference with a heightened awareness of the ecology and management of the area. We hope that you enjoy our presentations today and, most importantly, that you learn something new about an exciting and beautiful area--the Oregon high desert.

----Paul S. Doescher
Assistant Professor
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OREGON'S HIGH DESERT - LEGACY FOR TODAY

Lee E. Eddleman

PRE-SETTLEMENT

Many people tend to think that prior to European settlement, the vegetation of central Oregon and the high desert was relatively stable. Although it was in equilibrium with the environment, it is important to realize that two major disturbances to the vegetation were actually present which significantly influenced growth and development of plant species. These two common events were fire and drought.

Fire was a common event in the high desert, perhaps returning as frequently as every 10 years to the same area. Although lightning caused fires were common, perhaps those fires set by native Indian peoples were of equal or greater consequence in shaping the vegetation communities over time. These were set for a variety of reasons including food gathering activities, improvement for travel, and defense.

Drought undoubtedly played a significant role in the development of high desert plant communities. Tree ring studies indicate that major drought occurred about every 83 years and that dry years were much more common than major drought periods. Just prior to settlement there appears to have been a major drought beginning in 1839 and ending in 1854.

Unlike the Great Plains where plants were thought to have evolved with large grazing wildlife populations, vegetation of the Pacific Northwest's semi-arid lands was little affected by heavy grazing from native ungulates. It is felt that wildlife use was restricted to scattered groups of deer and elk and a few transient bison. Plant species and communities had for thousands of years been shaped by several important factors - climate, fire, geologic materials, and their interactions. However, current interpretation of the evolutionary history of the vegetation of the High desert suggests that grazing by large ungulates was not a major force on the evolutionary development of its vegetation.

SETTLEMENT

Euro-Amearican settlers began arriving in significant numbers in the 1860s. By 1911, the high desert was heavily populated, although a gradual decline in people occurred into the 1930s.

Many changes in the vegetation took place over the period of 1860 to 1930. These changes resulted from several factors: (1) introduction of three alien species of large grazing animals, (2) introduction of several alien plant species, (3) abandonment of land that had been plowed, (4) reduction in fire frequency, and (5) drought.

GRAZING

Cattle, sheep and horses all played a role in shaping the high desert vegetation as it is today. Numbers of cattle began building in the late 1870's and early 1880's and reached a peak in about 1910. Sheep populations built up rapidly in the 1870's and 1880's as well, perhaps reaching a maximum as early as 1900. Horses reached peak numbers about 1917 and as of 1929 they were so over-abundant and had such little value that they were let loose as people moved or starved out.

Many reports indicate that the grazing lands were fully stocked by cattle by the mid 1870's, yet numbers of cattle, sheep and horse continued to increase perhaps to numbers three or more times those of the 1870's. Even as early as 1875, central Oregon residents were commenting on the bare hills and lack of forage for livestock.

Total numbers of livestock in eastern Oregon appeared to be excessive for the amount of available forage. For instance, the sheep populations in eastern Oregon reached 2.5 million in 1900. In 1903 and 1904, a few thousand sheep were killed near Benjamin Lake and near Silver Lake by individuals perhaps seeking to protect certain grazing resources. Horse populations were not well recorded; however, one rancher reported having 25,000 horses while another was reported to have 10,000 plus 32,000 sheep in the Wagontire Mountain area.

By the end of the 1890's, transient bands of sheep were common and herders moved them onto mountain ranges very early in the year so as to get there before other flocks. This competition for forage between various bands frequently resulted in the land being converted to a dust-bed situation. For example, D. Griffiths of the USDA Bureau of Plant Industry who visited the eastern Oregon area in 1901 reported considerable overstocking on Steens Mountain and mountain ranges south into Nevada. These ranges were being grazed over twice each year by close-herded sheep bands. In some areas he commented "there was practically no more feed than on the floor of a corral." In 1901, 73 bands of sheep were were reported on Steens Mountain. Each band was thought to average 2,500 animals which, by Griffiths calculations, averaged 450 sheep per square mile. These bands were reported to be on the area for a minimum of four months!

In the Great Basin, overstocking of rangelands diminished available forage supplies. During the period 1915 to 1925, severe losses of sheep due to starvation occurred throughout the Great Basin area. Autopsies of dead animals revealed their stomachs to be full of sagebrush twigs, bark, and dry leaves.

Grazing by cattle, sheep and horses, on a rangeland composed of plant species which had not evolved under grazing pressures would naturally be expected to alter vegetation significantly. Not only were these animals alien to the system, the intensity of grazing pressure exerted on the vegetation was also much more extreme than wildlife grazing which occurred before settlement. Wholesale alteration in plant species and plant community structure was the net effect of the severe grazing pressures exerted by livestock. Loss of the herbaceous component, grasses, and forbs, was common and woody species increased across most of the high desert.

FIRE

During the same period when abusive grazing was occurring, fires became less frequent on the high desert, primarily due to two factors: active fire suppression and loss of fine fuels as a result of livestock grazing.

Prior to settlement, fire maintained a long-term balance between the grass-forb component of the vegetation and woody plants. Fire was a major factor controlling the distribution and abundance of sagebrush (Artemisia sp.) and juniper (Juniperus sp.)in eastern Oregon. Most of the species in these two shrub generas are susceptible to fire. Cessation of fire appeared to result in a tremendous advantage to woody plants in and around the high desert area.

CLIMATE

The period of overgrazing and fire frequency reduction was culminated by a rather intense drought. Pine growth response just north of Fort Rock indicates that as early as 1917, precipitation had dropped below normal. By 1924, precipitation was 65 % of normal and from 1929 through 1934 precipitation was perhaps less than 60 % of normal. This drought eas typical of throughout the Great Basin in general. The severe drought in the mid 1930's, coupled with the overstocking of rangelands left many sagebrush-grass areas in almost pure sagebrush and annual weed species. One range survey in the Great Basin at the end of this period reported accelerated soil erosion on 80% of the land.

PLOWING

Just after the turn of the century there was a big push by the Federal government to attract farmers to the high desert area. Advertisements in the east extoled the virtues of Harney and Lake counties as farming areas, indicating the area was able to produce high yields of all sorts of grains, fruits and nuts. Lands were homesteaded and plowed, but as settlers starved-out, these plowed lands sometimes remained devoid of native species until they were able to recolonize back onto the disturbed areas. In the 1930's erosion and overgrazing on these areas was severe.

ALIEN PLANTS

Another significant event in the Pacific Northwest was the introduction of numerous alien species. Probably, the most important of these was cheatgrass (Bromus tectorum), which was introduced from Asia in the 1890's. This alien annual grass species possessed excellent seed dispersal mechanisms and began to fill areas where native perennial herbaceous plants had been lost. By 1940 cheatgrass reached its present range and today it continues to dominate a significant portion of the northern Great Basin. Because of the presence of awns on the seeds of cheatgrass, domestic animals carried the seed everywhere. When rangelands were overgrazed and the ground surface was disturbed by trampling, this plant readily established itself. Drought and overgrazing that occurred in the 1930's probably facilitated the gain of dominance by this species. Since cheatgrass strongly resists reestablishment of native perennial grasses and forbs because of aggressive growth chracteristics, it will remain a member of high desert plant communities for a long time.

NATIVE WOODY PLANTS

In addition to alien plant species responding to disturbance factors to the events of the 1870's through the 1930's, several woody species increased dramatically in the High desert. Since 1900, tree ring and historical data indicate that western juniper began to move into sagebrush-grass communities. Grazing, climate, and fire suppression all played a role in initiating this expansion which continues to be active today.

SUMMARY

In summary, plant species and communities in the high desert are a product of past events that in many cases were rather traumatic disturbances. These disturbances include overgrazing by alien herbivores, reduction in fire frequency, drought, loss of native plant species at least locally, introduction of aggressive competitive alien plant species, and expansion of native juniper woodlands into the sagebrush-grass communities.

Since the 1930's, attempts have been made to control overgrazing by domestic livestock. Overgrazing of the past has limited the opportunities for appropriate grazing management. However, those factors of the previous 70 years which set in motion changes in plant species and community structure continue to exert an influence on the successional direction of vegetation of the high desert. The plant communities which are present today are a legacy of the past and can be expected to continue changing in a significant way at least for the next century.

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PLANT COMPETITION IN OREGON'S HIGH DESERT

Richard F. Miller

Oregon's high desert is a part of the Intermountain Sagebrush Steppe ecosystem, an area covering approximately 110 million acres. A large portion of the high desert lies within the Great Basin, where water flows into internal basins, containing no outlets to the oceans. Plant competition, along with environment, are major driving factors determining vegetation patterns and shifts in plant species dominance across the landscape.

Although many of us are aware of changes that have occurred in plant composition on Oregon's high desert during the past 100 years, we tend to think of the ecosystem being in a state of equilibrium prior to European settlement. Evidence, however, indicates that numerous shifts in plant community composition have occurred in Oregon's high desert since the end of the last ice age, ending 10,000 to 12,000 years ago. Throughout this period, changes in plant dominance and distribution occurred among western juniper, sagebrush, perennial grasses and numerous other species.

Although juniper has more than doubled its range since the turn of the century, it is thought to have been more widely distributed 2,000 to 4,000 years ago. As recently as 400 years ago, juniper distribution may have equaled today's distribution, with numbers and range declining approximately 200 years ago. Since the turn of the century, woody plants have increased on the high desert at the expense of perennial grasses and forbs. Reasons attributed to this change are overgrazing by livestock, cultivation and abandonment of crop lands, an increasingly more arid climate, and changes in fire frequencies.

The purpose of this paper will be to explore some of the reasons why woody plants have been so successful in the last 100 years, focusing on competitive interactions between woody and herbaceous plants (perennial grasses and forbs). We will also evaluate the hypothesis that under our current climatic conditions, woody plants are more competitive than herbaceous understory plants. Although poor grazing practices can increase the rate of encroachment of woody plants, these species will increase in number and density regardless of the presence or absence of grazing if fire is no langer a part of the environment.

In the absence of fire, why are woody plants such as sagebrush and western juniper, able to more successfully compete for limited resources, particularly water and nitrogen? Why in the absence of fire does plant succession go towards the dominance of woody plants? Current work by the Oregon State

University, Eastern Oregon Agricultural Research Center and OSU Department of Rangeland Resources are addressing these questions. Our discussion will focus on perhaps the two most successful species in Oregon's high desert, big sagebrush (Artemisia tridentata) and western juniper (Juniperus occidentalis).

Discussion

The success of a plant species to survive and effectively compete in the desert depends on its ability to tolerate or avoid stress (e.g. drought, severe cold, high salt levels), and to acquire limited resources for growth. Competition occurs when two or more organisms compete for a limited resource required for the survival of the species. Plants require mineral nutrients, water, light and CO_2. Their ability to use these resources depends on environmental characteristics of the habitat and plant characteristics enabling the plant to effectively acquire these resources.

In the high desert, water is generally thought to be the most limiting factor. The resource considered to be the second most limiting is nitrogen. The ability of a species to compete for both water and nitrogen often determines its level of dominance and possibly survival in a plant community. Since the early 1900's, western juniper has rapidly increased in both density and distribution. It has invaded adjacent big sagebrush grass communities, regardless of ecological condition. Sagebrush has also increased in areas protected from grazing.

Historically, fire was probably a key environmental factor enabling many of the grasses and forbs to maintain a co-dominant position with woody plants. Fire frequencies across the high desert generally varied from 20 to 80 years. Higher fire frequencies have been reported for some of the higher elevation wetter sagebrush communities. Possibly one of the greatest impacts livestock had on the high desert was the reduction of fine fuel which reduced fire frequencies.

Big Sagebrush

Big sagebrush (Artemisia tridentata) is the most abundant shrub in sagebrush steppe and grows best on well drained soils. Big sagebrush has been separated into a number of subspecies. Wyoming big sagebrush (ssp. wyomingensis), basin big sagebrush (ssp. tridentata) and mountain big sagebrush (ssp. vaseyana) are the most common subspecies found on the Oregon high desert. Big sagebrush is sensitive to fire. In the absence of fire this species gradually increases on most sites, while the herbaceous understory declines. One of the key characteristics that enables this species to outcompete its neighbors can be attributed to its leaves.

Big sagebrush is a semideciduous plant in that it drops about two thirds of its leaves during the summer drought period, while maintaining approximately one third of its leaves through the winter. On the vegetative non-flowering stems, this species develops two different kinds of tri-lobed leaves (fig. 1). The large ephemeral leaf is the first to develop in the spring. During early summer the smaller perennial leaves, which persist through the winter, develop in the axis of the larger ephemeral leaves. All the non-lobed leaves, located on the reproductive stems also only persist through the current growing season.

The development of an ephemeral and perennial leaf is one of the important characteristics allowing big sagebrush to effectively compete for limited resources required for growth. The persistence of perennial winter leaves allows this species to start utilizing soil water and nutrients at a more rapid rate early in the growing season than rabbitbrush, grasses and forbs which start the growing season with little or no green leaf area. The large ephemeral leaves, developed early in the spring, produce larger quantities of sugars and starches, than the perennial ones, but they lose more water than the smaller perennial leaves. However, when soil water becomes limiting, and evaporative potential high, big sagebrush reduces its evaporative surface (leaf area) by abscising both the winter persistent leaves produced the previous growing season and the current years ephemeral leaves.

These differences in leaf characteristics enable big sagebrush to maximize use of resources (water, nitrogen etc.) during optimum growing conditions and avoid desiccation during summer drought. Past research in eastern Oregon has shown that big sagebrush uses soil water more rapidly throughout the growing season than rabbitbrush and perennial bunchgrasses. This difference has been attributed to the early display of leaf area during the spring. Although leaves are present during the winter, big sagebrush does not use soil resources during this period of cold.

Big sagebrush has also been shown to absorb and utilize soil nutrients such as nitrogen and phosphorus more effectively than perennial bunchgrasses. Characteristics of the root membrane of big sagebrush enable the plant to more effectively acquire soil nutrients. In Utah, big sagebrush absorbed 86 % of the total phosphorus from the interspace shared with bluebunch wheatgrass. In eastern Oregon, big sagebrush response to increased nitrogen was three times greater than that of perennial grasses. It has been reported that sagebrush has a greater growth potential than perennial bunchgrasses. In desert systems, available nitrogen has been reported to fluctuate from year to year. In successive wet years, available nitrogen declines while during dry years available nitrogen levels increase. Yearly fluctuations in nitrogen availability in the high desert may be an important factor controlling the course of succession in plant communities. The characteristics of leaf development and longevity in big sagebrush compared to other shrubs and grasses commonly associated with it, may allow big sagebrush to take greater advantage of years when nitrogen availability is high.

Western Juniper

Western juniper has greatly increased its range and density throughout the Oregon high desert, most successfully moving into the mountain big sagebrush communities. On suitable sites it can outcompete shrubs, including sagebrush, grasses, and forbs. In the absence of fire, juniper appears to compete more successfully for soil resources than associated species.

Like sagebrush, western juniper's leaf characteristics probably contribute to its high competitive ability and enable the species to grow successfully in a semi-arid environment. Western juniper maintains the majority of its leaf surface area throughout the year, only replacing approximately 15 % annually. Not only does this allow juniper to begin the growing season with most of its leaves present, but it minimizes the cost of leaf replacement. However, since these leaves are present during summer drought, juniper must tolerate or avoid drought stress. Western juniper does this by reducing the amount of water lost per unit of leaf area.

Although juniper trees are relatively small compared to other coniferous trees, they display a relatively large leaf area for their size. For example, a western juniper 12 inches in diameter at the base has a leaf area of about 2,050 square feet. This large leaf area enables western juniper to harvest large amounts of light and CO2, which are converted to sugars for growth and maintenance of the tree. Western juniper can withstand drought and minimize the amount of water transpired (evaporated through the leaf) into the atmosphere because it has no stomates (openings in the leaf where CO2 enters for production of sugars and water is evaporated from inside the leaf to the atmosphere) on the exposed sides of the leaf (Fig. 2a). All the of stomates are found on the cupped side of the leaf which is compressed next to the stem (Figure 2c). A few openings are also found on the base of each leaf scale, which is covered by the adjacent subtending leaf (Figure 2b). The position of the stomates greatly reduces the plants potential water loss from high evaporative demands caused by wind, high temperatures and low humidity. Humidity in the cupped portion of the leaf (Figure 2c) is much higher, greatly reducing evaporative losses through the stomates. The exposed leaf surface, covered by a very thick waxy skin (cuticle), allows little water to pass through.

However, the juniper's large leaf area allows it to use large amounts of water when available. For example, a tree with a basal diameter of 12 inches will use approximately 15 gallons of water per day on a mild spring day and 30 gallons on a hot summer day when soil water is still available. Dense juniper stands are are capable of utilizing most of the water received on the site. Dense stands also affect understory species. It has also been speculated that due to interception of precipitation by the tree, increased transpiration, and reduced infiltration of surface water on juniper sites, subsurface flows of water may also be reduced.

Another competitiive adaptation of juniper is its extensive root system. A deep tap root coupled with wide spreading lateral roots allows the species to exploit soil resources at great distances from the tree. As nutrients are absorbed from the soils between trees, they are primarily recycled beneath the canopy. This is also true with big sagebrush. Levels of nutrient resources are greater throughout the soil profile beneath the tree or shrub canopy than in the soils between trees or adjacent to perennial grasses.

Summary

Even prior to the introduction of domestic livestock, the dominance of woody plants appears to have fluctuated over the last 10,000 years. During the last several hundred years fire appears to have been a major factor in maintaining the dominance of herbaceous species, while reducing the levels of woody plants across the landscape. We speculate that current climatic conditions are more favorable for shrubs. Accumulation of winter precipitation in the form of snow and melt in the spring allow for soil moisture storage deep in the soil profile. Precipitation that occurs during the growing season primarily is stored in the upper 12 inches of the soil profile. Rooting distribution of grasses, which very effectively occupy the upper 12 inches, are favored by precipitation during the growing seasons while deeper moisture storage favors the deeper rooted woody plants.

Big sagebrush's ability to maximize leaf area early in the growing season through overwintering one third of its leaves, and development of ephemeral leaves early in the spring has partially been attributed to its success in the high desert. A deep well-developed root system also allows it to capture soil moisture from a soil volume much larger than that of perennial grasses. Western juniper leaf characteristics and extensive root system also appear to attribute to the species success in the high desert. These deeper rooted woody species take better advantage of winter precipitation, much of which is stored below in the deeper depths of the soil profile.

Fire probably played a major role in maintaining the herbaceous understory. Today, however, fire on degraded rangelands probably promotes numerous weedy species (e.g. cheatgrass, medusahead, knapweed, dalmation toadflax, whitetop) which limit increases in many of the desirable plants (e.g. bunchgrasses). On sites where the integrity of perennial grasses and forbs have been maintained, fire is necessary to perpetuate this system.

Although the definition of what is good ecological condition on the high desert is highly disputed, a community with diversity, containing a mixture of woody plants and a strong herbaceous understory may best describe a good community. This combination of herbaceous and woody species should maximize ground cover, nutrient cycling, and total annual production of plant biomass. Such a community may also maximize soil water storage through increased infiltration rates and reduced water loss through evaporation and runoff. We must remember, however, that communities of the high desert are dynamic and never truly reach a state of equilibrium.

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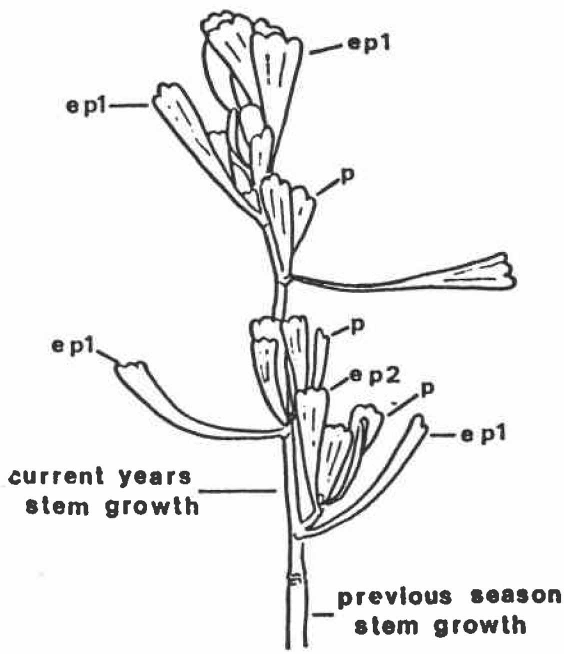

Figure 1. Current year's growth near peak development with large early ephemeral leaves (ep1), later-developing ephemerals (ep2) and separation of individual leaf clusters are more difficult to distinguish. Last year's winter-persistent leaves are not included. From Miller and Shultz, 1987a.

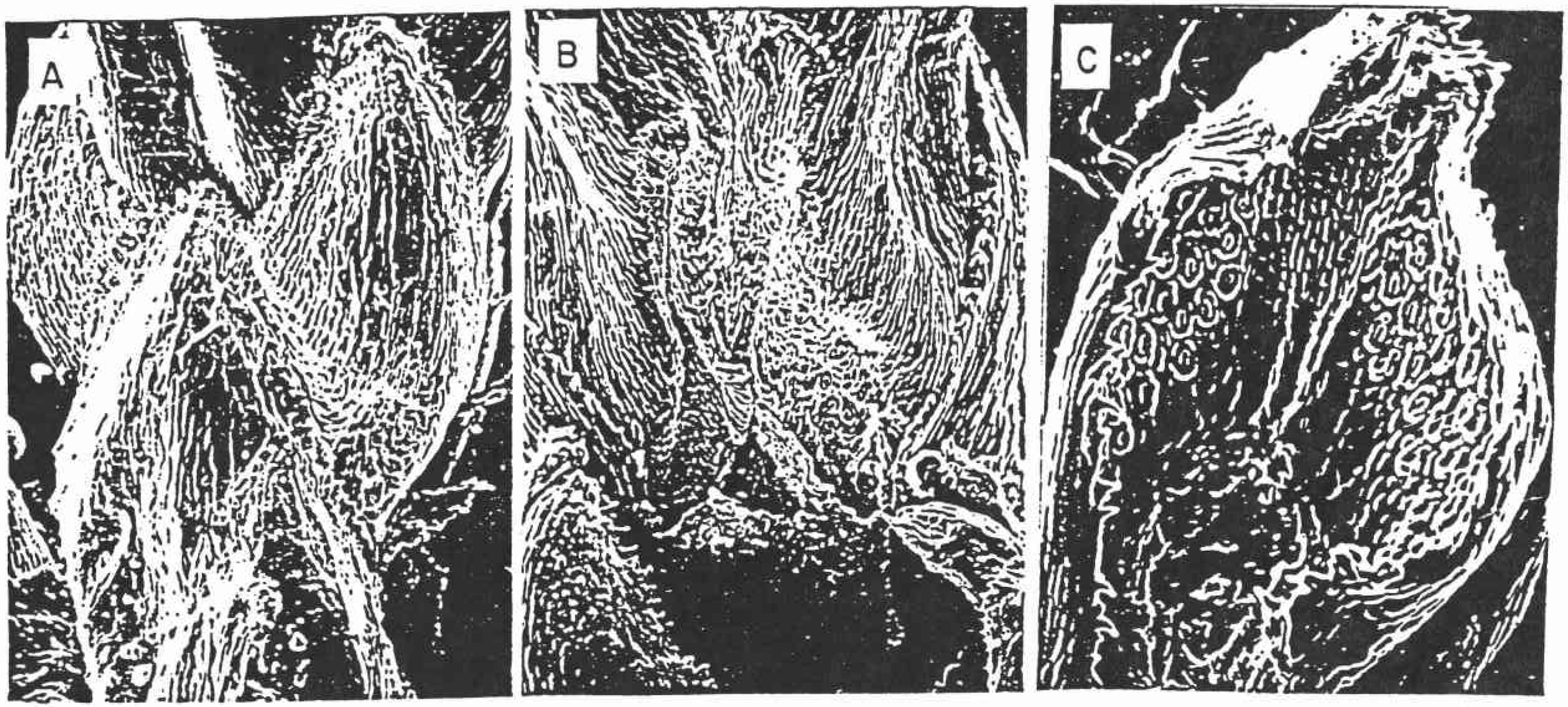

Figure 2. Western juniper leaf scales of both the abaxial (A, B; 150 x) and adaxial (C; 250x) surfaces. From Miller and Shultz, 1987b.

THE NATURAL ROLE OF FIRE IN OREGON'S HIGH DESERT

J. B. Kauffman and D. B. Sapsis

INTRODUCTION

Prior to Euroamerican settlement, fire was a dominant ecological factor that greatly affected the landscape of Oregon's high desert. Virtually all plants and animals native to the high desert evolved to survive fire which was a natural component of their ecosystem. Today, fire is too often considered as a destructive or negative influence on ecosystems rather than recognized as having an important role in a myriad of natural environmental processes. Fire is a process that affects landscape diversity, vegetation succession, and nutrient cycling. Dramatic alterations in the composition and structure of the biota have occurred as a result of alterations in fire occurrence in many high desert ecosystems. Today, much of the high desert country bears little resemblance to the landscape that the early trappers and settlers observed. The objective of this paper will be to review the ecological role of fire in the ecosystems of eastern Oregon and the causes and responses of altering this role.

FIRE REGIMES IN THE HIGH DESERT

Although fire was one of the dominant ecological forces that shaped the composition and structure of the high desert, its characteristics and effects were not the same in each plant community. The mean number of years for a fire to return to a given area (i.e. the fire-return interval), the severity of fire (e.g. severe crown fire or low intensity surface fire), and the extent of fire (from a few hectares to millions of hectares) are components of wildfires that fire ecologists use to segregate ecosystems into fire regimes. Whereas, the fire regime of ponderosa pine forests was frequent, low-intensity surface fires, the fire regime of many lodgepole pine and quaking aspen forests were infrequent, severe, stand replacement fires. In the former, fires swept through the understory on the average of every 8-10 years. In the latter, every 50-150 years or more, fires of great severity swept through the crowns of these stands killing virtually all aboveground vegetation.

Species composition, reproduction pathways, and vegetation structure reflect the various fire regimes of central and eastern Oregon forests and rangelands. Mature ponderosa pine forests are frequently open with a large separation between tree crowns and surface fuels (dead pine needles, grasses and shrubs). Ponderosa pine has thick bark to protect cambial tissues and insure survival following the surface fires. In the absence of ladder fuels the ponderosa pine crowns are safe from fire. In contrast, lodgepole pine stands are characterized as even aged stands with high stocking densities and continuous crowns. This structure allows for a sustained crown fire in mature stands.

Like lodgepole pine, fires in quaking aspen are usually stand-replacing; all aboveground vegetation is usually killed. Following fire, vigorous sprouting from dormant subterranean tissues occurs in quaking aspen. Reproduction from seed is extremely rare for this taxa in eastern Oregon. Almost all reproduction is from belowground tissues that are stimulated to form new shoots following fire.

The fire regimes in sagebrush dominated ecosystems are variable, but generally fire frequency tends to increase along a gradient of increasing elevation. This increase in fire frequency with elevation is most likely related to increased ignition sources (lightning) and greater rates of biomass accumulation. In higher elevation sagebrush sites that are ecotonal to ponderosa pine forests, it is not unreasonable to speculate that fire return intervals were only slightly longer than those of the pine forests (10-25 years). At lower elevations, biomass accumulation is limited by precipitation. In the most xeric sagebrush sites, fires have been reported to return only every 75 years or so. In the most xeric ecosystems of eastern Oregon, where aboveground plant biomass is exceedingly sparse, it is probable that fire was a rare occurrence (>75 year fire return interval).

A new thrust of fire ecology research at Oregon State University will be to ascertain the fire regimes of western juniper-dominated ecosystems. The presettlement fire return interval has been hypothesized to be 10-30 years in the vast area of central Oregon that is occupied by western juniper woodlands that are less than 100 years in age. In contrast, old growth western juniper stands are found only in sites where fire does not occur at this frequency. This would include rocky outcrops or areas where fire cannot carry due to a lack of herbaceous fuels. Ancient stands of western juniper (> 250 years old) are mostly located on sites that have a fire regime similar to that of subalpine forests occupying rocky, harsh sites: infrequent severe stand replacement fires with a return interval of 250 years or more.

VEGETATION ADAPTATIONS

The native plants of the high desert possess a variety of adaptations to survive in the fire regime in which they evolved. With aspen and rabbitbrush, this includes vigorous sprouting from belowground tissues. Similar sprouting adaptations exist in the native bunchgrasses and perennial forbs as well. In addition, increases in seedling abundance of many native bunchgrasses have been observed following fire. This may result from the often observed phenomenon of fire-induced flowering and seed production. For the first few years after fire, flower and seed production may be enhanced while postfire seedbeds may facilitate establishment of greater numbers of bunchgrass seedlings than in non-burned areas. Part of the explanation for increased growth may be explained by the effects of fire on nutrients.

We have recently examined nitrogen flux following fire in sagebrush and slashed juniper stands. As much as 90% of the aboveground biomass was consumed by fires resulting in significant volatilization of nitrogen. However, soil nitrogen in forms available to plants (ammonium-nitrogen) increased by more than 10-20 fold. It is this large pulse of available nitrogen following fire, in addition to reduced competition from shrubs, that may enhance postfire growth and reproduction of native bunchgrasses.

It must be remembered that fire can also result in increases in the abundance and invasion rates of alien annuals. Plant communities in which the herbaceous layer is dominated by cheatgrass will most likely remain so following fire.

Numerous plants reestablish from seed source following fire. Some of these seedlings may come from seeds buried in the soils that survived the fire, while others may invade the site via wind, animals, or people. For example, antelope bitterbrush has been found to germinate from buried rodent caches following fire. Many legumes, green-leaf manzanita, and snowbrush cenothus have long-lived seeds that may remain dormant but viable in the soils for hundreds of years until fire stimulates them to germinate. Green-leaf manzanita and snowbrush ceanothus seedlings may dominate the sites immediately following fire in central and eastern Oregon forests. Snowbrush ceanothus is a nitrogen fixer and plays an important role in nitrogen reaccumulation following fire. In high elevation sagebrush and quaking aspen stands of the Steens, tailcup lupine is the most abundant species the first few years following fire. Yet prior to fire, it is extremely rare if not completely absent in the composition.

EFFECTS OF ALTERING FIRE REGIMES

Euroamerican settlement resulted in many perturbances that greatly altered the fire regimes of many ecosystems. Grazing by domestic livestock throughout central and eastern Oregon and active fire suppression have significantly disrupted ecosystem structure and functioning of the high desert. Livestock grazing removes the fine fuels in the shrub interspaces necessary for sustained fire spread to occur. This was demonstrated in a series of prescribed fall burns in basin big sagebrush in 1988. We prescribed burned a sagebrush stand in an exclosure and measured flame lengths of greater than 18 meters. Much to our surprise, fire would not carry outside the exclosure where cattle had grazed fine fuels from the area under moderate stocking rates only in the early spring.

It is likely that perturbations associated with grazing by domestic animals are not only through mechanical or physiological damage to the forage plant, but also through disruption of fire cycles through removal of fine fuels. As a result of disruption or removal of fine fuels by livestock, fires no longer have the potential to spread as they did historically. Thus, in the absence of fire, woody species are likely to increase in abundance; dramatic increases in sagebrush and western juniper have been documented.

In the absence of fire, many high desert aspen stands will eventually decline and be replaced by sagebrush or western juniper. The most dramatic evidence of this replacement can be observed in quaking aspen stands of Steens and Hart Mountain below 2,000 meters (~7,000 feet). This type of stand replacement, however, is prevalent throughout the Oregon high desert. For example, we sampled one decadent and one recently burned aspen stand within the western juniper zone at the Steens Mountain. Stem density of the stand that was burned 4 years previous to sampling was 76,334 per hectare, while stem density of the decadent stand was 2,333 per hectare. Mature juniper, at a density of 667 per hectare were crowding out the declining aspen. Species richness (the number of species in 30 frequency plots) was 39 in the burned stand and 29 in the decadent stand. We suggest that continuing land management practices that lead to an absence of fire in these ecosystems will result in the disappearance of much of the quaking aspen stands in the high desert.

Although fire suppression is the primary anthropogenic alteration in fire regimes of most high desert ecosystems, some areas have experienced increases in fire frequencies. In areas close to urban centers fire occurrence is often an annual event. In situations such as this, frequent fires can result in almost pure stands of exotic annuals (e.g cheatgrass). The hills surrounding Boise, Idaho, solid carpets of cheatgrass, illustrate this phenomenon.

If society demands that we: (1) maintain or restore the quaking aspen stands of the high desert; (2) improve upon the current composition and productivity of bunchgrass prairies; and (3) maintain the wildlife and other values that arise from intact high desert ecosystems, then our goal as land managers and researchers must be to improve our understanding of how fire functions in these ecosystems. From this understanding we can implement actions geared to achieve these goals. In this regard, current ongoing research into fire effects on vegetation, fuels, and nutrient cycling is starting to give us some useful information.

It must be recognized that fire is not a black or white phenomenon. Season of burn and fire severity or level of biomass burned will influence postfire composition. At the John Day Fossil Beds National Monument, we have initiated studies to compare vegetation response to burns conducted in spring (late May) and autumn (late September). Postfire survival of Idaho fescue was 80% in the fall burn plots and 92% in spring burn plots. Bluebunch wheatgrass was more tolerant of fire at this site. Survival was 95% and 97% for fall and spring burns, respectively. In contrast, survival of big sagebrush and western juniper (< 2 meters in height) was less than 10% in both treatments. These prescribed burns appeared to be effective in restoration of this area to a bunchgrass prairie. Additional studies on postfire reproductive response of the bunchgrasses, alien annual grasses, and overall long term successional changes will yield additional information regarding the natural role of fire in the sagebrush region.

CONCLUSION - MANAGEMENT IMPLICATIONS

In many of Oregon's high desert ecosystems, fire was a natural component of the ecosystem, and today can be utilized to perpetuate, or improve community composition and productivity. However, there are a number of ecological and managerial considerations that must go into decisions concerning the use of fire in ecosystem restoration. If the decision has been made to use fire, additional considerations on season of burn, fire severity, and fire frequency need to be addressed. In some ecosystems, greater than 100 years of fire suppression and overgrazing has resulted in altered plant communities composed of dense stands of western juniper or sagebrush. Here, additional vegetation manipulations may be necessary (e.g. slashing standing juniper and allowing it to lie for 3-5 years prior to burning) for successful ecological restoration.

Other important questions relating to nutrient-soil responses, exotic species invasions, and smoke emissions also need to be addressed. Currently, there is a paucity of information concerning these possible limitations to burning. With additional research, we hope to provide information to land managers that will enable constructive use of fire within the overall social, biological, and political context of central and eastern Oregon rangelands. An improved understanding of the ecological role of fire incorporated in a management system that simulates or allows natural processes to function is a fundamental step in restoring the structure and function of Oregon's high desert.

ACKNOWLEDGEMENTS

Dian L. Cummings is a co-investigator in studies of fire and nutrient cyling in rangeland ecosystems. Research was funded by grants from the Agriculture Research Foundation, USDI-Park Service, USDA-Forest Service-Pacific Northwest Research Station, and the USDI-Bureau of Land Management. In particular, we would like to acknowledge the fire personnel of the Prineville District of the Bureau of Land Management and personnel of the John Day Fossil Beds National Monument for their innumerable contributions to much of this research.

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Grazing in the Great Basin: An Evolutionary Perspective and Applications for Today

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Livestock grazing has impacted the Great Basin and the Oregon high desert for over 100 years. During this period grazing has affected vegetation and watersheds. Concomitant with the disturbance due to grazing has been the invasion of exotic plants that has further changed the floristic composition of the Basin. In this paper we will review the evolution of the Great Basin with particular attention to plant communities and grazing animals, and offer management possibilities designed to enhance sustained productivity of present rangelands.

Changing Climates and Ecosystems

The foundation for change in the Great Basin came at the end of the Mesozoic Era (Figure 1). What was once a warm sea during the Cretaceous Period (last age of the dinosaurs) became a subtropical climate dominated by forests. This forest persisted through the beginnings of the Cenozoic Era and during the Paleocene and Eocene Periods. The Eocene saw the beginnings of herbivorous mammals colonizing the Great Basin, with the first horse, tapirs and rhinos comprising some of these early species. These early mammals were primarily browsers, consuming leaves of trees and shrubs. It was also during the Eocene that large migrations of animals from Asia to North America occurred. Many of these animals were similar to those found today and they readily replaced the existing wildlife in the Great Basin. Many of the early North American mammals became extinct during this period.

It was during the Oligocene that a well known animal, the horse, advanced evolutionarily in the Great Basin. In addition, other browsing animals appeared (camels, giant pigs, oreodonts) in the area. The climate also moderated subtropical to warm and temperate. Evolution of herbivores in the Miocene, continued with the same general trend; horses, pigs, camels, rodents and oreodonts were present in relatively large numbers on the forest and savanna vegetation. However, at the close of the Miocene another major change began which had a significant impact on the wildlife. The climate became increasingly arid and the dominant forests gave way to grasslands. Animal evolution began to shift accordingly, with a change from animals primarily adapted to browsing to animals primarily adapted to consuming grass. It was during this time the first ruminants appeared in the Great Basin.

During the Pliocene in the Great Basin, the Sierra Nevada and Cascade Mountains were uplifted enough to begin influencing the storm patterns from the Pacific Ocean. The climate barrier imposed by the mountains caused the Basin climate to dry. Early Pliocene vegetation was dominated by coniferous forests in the wetter areas, with oak and juniper-woodland occupying the drier areas. Herbivorous animals had almost completely evolved from browsers to grazers. The evolution of the horse is probably the outstanding example of this transformation. From the small browser that originally was present in the Great Basin during the Eocene, a larger animal capable of existing on a diet composed of coarse grasses was emerging.

During the Middle Pliocene the northern Great Basin was similar to the open country along streams of today. Species of willow, aspen, oak, and cherry were common in the moist uplands. Mild winters occurred and precipitation was probably 15 to 17 inches per year, distributed in the summer and winter (Axelrod 1948). Extensive grasslands probably existed between the emerging mountain ranges of the Basin. However, as the Cascade and Sierra mountains continued to build, decreasing amounts of rainfall were received in the Basin. The Middle Pliocene seems to be a time when a great modernization of both herbaceous and semi-woody plants of arid grasslands and semi-desert environments occurred. Grasses similar to those of the Basin today probably migrated southward into this region.

The disappearance of summer rainfall was probably the single most important factor shaping the future of the Great Basin. Woody plants seem to have changed little since the Pliocene, but grasses and herbs have undergone rapid evolution (Axelrod 1950). Many of the true and mixed prairie grass species common today in the Great Plains were thought to have existed in the Great Basin during the Pleiocene, but disappeared with the diminishing summer rainfall.

At the close of the Pliocene, modern plant assemblages were already in place. The Pleistocene Epoch was again one of drastic changes due to the advance and retreat of great ice sheets. Although the northern, continent-engulfing ice sheets did not extend south of northern Washington state, glaciation did occur in the mountains in and adjacent to the Great Basin. Large lakes occurred in the area during glaciation, indicating a higher rainfall than at present. Temperatures were also lower. Bison, camels, horses, sloths and elephants were common grazers. Grasslands were common and most likely coniferous forests and woodlands existed at elevations lower than today.

In the Great Basin, the driest parts of the region were about as moist as the moist parts are today. In fact, Arizona had an environment comparable to present day Oregon. According to Stebbins (1947), this was a time of rapid evolution in the grasses. The new types favored were those having vigor, aggressiveness, and ability to grow well under poor conditions and favorable combinations of the adaptive characters possessed by previous species. The Great Basin was the first area of western North America to undergo climatic desiccation and loss of the Pleistocene megafauna (Jennings and Norbeck 1955).

Herbivores

The previous section dealt primarily with changes in climate and vegetation. Brief mention was made of the presence of herbivores. Generally, early in the Cenozoic Era at the dawn of mammals, herbivores were small browsers as the vegetation was primarily forest or woodland savanna. The animals were also tropical in nature as the climates were warm and moist. In the more northern regions of the Great Basin, animals were temperate, or more adapted to seasonal changes in the weather.

A major change in climate which significantly affected animals of the Great Basin occurred at the close of the Tertiary Period and the beginning of the Quaternary (Pleistocene Epoch). Climates changed drastically with the the start of the ice age, and various advances in glaciers resulted in major impacts upon mammalian evolution. Tropical herbivores suffered high mortality due to the cold, long winters. Animals adapted to temperate climates were able to cope and, where tropical and temperate derived mammals once co-mingled, temperate animals dominated. Fossil evidence of the John Day Beds shows an excellent examples of change from tropical to temperate animals as well as the shift from browsers to grazers (Ingles 1965).

During the many ice advances of the Pleistocene glacial period, a a large number of mammals became extinct (Axelrod 1967). During the late Pleistocene, at least 200 genera of large mammals became extinct world wide (Martin 1967). It is interesting to note that these were large terrestrial herbivores that disappeared along with their associated carnivores and scavengers (birds as well). As mentioned above, many of them could not cope with the changes taking place. In changing environments large animals are more drastically affected because of their great demands for food and their reproductive habits. Typically large animals take several years to reach puberty, gestation periods are long, they bear only one young, and may not be reproductively active for a long period after birth. All those traits work against selection in a rapidly changing environment.

The extinction of habitats (Guilday 1967), prehistoric overkill (Martin 1967), colder, drier climates (Axelrod 1967) are a few of the hypothesized reasons for high extinction rates of larger animals. However, some animals should not have become extinct because their preferred habitats were not lost altogether; they only changed geographically. It seems that some of the animals that became extinct should have been able to cope with the post-glacial environments. In theory, mammoths could have moved north of the Great Basin and found favorable habitat. Horses, sloths and camels should have been able to cope with the Basin's present climate, but they disappeared anyway . Analysis of sloth feces found in caves in the Great Basin indicates their diets contained vegetation found there today. The bison of today is but a poor stunted example compared to those that became extinct. The wild horse of today, native to Asia, is an excellent example of adaptation to the Basin. Yet, these wild horses disappeared about 10,000 years ago. Why?

Post-glacial climates were more arid and annual forage production declined following glaciation. As pluvial lakes began to dry up, the availability of free water in the Basin also became critical . Small herbivores such as deer, pronghorn, bighorn sheep and even elk survived because they were highly mobile and could negotiate the rough terrain of Great Basin mountain ranges to acquire seasonally available food and water.

The Influences of Prehistoric People

The first humans in the Great Basin may date back 13,200 years Before Present (BP) if carbon dating of artifacts in the Fort Rock cave is correct. It is obvious that humans soon began to impact the Great Basin soon after their arrival. Some scientists even blame humans for the extinction of the megafauna in other parts of the U.S. (Martin 1967), but most likely the megafauna of the Great Basin were already gone by the time humans arrived (Jennings and Norbeck 1955). Archeological evidence in the Great Basin includes only modern fauna in the diet of humans; pronghorn, bison, bighorn sheep, jackrabbits, wood rats, fox, bobcat, dog (Jennings 1968); deer (Aikens 1986) and elk (McCabe 1982). Hunting was efficient and no doubt impacted local animal populations for years afterward. Chase (1986) reported that antelope trapping in the Great Basin was so successful that several years were required to regenerate the population. Vereshchagin (1967) explained that usually more animals were killed than needed. If animal stampedes over cliffs were successful, often only those animals on top were utilized.

Fire was a powerful tool employed by Indians, not only to capture and drive game animals, but to alter vegetation (Stewart 1956) and to communicate with other people (Strong 1976). Burkhardt and Tisdale (1976) estimated pre-settlement fire intervals of 13-18 years in southwestern Idaho sagebrush-grass plant communities. In other plant communities of the Great Basin, fire frequency was 45 to 80 years. Many fires in the Great Basin probably resulted from lightning, but a significant number were reported as being set by Indians (Gruell 1985). Frequent fires in dry regions inhibited optimal growth of woody vegetation (Gruell 1985) and likely suppressed populations of animal species dependent upon such vegetation for cover and browse. Decreased fire frequency since the late 1800's resulting from reduction of fine fuels by livestock grazing, elimination of Indian ignitions, and efficient fire suppression caused a dramatic increase in woody vegetation (Gruell 1982), likely favoring shrub-dependant animals.

Historical Livestock Use

We can only speculate about many of the impacts of pre-European inhabitants of the Great Basin. Despite the influences caused by fire and hunting, their effects on vegetation were probably minor compared to the changes that occurred since the appearance of European settlers.

A major cause of vegetation changes within the Great Basin was grazing by domestic cattle and sheep. The cattle industry was introduced into the region during the 1840's and 1850's. John C. Freemont camped southeast of Fort Hall in 1843 and commented on the grazing potential:

> "All the mountains here are covered with a valuable nutritious grass called bunchgrass, from the form in which it grows it has second growth in the fall. The beasts of the Indians were fat upon it; our own found it a good substance, and its quantity will sustain any amount of cattle, and make this a truly bucolic region".

During the 1840-60's, settlers were moving through the Great Basin on their westward migrations, or were staying to mine rich gold deposits. Suddenly there was a market for beef, and thousands of cattle were brought into the area, primarily from Texas and California. The cattle industry boomed during the period following the Civil War. Development of railroads into the Great Basin opened new markets to the east, and cattle sold at high prices. The lure of quick profit encouraged speculators who brought tens of thousands of cattle into the region. In Oregon alone, cattle numbers doubled in the decade between 1870 and 1880 to reach an estimated 600,000 by 1886 (Stewart 1936). A single ranch, A.J. Harrell's in the central Great Basin, reportedly had 150,000 head of cattle by the 1880's (Young and Sparks 1985).

Year-long continuous grazing was the rule until the late 1880's. Cattle were wintered on rangelands rather than removed and fed hay despite previous harsh winters when which numerous animals perished. The severe winter of 1889-90 was disastrous to the cattle industry in the Great Basin. Ranches lost an estimated 95% of their livestock according to early reports in Nevada newspapers. Although considerable hay was cut before 1889-90, the hay industry started in earnest after the terrible winter die-off. Ranges were eventually re-stocked and the business of raising cattle continued, but the winter of 1889-90 "struck a body blow to the beef bonanza" (Stewart 1936). The very early 1900's saw the end of the introduction and expansion period for cattle in the sagebrush/grasslands (Young and Sparks 1985).

Two decades of unrestrained livestock grazing on pristine plant communities of the Great Basin drastically altered vegetation composition. The result was an increase in native shrubs undesirable for browsing, a reduction in grasses and forbs, and the exploitation of these voids by alien annual weeds highly adapted to intensive grazing (Young et al. 1976).

As the cattle industry regained its strength, the temporary void was quickly filled by the emerging range sheep industry. Sheep are more efficient browsers, require less water, and can utilize winter forage while depending on snow for water (Young and Sparks 1985). Sheep numbers rose from comparatively low numbers in 1880 to "veritable hoards" (Stewart 1936) in the early 1900's. In Idaho, numbers increased from a few hundred thousand in the 1880's to about 2.6 million in 1903 (Stewart 1936). Heavy sheep grazing not only caused conflicts with cattlemen, but caused even further exhaustion of the range forage. Herds of sheep "left the range plants shaved to the ground and the soil exposed to wind and water erosion" (Stewart 1936).

Current Situation

The Great Basin is presently grazed by both cattle and sheep, but the future of the range sheep industry continues to be in doubt. Additionally, extensive herds of feral horses exist on public lands. Mule deer, pronghorn, and a few bighorn sheep make up the large herbivore wildlife component. In southeastern Oregon, elk are currently moving into previously (at least in modern times) unoccupied habitat. Controversy currently exists on whether or not the present plant communities evolved with grazing and in fact, if those communities can withstand grazing.

Native Great Basin plant communities support a preponderance of bunchgrasses unable to withstand repeated defoliation. Limited precipitation, short growing seasons, morphological and physiological characteristics of the bunchgrasses themselves contribute to the relative intolerance of the the native Great Basin bunchgrasses (Caldwell et al. 1981). Because the native vegetation of the Great Basin is sensitive to continuous grazing, it has been theorized these plant communities did not evolve with the heavy grazing pressure typical with the buffalo in the Great Plains (Mack and Thompson 1982). Native ungulates of Great Basin environments were probably low in density and widely dispersed before European man arrived (Young et al. 1976). Additionally, these animals are small-bodied and have adapted feeding strategies that consist of selecting small amounts of highly nutritious forage (Hanley 1982), such as browse and forbs.

Paleontologists hold views quite diverse from those of many plant ecologists. Martin (1967) stated:

> "The pristine range of the American West where the buffalo roam, where the deer and the antelope play, must contain many empty niches, space once shared by elephants, camels, horses, sloths, extinct bison, and four-horned antelope. Was late Pleistocene extinction so effective in upsetting the ecosystem that our national parks, wilderness areas, and wildlands are an illusion? On a continent where herbivore herds evolved and thrived for tens of millions of years, can there be a natural community without them? Perhaps the high susceptibility of North American 'wilderness' to fire, insect invasion, brush expansion, and erosion is the result in large part of depletion of the megafauna."

Barnard and Frankel (1964) offer another explanation for the sensitivity of Great Basin Flora. They hypothesize that North American grasslands did not evolve with members of the family Bovidae to which domestic cattle and sheep belong, and therefore cannot cope with intensive grazing by them. Martin (1967) even suggested that because browsing species were important in American Late Cenozoic times, that introduction into North Amearica of various African browsing or grazing-browsing species be accomplished in the western U.S. His idea would be to replace current livestock with animals less damaging to the Great Plains ecosystems.

One point is clear. Since the last ice age, grazing animals in the Great Basin have had to migrate to capture nutrients and gain free drinking water or restrict their ranges to those near permanent water. Native herbivores of the Great Basin only used most areas seasonally. In most areas grazing was probably light because animals moved on once they removed the plant available material. Seasonal migrations across elevations also occurred. Darling (1956) made the point clearly; in the semidesert, cattle are exotics, pastoralism must be light and fast if the habitat is to be maintained.

Native bunchgrasses of the Great Basin likely evolved with light grazing interrupted by long periods of rest during which the plants set seeds and restored depleted carbohydrate reserves. Platou and Tueller (1985) suggested three management alternatives to maintain native bunchgrasses of the Great Basin: (1) allow plants to have adequate growing season rest; (2) develop a market for exploitation of wild animals native to the system; and (3) breeding domestic livestock for characateristics of foraging similar to the wild animals with which the ecosystem evolved.

Livestock grazing is an important component of the economy of the Great Basin. It is of particular importance to the small communities and to many county revenues. The vegetation available can be looked at as a renewable resource that can be harvested annually, while the integrity of the environment is maintained. Only recently have the people of the United States begun to shift from exploitation to concern for a sustainable environment. The issue of livestock grazing is but a small part of that concern. That concern is present among both livestock producers and range scientists as new and better systems of grazing management are explored.

Once, no thought was given to the behavioral aspects of livestock; any management usually fit what was convenient. Considerable effort now goes into the study of animal behavior and the inclusion of those data into grazing systems development, pasture design, and allocation of forage.

The winter of 1889 turned the livestock industry away from winter grazing and to the feeding of harvested forages. Now, a century later, there is a shift back to winter grazing because it offers an inexpensive alternative to feeding harvested forages. Grazing plants when they are dormant has less detrimental impact on their physiology. Contingency plans being developed are for severe winters to prevent cattle losses. Supplementation programs are being instigated to balance available nutrients with animal requirements. Ranges grazed in the winter would be rested during their active growth cycle and not grazed until the next winter.

Nutritional values of plant communities vary with time and space even within the narrow scope of one ranch. Grazing systems designed to capture nutrients when available have the potential to increase livestock production on rangelands perhaps 20% without increasing animal numbers. Biological diversity can be an economic benefit.

Classic grazing systems studies have usually been inconclusive. Most studies show greater affect due to changing stocking rate rather than systems. The new short duration systems have been used primarily on crested wheatgrass seedings (a non-native grass) and not on the large expanses of native range. New grazing systems should incorporate periodic rest to maintain vigor of bunchgrasses and prescribed fire or a similar disturbance to reduce woody plant competition. The complicating factor of exotic invaders such as cheatgrass continually challenge the natural system and the developmnent of sound grazing practices.

Concerned livestock producers, land managers, extension personnel, and scientists have struggled long to develop efficient and environmentally sound systems of grazing livestock and other herbivores. The awakening concern for the environment by the general public, if properly focused, can assist in the development of range use practices compatible to livestock, wildlife, and the range resource. Looking at both natural evolution and the effects of human exploits can assist us in developing sound management practices allowing for improvement of ecological integrity of Great Basin ranglands while meeting the demands of society.

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ERA	Period	Epoch	PRINCIPAL GEOLOGIC EVENTS	Age (in millions of years)
	QUATERNARY	Recent	Glaciers in mountains receding.	
	QUATERNARY	Pleistocene	Greatly enlarged glaciers in mountains. Mastodons and giant beavers in Willamette Valley; camels and horses in Fossil Lake area. Rapid evolution of grasses.	
CENOZOIC	TERTIARY	Pliocene	First eruptions of lava cones at crest of Cascade Range. Extensive outpouring of lava in southcentral Oregon. Horses, rhinos, camels, antelope, bear, mastodons living in John Day country. General mild humid climate with extensive forests of Metasequoia. Cascade and Coast ranges begin uplift. Beginning of drier climate in eastern Oregon.	13
CENOZOIC	TERTIARY	Miocene	Thick layers of lava extruded over much of State (middle and upper Miocene). Oreodonts, rodents, 3-toed horses, giant pigs, rhinos, tiny camels, wolves and saber-tooth cats living in John Day country. General mild humid climate with extensive forests of Metasequoia. Cascade and Coast ranges begin uplift. Beginning of drier climate in eastern Oregon.	25
CENOZOIC	TERTIARY	Oligocene	Warm temperate flora growing in both eastern and western Oregon, with Metasequoia, maple, sycamore, ginkgo, and katsura trees plentiful. Three-toed horses, camels, giant pigs, saber-toothed cats, oreodonts, topirs in John Day country. Cascade Range too low to affect climate of eastern Oregon.	36
CENOZOIC	TERTIARY	Eocene	Coast Range begins to rise in south. Subtropical forests with palms, figs, avocados, pecans, and walnuts in central Oregon. Four-toed horses, rhinos, topirs, crocodiles in Clarno area. Numerous volcanoes in area of the Cascades ending marine invasion into central and eastern Oregon	63
MESOZOIC	Cretaceous		Most of State covered by warm seas.	135
MESOZOIC	Jurassic		Oregon largely covered by seas. Some marine reptiles. Ferns, cycads, ginkgoes, and conifers growing on land areas.	180
MESOZOIC	Triassic		Most of Oregon covered by warm seas. Volcanoes active and widespread especially in north-eastern and southwestern Oregon.	230
PALEOZOIC	Permian		Volcanoes cover much of State. Limestone reefs forming.	280
PALEOZOIC	Carboniferous		Much of State covered by warm seas.	345
PALEOZOIC	Pre-Carboniferous		"Pre-Carboniferous" includes the vast stretch of geologic time extending back to the oldest rocks found on the earth. Rocks of this age are not well known in Oregon because of covering by younger sediments and volcanics.	3400

Figure 1. Summary of Oregon geologic events. (Baldwin 1964)