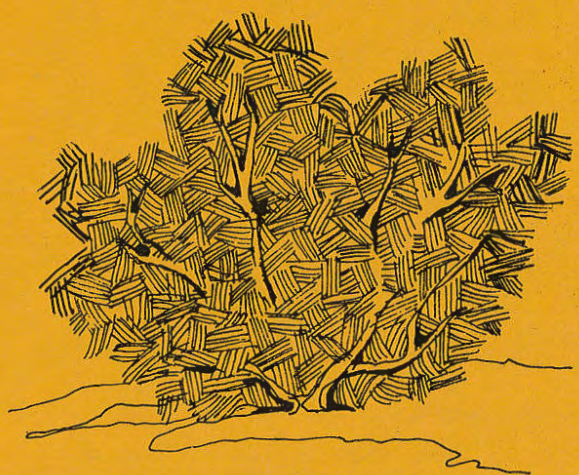
THE SAGEBRUSH ECOSYSTEM: A SYMPOSIUM



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The Sagebrush Ecosystem: A Symposium

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HISTORICAL PERSPECTIVES REGARDING

THE SAGEBRUSH ECOSYSTEM

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Abstract

This paper traces the history of man's activities in the sagebrush/grasslands of western North America in the nineteenth and twentieth centuries. The sagebrush/grass ecosystem has been impacted and irreversible changes of plant communities have occurred due to grazing by livestock and other activites of man. Development of range science and improvement of these degraded rangeland communities through weed control, seeding, and judicious grazing management mark later stages of man's influences. Finally, controversy between range users and environmentalists has arisen, leading to litigation and ensuing inactivity.

During the last century the sagebrush/grasslands of western North America have been irrevocably altered by the implementation of an agrarian culture derived from Spanish roots and applied by the descendants of northern Europeans. The period of contact between herdsmen of domestic livestock, the cowboys, and the indigenous cultures of sagebrush/grasslands, the indians, is important because of the glimpses its historical record provides of the nature of the pristine environment. The period of expansive livestock production on the open sagebrush ranges provides a chronicle of the degradation of an ecosystem that was not adapted to concentrations of large herbivores. The revolution in plant succession created by the accidental introductions of alien plant species to the sagebrush/grasslands testifies to the irrevocability of environmental changes that reflect cultural innovations. The tribulations, tragedies, and triumphs of attempts to conscientiously stabilize and optimize the productivity of sagebrush/grasslands are recorded in the development of range management as an applied scientific field of endeavor. Each of these things provides historical perspective for use in the interpretation of sagebrush ecosystems.

Our purpose is to document and provide a time scale for the history of sagebrush/grassland in western North America.

CONTACT PERIOD

The term "contact period" is generally used by anthropologists in western North America to indicate the period of first contact between indigenous cultures and European or American trappers, explorers, and finally settlers. The sources of information we have for the contact period are largely the journals of trappers often written or edited after the actual contact in the field. The subject of these journals is the fur trade. Comments on plant communities are only asides or must be interpreted from other statements. Trappers tended to travel and camp in river or stream valleys where beaver (*Castor* sp.) were found, so most of their written comments concern these areas. In the Great Basin, where the mountain ranges tend to run north to south and are oriented in echelon , travelers could avoid crossing the steep mountain ranges by going around the mountains. Therefore, most early descriptions include only the desert valleys which generally are below the environmental potential required for growth of big sagebrush (*Artemisia tridentata*). To further cloud the issue, 19th century travelers, as well as their modern counterparts, grouped all shrubs in the intermountain area as sage or wormwood even though the trails passed through *Sarcobatus*- and *Atriplex*-dominated landscapes. Essentially one can use the records left by trappers and early explorers of the

intermountain region to justify any preconceived ideas of the pristine vegetation of sagebrush/grasslands. Good sources for quotations from most of the journals written during the contact period are Stewart (1941), who emphasized the abundance of grass under pristine conditions, and Vale (1975) who concluded the opposite and stressed shrub dominance.

Fur Trappers

Most of the activities of trappers was confined to the upper Snake River and adjacent areas. Anglo-American exploration and fur trade had begun in the Snake River area by 1809 and continued until 1846 (Ross 1924). Peter Skene Ogden who commanded the Snake Country Brigades for the Hudson Bay Company left detailed and believable records of his extensive travels in the intermountain area (Ogden 1950 and 1972). The Snake River Brigade traveled with 200 horses for riding and packing (personal communication from Mary Rusco, Nevada State Museum). These animals depended on forage obtained from grazing along the line of march and in the vicinity of winter camps. When traveling in the Great Basin, Ogden considered forage for the horses easy to find, potable water scarce, and big game for food very difficult to locate (Ogden 1972). Rinehart (1932) gives the same interpretation for Odgen's travels in southern Idaho.

The American bison was the only large herbivore to exist in large numbers on sagebrush/grasslands during recent geologic times. Butler (1976) traces the evolution of the modern sagebrush/grasslands on the Snake River plains from the close of the Pleistocene. The ecosystem evolved from a complex of mastodon - camel - horse and *Bison antiquus* at the close of the last ice age to the modern American bison (*Bison bison*) grazing sagebrush/grassland some 7,000 years before the present. In the late 18th century, the American bison apparently occasionally extended its range across the northern portions of the sagebrush/grasslands into northeastern California, the Columbia basin, and eastern Oregon (Merrian 1926). The American bison had withdrawn its range from northern Nevada long before historic times (Hornaday 1889). In the early 19th century, the number of American bison on the upper Snake River and Green River drainage was first increased from hunting pressure east of the Rockies; after 1830, the populations were exterminated west of the mountains. The spread of trade that provided rifles to the Indians, hunting for robes, promiscuous hunting by trappers, and several severe winters contributed to the destruction of the American bison west of the Rockies.

Mormon Settlements

Throughout most of the mountainous and intermountain areas of western North America, the location of the initial settlements was determined by the discovery of minerals or convenient points along transportation routes. The Mormon settlements of the intermountain area are an exception to this rule. Within 13 years after 1847 when Salt Lake City was founded, a series of outlying colonies was established from Lemli in Idaho, to Carson City, Nevada and San Bernadino, California (Stewart 1941). The sites for these settlements were carefully selected to include areas suitable for irrigation to support intensive agriculture and grazing lands capable of producing the meat, milk, and draft animals for the colonizers. The records kept by these early colonies provide the best account of the pristine environment available for the sagebrush/ grasslands. George Stewart, then with the Intermountain Forest and Experiment Station, summarized the available records in 1940. Generally the abundance of sagebrush increased as the Mormon colonists moved westward and southward in the intermountain area until they passed into true desert vegetation. Many of the valleys of central and western Utah that are in the sagebrush zone had the aspect of grasslands with dominance by wheatgrass (*Agropyron*) or Great Basin Wildrye (*Elymus cinereus*). The picture Stewart (1941) recreated of the pristine vegetation of the eastern portions of the sagebrush/ grasslands is very similar to that portrayed by Hull and Hull (1974) for the presettlement vegetation of Cache Valley in Utah and Idaho.

Oregon Trail

Early travelers along the Oregon Trail had the opportunity to view a good cross section of the sagebrush ecosystem from Fort Laramie to the Columbia River. In reviewing the written record of several of these travelers, Tisdale et al. (1969) noted that the travelers' opinions of the sagebrush was partially dependent on the time of year they crossed the Snake River plains. If they crossed the area in late summer or early fall, the journals stress sagebrush, dust, and lack of forage. Because of the time interval required for an overland journey from Missouri to Oregon, most travelers crossed the sagebrush/ grasslands during the late summer. They traveled through the sagebrush/grasslands after they crossed the Great Plains, one of the world's foremost grasslands.

There is no question that sagebrush was an important and often dominant part of many plant communities. Fremont (1845) commented on the difficulty of wagon travel through dense stands of sagebrush. Wislizenus (1912) contrasted the sagebrush abundance west of Fort Laramie with the grass dominance of the Great Plains. The sagebrush plains of southwestern Wyoming had grass in late summer according to Townsend (1839), but it was dry and hard at that time of year.

Natural Areas

Historical records are too incomplete and lacking in detail to precisely tell us what was the pristine vegetation of the sagebrush ecosystem. We must deal with potential vegetations or ecological

classification based on the potential productivity of the landscape (Tisdale et al. 1969). Such classification systems are devised from interpretation of sagebrush/grass communities in or near equilibrium with their environments (e.g. Eckert 1957) and then must be applied to largely seral communities (e.g. Tueller 1962). A plant community in equilibrium with its environment is a phytometer of the effective environment of a site. A seral community growing on the same site potential is a phytometer of the effective environment plus an unwritten history of perturbation in that environment.

RANGE LIVESTOCK

Despite the inexplicability of written histories about the nature of the pristine environment of the sagebrush/grasslands, they do provide a base date for our chronology of the exploitation of this ecosystem. The Mormon settlements starting in Utah in 1847 ushered in the era of range livestock in the sagebrush grasslands.

Productivity

We assume that prior to the decade of the 1840's, productivity in the sagebrush/grasslands was optimum. This does not mean that all sagebrush communities were in equilibrium with their environments. Seral communities existed in pristine as well as exploited envrionments. Wild fires probably destroyed big sagebrush populations at periodic intervals. Larvae of the native insect *Aroga websteri* undoubtedly periodically defoliated large areas of sagebrush. Some areas of the Great Basin probably had nearly complete vegetational destruction by outbreaks of Mormon crickets (*Anabrus simplex*) (Schweis et al. 1939). It is impossible to say how much of the sagebrush/grasslands were in seral status under pristine conditions. Even the incidence of wild fires is difficult to precisely reconstruct. Wright (1978) offers the innovative concept that the interval between fires in the pristine sagebrush/grasslands had to be greater than the dominance period of root-sprouting subdominant shrubs. If the interval was shorter, the root sprouting shrubs would have characterized the environment under pristine conditions. The period of dominance for the sprouters green rabbitbrush (*Chrysothamnus viscidiflorus*) or horse brush (*Tetradymia canescens*) is generally considered to be about 15 years (Young and Evans 1974). This is a much longer interval between recurrence of fires than has been noted for woodlands that border sagebrush/grasslands (Burkhardt and Tisdale 1969).

Fires that burned in pristine sagebrush/grasslands may not have conditioned the same dynamics from root-sprouting shrubs because the density of perennial grasses may have been sufficient to dampen the seedling establishment of the root sprouters.

Mormon settlements

Initially the Mormon settlements practiced subsistence agriculture, striving to produce sufficient meat, milk products, and wool for their own existence. They had no choice because transportation systems did not exist to move products to a market. On the Great Plains, cattle could be driven to market through grasslands and arrive at their destination in reasonable condition. The isolation of the sagebrush/grasslands made this type of marketing impossible.

The Mormon settlements practiced a type of community livestock production that was unique in the Great Basin (personal communication from J.H. Robertson, Professor Emeritus of Range Ecology, University of Nevada, Reno). The livestock of a settlement, milk cows, meat cattle, draft animals, and sheep were herded together during the day and returned to the settlement at night. This northern European type of livestock culture resulted in severe over-grazing in areas adjacent to the settlements. Christensen and Johnson (1964) cite narrative sources that report attempts to alleviate this problem by moving dry animals farther from the villages. Stewart (1941) considered that the main reason for early Mormon settlements failing was lack of sufficient rangeland in the vicinity of the settlement.

Mining booms

The discovery and subsequent boom development of mineral deposits, first on the periphery and then in the interior of the sagebrush/ grasslands, provided the consumers necessary for extensive livestock production. The discovery of gold in California in 1849 ushered in this era.

It is one thing to have a demand for livestock products; it is another to find the stock to satisfy the demand. The Mormon settlements were quick to cash in on the new markets and were the first source of livestock for virtually every mining camp in the intermountain west. Tremendous numbers of livestock were required quickly to stock the sagebrush/grass ranges.

The sphere of Spanish influence in western North America, especially Alta California, New Mexico, Texas, portions of northern Mexican states, and Arizona, had been the scene of extensive livestock culture since late in the 18th or early 19th centuries. Cattle and horses were essentially feral animals looking after themselves on vast expanses of semi-arid rangelands. These animals could be obtained very cheaply. Other than hides and tallow, there was no acceptable market for these animals. Kit Carson and Lucien Maxwell purchased roughly 13,000 sheep in New Mexico in 1852 for prices ranging from $0.25 to $2.00 per head and trailed them north to Fort Laramie, then overland to California, bisecting the sagebrush/grasslands (Wentworth 1948). During the remainder of the decade of the 1850's numerous other bands of New Mexican sheep followed this or more southernly routes to California for a total of 100,000 animals a year.

The potential of the sagebrush/grasslands was not lost to experienced livestockmen. Members of the wagon trains of emigrants crossing the Overland Trail to California to Oregon also appreciated the

potential of the sagebrush/grasslands for livestock production. Only a ready market or a transportation system to market was lacking.

The first cattle operations in the sagebrush/grasslands, other than the Mormon settlements, were tenderfoot operations. From Fort Laramie on the east to Brady Hot Springs on the 40-mile desert in Nevada enterprising individuals operated trading businesses where one rested draft animal was traded for at least two with sore feet (Paden 1948). The ratio in these trades increased as the trains moved westward. The first ranches in Carson Valley, Nevada were stocked with abandoned livestock picked up on the 40-mile desert (Young 1976).

Comstock Lode

The discovery of the Comstock Lode in 1859 and the ensuing rush in 1859 and 1860 abruptly changed the Nevada livestock picture (Short 1965). Meat, milk, butter, and cheese found a ready market in Virginia City, Gold Hill, Silver City, Dayton, and Washoe City. The significance to the sagebrush/grasslands is that the Comstock was only the beginning of mining boom towns that spread throughout the west. Austin, Eureka, and Hamilton, Nevada; Bodie, California; John Day, Oregon; Silver City, and Birch Creek, Idaho; and the coal-mining areas of Wyoming provided the local markets for livestock from the sagebrush/grasslands.

California expansion

California ranges were generally overstocked with cattle by mid-19th century. A severe drought in 1863 crippled California's livestock industry. Ranching in California was conducted in a Mediterranean ecosystem. Green feed occurs with the first effective fall rain and continues until late spring. Cattle survived the summer drought on dry forage and utilization of tule marshes in the Great Valleys. Lack of winter rains means no summer forage. California ranchers remembered the bunchgrasses of the sagebrush/grasslands and drove large numbers of cattle across the Sierra Nevada Mountains to the Great Basin. Lewis Rice Bradley trailed thousands of Spanish longhorns (he called them broadhorns and he was known as Broadhorn Bradley) to the upper Rease River Valleys of central Nevada (Goodwin 1971). W.B. Huft drove cattle to Paradise Valley on the Little Humboldt River and Jack Sutherlin brought 20,000 head of cattle from the Tulare area of California to Carson Valley, Nevada (Short 1965). By 1869, there were several thousand Texas longhorns in Owyhee County, Idaho (Oliphant 1968). The animals not only survived the trip and flourished on the native bunchgrasses, but also largely survived the following winter. Once these few showed the way for the range livestock industry, a true open ranging of cattle on the sagebrush/grasslands boomed as an expansive industry until the last decade of the 19th century. The completion of the transcontinental railroad in 1869 provided the transportation system necessary to reach expanding markets in California and the East. The railroad did not reach all parts of the sagebrush/grasslands, but the cattle could be driven to rail centers for transportation. Dr. Hugh James Glenn expanded his Sacramento Valley livestock operations into southeastern Oregon under the able direction of Pete French. Market animals from this huge ranching enterprise were trailed to Winnemucca, Nevada for shipment (Jackman and Long 1969).

There were temporary setbacks in the livestock boom such as the depression of 1873, but the tide of expansion continued into the decade of the 1880's. In one year, 1883, cattle companies had a total capitalization of more than 12 million dollars (Stewart 1936).

The Fatal Flaw

The tremendous growth in range cattle, however, carried with it a weakness that in the end proved fatal. It was based on a husbandry transplanted from Mexico, which brought to English-speaking people for the first time in history the practice of rearing cattle in great droves without fences, corrals, or conserved feed (Stewart 1936). It is little wonder that cattle instead of grass came to be regarded as the raw resource and that neglected forages began to give way before the heavy and unmanaged grazing to which they were subjected.

The Spanish system of livestock production had evolved in a Mediterranean environment and the climate of the sagebrush/grasslands proved its undoing (Young and McKell 1976). Through the expansive livestock period each decade was generally ushered in with drought and ended with a severe winter (Hazeltine et al. 1961). Each severe winter converted more range livestock operations to at least partial farming enterprises for the production of hay for supplemental feeding of brood cows during the winter. Chile Clover or alfalfa (*Medicago sativa*) was cultivated on irrigated alluvial soils along the Humboldt River by 1885 (Short 1965). The modal livestock operation continued to depend on range for the entire season.

Range conditions

The sudden introduction of concentrations of large herbivores into an environment that had not been heavily grazed since the close of the Pleistocene had spectacular results (see Young et al. 1976 for discussion of abundance of native herbivores in pristine environments). After 25 years of expansive livestock production, the cream of the potential of the sagebrush/ grasslands for supporting cattle was gone. Undoubtedly many ranges distant from water remained in pristine condition, just as such examples can be found today; for most of the sagebrush/grasslands, however, the native perennial grasses were greatly reduced. The inherent potential of the native perennial grasses left them extremely susceptible to intensive, continuous grazing pressure. If the sagebrush/grasslands had been true grasslands, the perennial grasses could have returned with relaxed grazing pressure. However, the shrub portion

of the community proved remarkedly resistant to grazing. Most forms of the big sagebrush were protected by essential oils that inhibit the activity of rumen microflora (Nagy et al. 1964) (see MacArthur this volume for taxonomic breakdown of *Artemisia* species and evolution of section). Most species of *Chrysothamnus* were not preferred by livestock and species of *Tetradymia* and *Sarcobatus* are toxic to large herbivores. Shrubs, especially big sagebrush, increased in density as perennial grasses were removed from communities.

The Great Debacle

There had been several bad winters during the livestock expansion period that had resulted in excessive loss of livestock, but sufficient livestock remained to restock the ranges. The hard winters before 1889-90 tended to be localized in the sagebrush/grasslands. For example, the winter of 1874-75 was exceptionally severe in the Palouse, the northern extension of the sagebrush/grasslands in eastern Washington and northern Idaho (Rinehart 1932). The winters of 1861-62 and 1880-81 were severe in eastern Oregon (Oliphant 1968). The winter of 1882-83 was severe in eastern Idaho. These winters encouraged more hay production and the saving of Great Basin wildrye stands for winter forage (Lesperance et al. 1978). The winter of 1889-90 was extremely severe throughout the sagebrush/grasslands and throughout western North America. It was especially severe for range livestock because the previous season was one of the driest on record at most locations.

The winter of 1889-90 started with heavy rains in November. Heavy, wet snows pelted the west in early December. Hay supplies were exhausted by Christmas. Rinehardt (1932) quotes an interview with a rancher who lived through the winter:

> "The 17th of March, 1890, was a memorable day for stockmen. Late in the afternoon a storm broke over Southern, Idaho. . . .First it saturated the animals' coats, then packed them with ice and snow that would not shake out, then the temperature dropped as the blizzard filled the air with fine snow. . . .sheds and stables were thatched with ryegrass and during the winter of 1889-90 this was taken off and fed to the stock. . .In the spring when the district judge went to hold court at Challis, the stench along the road through part of the Lost River Valley was so terrible that he issued a court order to the officers to take whatever action might be effective to get the carcassed burned or buried. People who depended on the streams for domestic water had to sink wells and do it quickly to save themselves from a general epidemic."

In northern Nevada a quarter of a million head of livestock died on the ranges (Hazeltine et al. 1961). F.B. Poore of northern Washoe County Nevada had the opportunity in the fall of 1889 to buy hay from homesteaders for $5.00 per ton (Hazeltine et al. 1961).. He had no use for homesteaders and refused. He lost his entire herd and went out of business. The homesteaders inherited the vacant range.

John Sparks was a tough Confederate Cavalryman who drove Texas longhorns to Elko County, Nevada in the late 1860's. By 1889, he was the epitome of the range livestockman and the most extensive livestockman in Nevada, Idaho, and Oregon. In 1885, Sparks branded 38,000 calves. In 1890, his crews branded 68 calves on the same range (Rinehardt 1932). Remember that in 1885 a 50% calf crop was probably exceptionally high, with cows generally raising a calf every 3 years.

RECONSTRUCTION

The sagebrush/grasslands were hurt by the expansive period, but the basic potential of the plant communities was still intact. The exception may have been meadows within the sagebrush ecosystem where a cycle of errosion and desiccation had destroyed the potential of many sites (Cottam and Stewart 1940).

In the spring of 1890, the ranges throughout the sagebrush/grasslands had fewer large herbivores than in 30 years. Strangely, there are no historic records which indicate that native perennial grasses were able to take advantage of the reduced grazing pressure and ample moisture. At the same time, there are ample indications that shrubs and conifers did increase. Many of the very productive bitterbrush stands in northeastern Nevada were established in 1890 (Hazeltine et al. 1961). Was the reproductive potential of the perennial grasses gone by 1889?

Making Hay

Hay production rapidly increased after the great debacle of 1889-90. At first, only cows were fed. Steers, which were not marketed until 3 or 4 years old, were allowed to fend for themselves (McCormick et al. 1978). From this hay production, a livestock production system evolved in which one-half of the forage base comes from irrigated land which constitutes roughly 4 percent of the total landscape and one-half from rangelands.

Horses

One by-product of increased emphasis on producing hay was a large increase in the number of draft horses kept on ranches. More horses were needed during the summer haying than during the winter feeding period. Large numbers of domestic horses were turned loose to winter for themselves, both from ranches and commercial freighters.

Horses are the only large herbivore to successfully become feral animals in the sagebrush/grasslands (McKnight 1964). Feral horses had become a problem on Nevada ranges in the 1870's (Short 1965). Many horses died during the winter of 1889-90, but they survived proportionately

better than any other class of livestock. Interestingly, both in Nevada (Hazeltine et al. 1961) and Idaho (Rinehart 1932), there were instances of horses surviving the winter with their manes and tails eaten off by other horses.

The horse problem was alleviated first by the Boer War and later the Russian-Japanese Wars. However, the idea that feral horses could be profitable had been implanted.

Sheep

As previously mentioned, sheep were early introductions to the sagebrush ecosystem. Sheep suffered from the hard winters, probably proportionately more than cattle. However, a management system for sheep evolved coordinating grazing in the salt desert and higher elevation areas with the sagebrush ecosystem to form a forage base. Sheep escaped the severe winters of the sagebrush by wintering on shrubs in the salt deserts. The lower water requirement of sheep compared to cattle and the ability of sheep to use snow as a source of water made this possible (Jardine 1915).

Sheep operations became substantial parts of the livestock production economy. Many sheep operations had home ranches, similar to cattle operations. However, it was possible to become established in the sheep business with much less capital than was required for cattle. Herders took their wages in sheep and banks tended to make very liberal loans for buying ewes (Sawyer 1971). This led to the so called "tramp sheep" outfits which owned no land and ranged their sheep wherever they could find pasture. This led to many conflicts that have received much attention in historical writings (e.g. Diamondfield Jack Davis in Sawyer 1971).

What is important is that there was no way for individual ranchers to obtain title to sufficient land to support an economic range livestock operation. The inherent herbage production of the sagebrush/grasslands, especially after they were degraded during the expansive period, required too many acres per cow. Hay land could be homesteaded, and water sources could be bought as state-selection-land, but the vast acreages needed for rangeland were difficult to obtain. Oliphant (1968) provides the example of a Klickitat County, Washington rancher who in 1878 had $5,600 invested in 160 acres of land, fences, horses, and wagons, etc., and ranged a 5,000 brood cow herd on public land. Many ranchers failed to see the need for buying "free" range and most lacked the capital. If public land had been availabe for purchase, it may well have fallen under the control of foreign capital investments.

Birth of U.S. Forest Service

From 1878 to 1891, Congress debated the fate of government timberlands, but no action was taken until the passage in 1891 of an act setting up forest reserves (Forsling et al. 1936). The fight for conservation acquired real life in 1901 under the leadership of President Theodore Roosevelt and Gifford Pinchot. Regulations of the forest reserves stated that there would be no interference with existing livestock grazing, but all states except Oregon and Washington chose to prohibit the grazing of sheep on forest reserves. Nevada and Utah were not included in any of the original forest reserves. However, national forests were later established in sagebrush/grassland areas of several western states. Some of the districts of the national forest in Nevada were virtually treeless. They were established to obtain control over the spread of nomadic sheep operations and to stabilize grazing for the established ranches, largely cattle operations.

The creation of national forests established a) the idea of conservation of natural resources and b) the concept of commensurate property where the amount of grazing privleges on public lands in the sagebrush ecosystem was controlled by the potential of privately owned lands to support the livestock during winter.

The efforts of the Forest Service to establish the conservation of natural resources received a severe blow during World War I when livestock use on national forests was allowed to increase by 10 percent as part of the war effort (Forsling et al. 1936). Because of the severe agricultural depression after the war, this increase was not adjusted until 5 years after the war.

Scientists visit rangeland

At the turn of the century, the sagebrush/grasslands were studied and or at least extensively visited by scientists familar with range forage production. During the summer of 1900 P. B. Kennedy and S. B. Doten (1901) of the University of Nevada Agricultural Experiment Station reported on range conditions in western Nevada. The sagebrush/grasslands north of Reno, Nevada that were used for spring/fall range by sheep were virtual dust beds, with even the sagebrush destroyed in some areas. The alien weeds Russian thistle (*Salsola iberica*) and tumble mustard (*Sisymbrium altissimum*) were colonizing the degraded landscape, but downy brome (*Bromus tectorum*) had not yet become established. During 1902 Kennedy (1903) toured northeastern Nevada. He noted accelerated erosion and overgrazing, but no invasion by alien plants. David Griffiths, expert in charge of field management, Grass and Forage Plant Investigations of the Bureau of Plant Industry, U.S. Department of Agriculture, traveled from Winnemucca, Nevada to Ontario, Oregon in 1901. The report of this trip provides a classic description of range conditions at the turn of the century. Several points stand out in this report: a) the large ranches were making great efforts toward hay production; b) most sagebrush ranges were overgrazed; c) high elevation ranges, such as the Steens Mountains in Oregon, were denuded by tremendous concentrations of sheep; and d) during the entire trip wildfires were common in the sagebrush/grasslands. He attributed many of the wildfires to promiscuous burning by nomadic

sheep operators. If wildfires were as common as Griffiths indicated, there must have been some ranges on the mountains with sufficient herbaceous fuel to carry fires.

ALIEN INTRODUCTION

The native plant communities within the big sagebrush/bunchgrass type are extraordinarily subject to invasion by alien annual plant species (Jardine and Andersen 1919). The over-utilization of the herbaceous portions of sagebrush/ rangelands left a near biological vacuum. No native annual species were adapted to increase under heavy grazing (Young et al. 1972). Russian thistle, tumble mustard, and downy brome have revolutionized the processes of succession in the sagebrush/grasslands (Hironaka and Tisdale 1963). These species form a seral continuum that closes disturbed sites to the re-establishment of perennial grass seedlings (Robertson and Pearse 1945). While they preempt environmental potential and close plant communities to the establishment of perennial grass seedlings, the communities of annuals are changing because of invasion by other alien annual plants such as halogeton (*Halogeton glomeratus*) (Tisdale and Zappettini 1953), medusahead (*Taeniatherum asperum*), and barbwire Russian thistle (*Salsola paulsenii*) (Beatley 1973).

Land Reclamation

The connection between land reclamation and alien annual plants is not as remote as it might seem. The Newlands Project at Fallon, Nevada was the conceptual model for irrigating the shrub deserts (McCormick et al. 1978). It was rapidly followed by similar projects along the Snake River in Idaho. These projects, although relatively limited in area compared to the sagebrush/grasslands, had influence on the entire ecosystem. One influence was positive in that for the first time a surplus of forage and concentrate feeds was available for finishing range livestock (McCormick et al. 1978). Another influence was decidely detrimental. The settlers who flocked to the reclamation project brought draft animals and meat, milk, or wool stock with them. These animals were allowed to concentrate on the margins of the reclamation projects while fields and fences were developed. In Idaho this was responsible for complete destruction of the sagebrush/grasslands in many areas (Rinehart 1932).

Homesteaders

The reclamation projects that brought irrigation water to the semiarid shrub-lands had many problems, but they did have a good chance to succeed. However, except in the most favorable parts of the sagebrush/ grassland, dry land farming on homesteads was a very risky business. The clearing and subsequent abandonment of sagebrush lands left many areas dominated by alien weeds.

Wildfires

After the native perennial grasses and forbs are removed from big sagebrush communities, the shrubs remain as stark monotypic communities. These communities can remain remarkedly stable for long periods of time, especially when continued grazing attrition holds down the herbaceous vegetation (Tisdale et al. 1969). These stark communities are relatively fire proof because of the lack of herbaceous vegetation to carry fires. Once downy brome invades the degraded sagebrush communities, the way is paved for catastrophic stand renewal through burning (Pickford 1932).

R.L. Piemeisel

The full ramifications of the meaning of alien annual plant invasion to the ecology of the sagebrush/grasslands were enumerated by the remarkable research of R.L. Piemeisel. His efforts, which produced results having great application to range management, were directed toward solving the beet leafhopper problem. The lower successional levels of the alien flora provide an alternate host for the insect vector which transmits the curly leaf virus to susceptible crops.

In a series of articles (summarized in Piemeisel 1951) Piemeisel demonstrated how the preemption of the seral environment by alien plant species irrevocably changed the ecology of the sagebrush/ grasslands. One of his interesting comments was that the sagebrush/grasslands were so degraded that if the aliens had not invaded, accelerated erosion would have destroyed the potential of many sites.

Competitive advantage

Many studies have attempted to identify the characteristic that makes the alien annuals so competitive. One of the most probable explanations is that the breeding systems of the aliens provide a method of rapidly adjusting their genotypes to changing environmental conditions (Young et al. 1972). The irrevocability of the change brought by alien plant introduction is further illustrated by the finding of Daubenmire (1946) that downy brome had inserted itself successfully into bunchgrass stands that had not been grazed or burned for as long as 50 years.

J.H. Robertson retraced P.B. Kennedy's route in northeastern Nevada 50 years later (Robertson and Kennedy 1954). The ravages of wildfires, excessive grazing, accelerated erosion, and alien plant invasion had revolutionized the environment. The same results are apparent from Shantz and Peimeisel's (1940) study of Escalante Valley in Utah. The process of alien plant invasion and conversion of the sagebrush/grasslands to root-sprouting shrubs and annual grasses has not stopped. The incidence of wildfires increases each year and unless these burned areas are revegetated and managed, the eventual conversion is certain

(Evans and Young 1978; Young and Evans 1978).

SAGEBRUSH SCIENTISTS

A.W. Sampson wrote an article for the National Wool Growers (Sampson 1913) in which he gave voice to the application of scientific findings to the management of western rangelands. For the next 25 years the idea slowly grew that science could play a role in developing management systems for natural resources. Among the pioneer contributors were J.T. Jardine (Jardine 1916; Jardine and Anderson 1919) and Sampson who (1919) recognized the role of plant succession in range management. Much of the early research applicable to sagebrush/grasslands was conducted at the Great Basin Experiment Station (Keck 1972). Sampson's work with plant succession eventually led to Lincoln Ellison's contribution on the indicators of condition and trend (Ellison et al. 1951). Not only were studies conducted on the basic dynamics of grazed plant communities, but also the management of grazing animals to affect these dynamics was investigated (e.g. Fleming 1922). An important contribution to our knowledge of the sagebrush/ecosystem was the comprehensive monograph on the taxonomy of *Artemisia*, *Chrysothamnus*, and *Atriplex* by Hall and Clements (1923).

TAYLOR GRAZING ACT

The forest reserves and eventually the national forests led to a measure of grazing management backed by range research on a portion of the sagebrush/grasslands. Outside the national forest much of the landscape remained vacant public lands subject to whatever grazing management or mismanagement the local ranchers cared for or tried to enforce. From 1914 to 1934 a succession of bills was introduced in Congress to do something about grazing on the public domain [e.g. the Kent, Leawitt, Colton, and Garfield bills (Buckman 1935)]. On June 28, 1934 the Taylor Grazing Act was finally passed with the following objectives:

1. To stop injury to public grazing lands.
2. To provide for orderly and better use in improvement and development of the remaining vacant public domain for grazing.
3. To stabilize the livestock industry dependent upon the public range.

On November 26, 1934 President Franklin D. Roosevelt issued an executive order withdrawing 173 million acres of public land in 12 western states. In Nevada this included 71 percent of the total land area (Buckman 1935). The era of open range on the sagebrush/grasslands had come to an end 87 years after the first settlements in Salt Lake Valley. Not all grazing districts were established immediately and in parts of Nevada the open range did not end until the 1950's.

To obtain a perspective of why the Taylor Grazing Act finally passed it is necessary to consider the economic, climatic, and social environment of the early 1930's. Since the end of World War I, agriculture in general had known reccurring hard times. The droughts of the early 1930's had severely hurt sagebrush/rangelands. Bank failures had forced many livestock operations into bankruptcy. Several banks in Nevada had been especially liberal in making loans to range sheep operations. The failure of the Windfield banks wiped out most of the large range sheep operations (Laxalt 1957).

IMPROVEMENTS OF SAGEBRUSH/GRASSLANDS

The first 25 years of application of science to range management had been concerned primarily with stopping further destruction of rangelands. R. L. Piemeisel suggested and demonstrated that the way to stabilize degraded sagebrush/grassland communities was to establish perennial grasses (Piemeisel and Chamberlin 1936). Besides the desire to restore public rangelands, a basic change in philosophy was associated with the New Deal era in that federal financing of improvements on public land was begun.

The reseeding of degraded sagebrush/grasslands with native grass species had enjoyed little, if any, success. Sources of seed were limited to collection from native stands and germination and seedling vigor of the native species were often quite limited. Several species of *Agropyron* collected in central Asia had been introduced and tested on the northern Great Plains early in the 19th century (Hanson 1972). Crested wheatgrass (*A. desertorum*) proved to be one of the most drought tolerant of these species (Love and Hansen 1932). Rehabilitation started slowly in the 1930's because the necessary mechanical equipment for land preparation and seeding in degraded sagebrush/grasslands was not available. After World War II, this program was greatly expanded with millions of acres returned to productivity (Plummer et al. 1955). Degraded sagebrush stands were plowed with rangeland plows and seeded with specially developed rangeland drills. For the first time since 1860, the net forage production on at least a part of the sagebrush/grasslands increased instead of becoming further degraded.

Shrub control

Many areas of sagebrush/grassland still had sufficient desirable perennial grasses to respond in terms of ground cover and forage production if the overabundance of shrubs was reduced. During World War II the growth regulator herbicide 2,4-D [(2,4-dichlorophenoxy)acetic acid] was discovered. After the war, 2,4-D was found to be effective in the control of big sagebrush (Hull and Vaughn 1951; also see Evans this volume). With refinement of the methodology, control of big sagebrush and associated root-sprouting shrubs was possible (Hyder et al. 1962). Eventually millions of acres of partially degraded rangeland were returned to productivity (Pechanec et al. 1964).

Second generation technology

Starting with an accelerated program to stop the spread of halogeton in 1951, considerable research money was allocated to the sagebrush/grasslands. Growing out of these programs were second generation technologies designed to improve range communities where existing methods had failed. Downy brome had proven so competitive that the chances of establishing wheatgrass seedlings were slight (Hull and Stewart 1948). New technologies were tested, and proven economically feasible for control and revegetation of downy brome infested sites (Evans et al. 1967; Eckert and Evans 1967). Also, during this period improvements and refinements were made in control technology of hard-to-kill shrubs, such as rabbitbrush, with new herbicides and more precise application techniques (e.g. Evans and Young 1975; Evans et al. 1973).

In the mid-1960's the era of range improvement suddenly ended. The desire for improvement of the public rangelands was dampened by expressions of concern by environmentalists.

ENVIRONMENTALISTS

Our initial premise was that the ecology of the sagebrush/grasslands was irrevocably changed by the imposition of a livestock-oriented culture. This culture included consumers as well as producers. At least a portion of these consumers had by the mid-1960's strong enough sentiments about the sagebrush/ grasslands environment to bite the hand that fed them beef, mutton, and wool. The basic problem was that the environmentalists believed that the range improvement and grazing practices were changing what they perceived to be the pristine sagebrush/ grasslands. With only a brief glimpse of the history of the sagebrush/grasslands, it can be seen that the present condition of these rangelands bears little resemblance to the pristine potential. On the other side of the coin, grazing continues in excess of the current production in many parts of the sagebrush/grasslands. An attrition type of grazing keeps many degraded communities in stark monotypes of brush with forage production remaining at roughly 10 percent of its potential. Out of a complexity of management decisions, the attitude has become established that the public land management agencies are either in league with the rancher or the environmentalist, depending on an individual's point of view.

Grazing Management

With their backs turned to the cold scorn of a multitude of special interest groups, the Bureau of Land Management of the U.S. Department of Interior, which administers much of the sagebrush/grasslands, initiated grazing management systems as an alternative to weed control and seeding for range improvement in 1968.

Range Scientists deserve much of the credit and/or blame for this change in attitude. Since the first papers of A. W. Sampson, range scientists have stressed good range management as the key for stabilization and improvement of the resource. During the era of range weed control and seeding, scientists had stressed that the improvements would not maintain themselves unless good management was practiced. The problem was to define good management. It meant different things for specific range communities in different stages of succession used by different classes of domestic and wild animals. Professors of range science stressed that good training in the fundamentals of range science coupled with adequate experience would produce range managers who were capable of accomplishing good range management. This concept may have been practical but is difficult to reduce to regulations that are necessary for a bureaucracy to function.

An answer to this problem was provided by August L. Hormay. During his career in research with the U.S. Forest Service, Hormay published on a grazing management system called "rest-rotation grazing" which he had tested on the Harvey Valley cattle allotment on Lassen National Forest in northeastern California (Hormay 1956; 1961). Under the conditions that Hormay tested rest-rotation, it apparently was a very successful management system that was well tuned to the physiology of the grazed species. For a discussion of the pros and cons of various grazing systems see Heady, 1961 or Herbel, 1971.

Rest-rotation grazing management was scheduled for all the sagebrush/grasslands administered by the Bureau of Land Management (Hormay 1970). The facilitating actions necessary to implement the management systems: fences, water developments, and the actual management systems themselves constitute a new stand renewal system and therefore change the ecology of the sagebrush/ grasslands. The consequences of these changes will have to wait the test of time. However, preliminary results indicate that rest-rotation grazing is a useful management system for sagebrush/grasslands in fair to high condition. For degraded sagebrush/ grasslands with an overabundance of brush and little or no seed source for perennial grasses, rest-rotation grazing as a technique for range improvement is little more than wishful thinking.

The full implementation of grazing management systems was delayed by the filing of a law suit in federal court by the Natural Resources Defense Council against the Bureau of Land Management. The law suit was brought against the Bureau for not complying with the National Environmental Protection Act in issuing licenses for grazing privileges. Essentially, compliance with this act requires the preparation of Environmental Impact Statements on the effects of current grazing practices and proposes that land use plans be written on proposed practices in the sagebrush ecosystem.

REQUIEM FOR THE SAGEBRUSH ECOSYSTEM

This symposium is in many respects a solemn wake for the sagebrush ecosystem of 1850. The analysis of lake sediments within the sagebrush/grasslands during the last 100 years shows increased deposition rates, changes in pollen concentration and species composition, and abundance of moss and fungal spores. The introduction of domestic livestock had more effect on the environment than any event in the previous 1,000 years (Davis et al. 1977).

No constructive purpose is served by damning the 19th century livestock husbandmen who established ranching as a culture in the sagebrush/grasslands. They did not have available a historical precedent for utilization of semi-arid shrub/grassland. They attempted to adapt a system of extensive animal husbandry evolved in the Mediterranean ecosystem and the results were disastrous. We can not go back to pristine conditions and we can not stand still with a semi-degraded environment. We now have ample archeological and historic evidence from southwestern Asia of the ultimate consequences of degrading shrub/grasslands (Flannery 1969). Time is deceptive in this environment. Observations on degraded sagebrush areas where grazing has been excluded reveal little successional change after 30 or more years of no grazing by large herbivores. These areas are time bombs waiting for wild fires to trigger dynamic successional changes that can lead to further degradation.

Have the basic potentials of the habitat types that encompass the sagebrush/ grasslands changed with a century of excessive grazing? We have suggested that the plant communities have been irrevocably changed by alien plant introduction, but has the potential biomass productivity of specific environments been changed? Many meadows within the sagebrush/ grasslands have been dissected, desiccated, and invaded by shrubs (Cottam and Stewart 1940), but these areas can be rehabilitated (Eckert 1975). The occurrence, origin, and characteristics of vesicular surface horizons in the soils of portions of the sagebrush/grasslands may be evidence of long-term degradation.

The sagebrush/grasslands were born as an ecosystem in a time of general desiccation that followed mountain building at the end of the Tertiary and the beginning of the Quaternary Periods and evolved through the wild climatic fluctuations of the Pleistocene (Axelrod 1950). Since the close of the Pleistocene, this ecosystem has existed a scant 10,000 years in equilibrium with the prevailing climate and only 100 years under the influence of livestock grazing.

The ideas that are expressed, interpreted, and acted on as a result of the conference may well have a significant impact on the sagebrush ecosystem in the 21st century.

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SAGEBRUSH SYSTEMATICS AND EVOLUTION

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Abstract

The name *Artemisia* L. derives from the Greek goddess Artemis and more directly from the Greek queen Artemisia. Linneaus described the genus and 9 species in the mid-18th century. Besser gave a subgeneric framework in the early 1800's. With modifications, his framework is still used. By 1900, most of the contemporarily recognized species of *Artemisia* had been described. The North American sagebrushes comprise the section *Tridentatae* Rydb. Although its taxonomic limits remain in some dispute, section *Tridentatae* is a natural grouping of species based on habit, morphology, anatomy, chemistry, and cytology. Several non-*Tridentatae Artemisias* occur within the sagebrush ecosystems. Compositae in general and *Artemisia* in particular were late arrivals on the flowering plant scene. *Artemisia* likely evolved in Eurasia with many of its *Anthemideae* relatives. However, the phylogenetically advanced section *Tridentatae* probably arose *in situ* in North America from less specialized *Artemisias* that had migrated from Eurasia.

Introduction

Artemisia L. is a genus containing more than 200 species (de Candolle 1837, Willis 1973, Bailey Hortorium Staff 1976). The genus not only includes the sagebrushes, which give this symposium its name, but also the wormwoods and southernwoods of the Old World and the herbaceous circumboreal mugworts (Grieve 1931, Bailey Hortorium Staff 1976). *Artemisias* are important plants that occur as dominants in their associations over vast areas--principally in the northern extratropical latitudes (Boissier 1875, Wulff 1943, Beetle 1960, Polyakov 1961, Good 1974, McArthur and Plummer 1978, McArthur *et al.*, *in press*).

Artemisias are used for browse production (USDA Forest Service 1937, Larin 1956, Plummer *et al.* 1968, Hanks *et al.* 1971 and 1973, and Scholl *et al.* 1977) soil stabilization (McArthur *et al.* 1974, Monsen 1975, Plummer 1977), drug production (Grieve 1931, Geissman and Irwin 1974, Rodriguez *et al.* 1976), landscaping (McArthur *et al.*, *in press*), and food and drink flavoring (McArthur *et al.*, *in press*). They are also useful for predicting site potential (Stevens *et al.* 1974). Early Eurasian and American Indian peoples regarded *Artemisias* as having medicinal properties. On the other hand, some *Artemisias* cause hay fever and allergenic reactions (Rodriguez *et al.* 1976). Some may become unproductive closed stands on ranges (Plummer *et al.* 1955, Frischknecht *in press*, Gifford *et al.*, *in press*); some may have allelopathic properties (Schlatterer and Tisdale 1969, Halligan 1975, Friedman *et al.* 1977, Weaver and Klarich 1977).

In this paper, I review the systematic history of the sagebrushes, comment on the naturalness of sagebrush classification systems, and give evidence on the origin of sagebrushes and on their relationships with other *Artemisias*. The sagebrushes are woody plants endemic to western North America. They belong to section *Tridentatae* Rydb. Occasionally, other woody *Artemisias*, such as *A. spinescens* and *A. filifolia* are called sagebrushes. In this paper, I refer to only the *Tridentatae* as sagebrushes. I favor using "sage" but omitting the "brush" portion of the names for non-*Tridentatae Artemisias*, such as sand sage for *A. filifolia* and bud sage for *A. spinescene*.

I think it is appropriate for this symposium, with its emphasis on manipulation and management of sagebrush, to address sagebrush systematics. The time is past when all sagebrushes can be considered "just" sagebrush. The various kinds of sagebrush are valuable or pestiferous in different degrees and in various locations; hence, management strategies for each taxon should be different (Winward 1970, Brunner 1972, Schlatterer 1973, Plummer 1977, Winward and Tisdale 1977, McArthur and Plummer 1978, McArthur *et al.*, *in press*).

Artemisia

Origin of the name

Artemisia is a distinguished name--an etymological descendant of an early Mother Nature. Artemis was the ancient Greek goddess of wild animals, the hunt, and vegetation, and of chastity and childbirth. She was the twin sister of Apollo; her Roman name was Diana. Naturally enough, her name was given to plants useful in gynecology. Mugwort (*A. vulgaris* L.) was one of these (André 1956). Linneaus (1778) gave the genus the formal generic name *Artemisia*; perhaps in honor of

Table 1. -- Besser's sections of Artemisia

Name	Derivation	Floral Criteria	
Abrotanum	Greek word for Aromatic[1/]	Fertile ♀ ray + ☿ disc	glabrous receptacle
Absinthium	Greek name for A. absinthium L.[2/]	Fertile ☿ ray + ☿ disc	long, hairy receptacle
Dracunculus	Greek word for little dragon[1/]	Fertile ☿ ray + ♂ disc	glabrous receptacle
Seriphidium	Greek name for A. caerulencens L.[2/]	No ray	☿ disc glabrous receptacle

1/ Neilson et al. 1950
2/ André 1956

Table 2. --Principal subgenera and sections of Artemisia [1/]

Besser's Treatment	Rydberg's Treatment		Polyakov's Treatment		
Sections	Subgenera	Sections	Subgenera	Sections	No. of Series
Abrotanum Bess.	Abrotanum	(Bess.) Rydb.	Artemisia L.		
		Annuae		Artemisia	6
		Klotzchianae		Stelleriana	-
		Glomeratae		Abrotanum	13
		Novegicae		Absinthium	10
		Franseriodes		Artanacetum	-
		Vulgares			
		Gnaphalodes			
		Stellerianae			
		Discolores			
		Wrightanae			
		Ponticae			
		Rutaefoliae			
		Bigelovianae			
Absinthium DC.	Absinthium	(DC) Rydb.			
		Frigidae			
		Lanatae			
Dracunculus Bess.	Dracunculus	(Bess.) Rydb.	Dracunculus	(Bess.) Rydb.	
		Dracunculoides		Dracunculus	
		Filifoliae			
Seriphidium Bess.	Seriphidium	(Bess.) Rydb.[2/]	Seriphidium	(Bess.) Rydb.	
		Tridentatae		Seriphidium	11
		Rigidae		Junceum	2
		Pygmaeae			

1/ Besser's studies (1929) and Besser in de Candolle (1837) and Hooker (1840) treated the genus in a worldwide context. Rydberg's (1916) and Polyakov (1961) treatments were limited to native, naturalized, and cultivated plants in North America and in the U.S.S.R., respectively. However, if a taxon met these distributional criteria, the author involved discussed it on a worldwide basis.

2/ *Artemisiastrum* Rydb., a new genus, was created to house *A. palmeri*.

the goddess, but more directly in honor of Artemisia, queen of Caria, a part of Anatolia (Gleason 1952). Queen Artemisia (ca. 350 BC) was known as a botanist and a medical researcher. A plant genus is not all that honors her memory. She built in her capital city of Halicarnassus (the modern Bodrun, Turkey) one of the seven wonders of the ancient world, a magnificent tomb for her husband and brother--Mausolus, the Mausoleum (Encyclopedia Britannica Committee 1976).

Growth of the genus and subgeneric taxonomy

Linneaus (1753) recognized 9 species of *Artemisia* Besser (1829), the Russian taxonomist, began a comprehensive monograph on the genus early in the 19th century. He divided *Artemisia* into 4 sections based on various combinations of disc and ray flower presence and fertility (Table 1). Although he died before his monograph was completed, much of his work was included in de Candolle (1837) and Hooker (1840). Besser listed nearly 200 species in the sections *Abrotanum* Bess., *Absinthium* DC., *Dracunculus* Bess., and *Seriphidium* Bess. De Candolle had previously described *Absinthium* (Persson 1974). Besser's sections have, in the main been retained, although Rydberg (1916) elevated them to subgenera and created subordinate sections, and Polyakov (1961) reunited *Abrotanum* and *Absinthium* into the subgenus *Artemisia* L. (Table 2, Persson 1974).

Torrey and Gray (1843) listed 34 species and 21 varieties of *Artemisia* that were native (most) or naturalized (a few) in North America. Rydberg (1916), a taxonomic splitter, recognized 120 North American *Artemisia* species. Hall and Clements (1923), in a much more conservative treatment, recognized 29 species in North America. Present consensus on the number of North American *Artemisias* lies somewhere between these two extremes (Fernald 1945, Keck 1946, Estes 1968, Cronquist 1974).

The sagebrushes (Section *Tridentatae*)

The most important North American *Artemisias* are the sagebrushes. These are the 20 or so taxa of section *Tridentata* (Figure 1). In 1814, Pursh described the first *Tridentatae* species, *A. cana* Pursh, from material collected in 1804 by the Lewis and Clark expedition (Torrey and Gray 1843, Rydberg 1916). Nuttall (1841) described two wide-ranging species, *A. tridentata* Nutt. and *A. arbuscula* Nutt., in the early 1840's. He also described *A. rigida* (Nutt.) Gray under the name of *A. trifida* ssp. *rigida* Nutt. (Nuttall 1841). No new taxa were discovered until the 25-year period, 1876-1900, when Asa Gray, Aven Nelson, George E. Osterhout, and Per Axel Rydberg named the taxa we know today as *A. cana* Pursh ssp. *bolanderi* (Gray) Ward, *A. rothrockii* Gray, *A. longiloba* (Osterhout) Beetle, *A. nova* Nelson, *A. tripartita* Rydb. and *A. pygmaea* Gray (Figure 1, Rydberg 1916). Rydberg (1916), in the North American Flora, gave a systematic treatment of *Artemisia*. He elevated Besser's *Seriphidium* to subgeneric status and created within it the sections *Tridentatae*, *Rigidae*, and *Pygmaeae*. Rydberg's framework has served subsequent workers well (Figure 1). Hall and Clements (1923), Ward (1953), and Beetle (1960) have made monographic treatments of the *Tridentatae*. Beetle's (1960, and Beetle and Young 1965) treatment is followed by most modern workers such as Geissman and Irwin 1974, Garrison *et al.* 1976. Several subspecific taxa are now recognized in the species *A. arbuscula*, *A. cana*, *A. tridentata*, and *A. tripartita* (Figure 1).

Recently, further modification of and changes within *Tridentatae* have been made. Winward (1970) and Winward and Tisdale (1977) discuss a variant *A. tridentata* "x," which they have not formally named but which is closely allied to *A. tridentata* ssp. *vaseyana* (Rydb.) Beetle. Unlike typical *vaseyana*, form "x" has an uneven top. Form "x" is generally found at lower elevations. Hanks *et al.* (1973) characterized a low elevation *A. tridentata* ssp. *vaseyana* that may be analogous to form "x." Brunner (1972) listed several undescribed sagebrushes from his studies in Nevada. Typical *A. rothrockii* grows in the Sierra Nevada and its outliers. However, *A. rothrockii* has been reported in the Rocky Mountains (Beetle 1960, McArthur *et al., in press*). Some authors (Cronquist 1974, Winward 1975, Winward and Tisdale 1977) suggest the Rocky Mountain material may not be *A. rothrockii* but an undescribed variant of *A. tridentata*. The Rocky Mountain material is diploid, $2n = 18$, whereas the Sierra Nevada material is polyploid, $2n = 36$, 54, and 72 (Ward 1953, McArthur and Plummer 1978). Perhaps at some future date, critical studies will establish new taxa at the species level and below. However, for the present, I believe (with the possible exception of the Rocky Mountain *A. rothrockii*) that plants can be fitted into Beetle's classification scheme (Beetle 1960, Beetle and Young 1965). Further taxonomic splitting could get out of hand since the experienced observer can often see *Tridentatae* population differences. We (Welch *et al.* 1977, McArthur and Welch 1978) have noted differences in growth rate and protein content at the population level of *A. tridentata* and its subspecies.

Limits of Tridentatae

Beetle's (1960) treatment of the *Tridentatae* is a liberal one including as it does *A. bigelovii*, *A. pygmaea*, and *A. rigida*. *Artemisia bigelovii* had been considered to be part of section *Abrotanum* (or subgenus *Artemisia*) because its floral heads include 0 to 2 ray flowers in addition to disc flowers. Using chromatographic criteria, Holbo and Mozingo (1965) thought *A. bigelovii* was best retained in *Abrotanum*, whereas Hanks *et al.* (1973) and Geissman and Irwin (1974), also using chromatographic criteria, gave evidence for including it in *Tridentatae*. Moss's (1940) studies, based on presence and abundance of interxylary cork, support a position in *Tridentatae* for *A. bigelovii*. *Artemisia pygmaea* is another species that has been placed in and out of *Tridentatae* (Figure 1). Although Beetle (1960) placed it in the section, he is inclined to exclude it now (personal communication). Holbo and Mozingo (1965) and Geissman and Irwin (1974) gave evidence for placing it outside the *Tridentatae*. Moss (1940) contrariwise gave evidence for its inclusion. My own opinion is that if *A. pygmaea* is not a bona fide *Tridentatae*, it is more closely allied to that section than to any other in the genus. Before a definitive answer can be given, more study is needed. Since Rydberg's time, *Artemisia rigida* has been included in the *Tridentatae* (Hall and Clements 1923, Moss 1940, Ward 1953, Beetle 1960, Geissman and Irwin 1974), except by Holbo and Mozingo (1965). Our chromosome studies (McArthur and Plummer 1978 and unpublished) support its inclusion in *Tridentatae*. Beetle (*in press* and personal communication) recently suggested that *A. filifolia* Torr. belongs in the *Tridentatae*. This novel suggestion will take time to evaluate. However, Moss's (1940) work on interxylary cork doesn't support such a section transfer.

Figure 1.--Development of Section Tridentatae[1/]

Beetle (1960) Beetle and Young (1965)	Ward (1953)	Hall and Clements (1923)	Rydberg (1916)	
A. arbuscula Nutt. ssp. arbuscula	A. arbuscula ssp. arbuscula	A. tridentata ssp. arbuscula (Nutt.) H&C.	A. arbuscula	
A. arbuscula Nutt. ssp. thermopola Beetle	-	-	-	
A. argilosa Beetle	-	-	-	
A. cana Pursh ssp. cana	A. cana ssp. cana	A. cana	A. cana	
A. cana Pursh ssp. bolanderi (Gray) Ward	A. cana ssp. bolanderi	A. tridentata ssp. bolanderi (Gray) H&C	A. bolanderi Gray	
A. cana Pursh ssp. viscidula (Osterhout) Beetle	A. cana ssp. cana	A. cana	A. cana	
A. longiloba (Osterhout) Beetle	A. speciformis var longiloba Osterhout	-	-	
A. nova Nelson	A. arbuscula ssp. nova (Nelson) Ward	A. tridentata ssp. nova (Nelson) H&C	A. nova	
A. rothrockii Gray	A. rothrockii	A. tridentata ssp. rothrockii (Gray) H&C	A. rothrockii	
A. tridentata Nutt. ssp. tridentata	A. tridentata ssp. tridentata	A. tridentata ssp. typica	A. tridentata	
A. tridentata Nutt. ssp. tridentata	A. tridentata ssp. tridentata	A. tridentata ssp. typica	A. angusta Rydb.	
A. tridentata Nutt. ssp. tridentata f. parishii (Gray) Beetle	A. tridentata ssp. parishii (Gray) H&C	A. tridentata ssp. parishii	A. parishii Gray	
A. tridentata Nutt. ssp. vaseyana (Rydb.) Beetle	A. tridentata ssp. tridentata	A. tridentata ssp. rothrockii (Gray) H&C	A. vaseyana Rydb.	
A. tridentata Nutt. ssp. vaseyana (Rydb.) Beetle f. spiciformis (Osterhout) Beetle	-	A. tridentata ssp. rothrockii (Gray) H&C	A. spiciformis Osterhout	
A. tridentata Nutt. ssp. wyomingensis Beetle and Young	-	-	-	
A. tripartita Rydb. tripartita	A. tripartita	A. tridentata ssp. trifidia (Nutt) H&C	A. tripartita	
A. tripartita Rydb. ssp. rupicola Beetle	-	-	-	
A. pygmaea Gray	A. pygmaea	A. pygmaea	A. pygmaea	TRIDENTATA PYGMAEAE
A. rigida (Nutt.) Gray	A. rigida	A. rigida	A. rigida	RIGIDAE
A. bigelovii Gray	A. bigelovii	A. bigelovii	A. bigelovii	ABROTANUM

1/ Rydberg (1916) and Beetle (1960) used section Tridentatae whereas Hall and Clements (1923) and Ward (1953) referred to North American members of the section Seriphidium.

2/ Some of Beetle's (1960) Tridentatae species were assigned to other sections by earlier workers.

When Rydberg (1916) created section *Tridentatae*, he included it in *Seriphidium*, which he elevated from sectional to subgeneric rank. Since that time, the sagebrushes have been treated as *Tridentatae* or alternatively, by those who preferred to follow Besser, as North American *Seriphidia*. We (McArthur and Plummer 1978) pointed out several compelling reasons favoring *Tridentatae*, including present and evident past distributional patterns, karyotypes, and chemistry.

Other *Artemisias* in the sagebrush ecosystems

Several nonsagebrush (=non-*Tridentatae*) *Artemisias* occur within sagebrush ecosystems (McArthur *et al.*, *in press*). *Artemisia frigida* Willd. and *A. ludoviciana* Nutt. of the subgenus *Artemisia* are quite common. *A. ludoviciana* is an herbaceous perennial, whereas *A. frigida* has a woody base and is regarded as a low shrub or subshrub. These species differ from the *Tridentatae* in their floral morphology (Table 1) and stem anatomy (Moss 1940). Another subgenus *Artemisia* species, *A. californica* Less., occurs on the southwest fringe of *Tridentatae* distribution. This shrubby species differs from the *Tridentatae* in the same floral and stem characteristics that *A. frigida* and *A. ludoviciana* do. *Artemisia dracunculus* L., *A. filifolia*, *A. pedatifida* Nutt., and *A. spinescens* Eaton are members of subgenus *Dracunculus* that are common in places in the sagebrush ecosystems. The last three are shrubs, but *A. dracunculus* is herbaceous. All differ from the *Tridentatae* in floral characteristics. The wood anatomy is not consistent within this group (Moss 1940). *Artemisia spinescens* is anomalous because it is deciduous and spring flowering. Nuttall (1841) originally placed it in the monotypic genus, *Picrothamnus*.

Classification Systems and Phylogeny of *Artemisia*

Tribe *Anthemideae* of Compositae

The Compositae are a natural plant grouping even though they are diverse and comprise the largest family of flowering plants (Cronquist 1955, Carlquist 1966, Wagenitz 1976, Cronquist 1977). Among the angiosperms, the Compositae were late arrivals. It was only in midtertiary time that the family began to play a major role in the earth's vegetation (Raven and Axelrod 1974, Wagenitz 1976). Raven and Axelrod (1974) postulate an origin of the family in northern South America because the primitive generalized tribes *Heliantheae* and *Mutisieae* are concentrated there (Table 3). Regardless of its place of origin, the family quickly (geologically) radiated out. Wagenitz (1976) suggested that its principal evolution and diversification took place in xeric environments and in tropical mountains. In general, the family's migrations were achieved with the continents close to their present positions (Raven and Axelrod 1974). The great Eurasian and North African landmass is the center of diversity for several of the tribes, including *Anthemideae* (Table 3). This tribe is one of the more advanced parts of Compositae (Cronquist 1955). Likely, much of its development occurred in Eurasia.

Table 3. -- Compositae tribes with centers of diversity.[1/]

Tribe	Number of Genera	Number of Species	Center of Diversity
Anthemideae Cass.	50	1,000	Eurasia & North Africa
Arctoteae Cass.	20	200	Eurasia
Astereae Cass.	100	2,000	Cosmopolitan
Calenduleae Cass.	10	160	Eurasia & North Africa
Cardueae Cass.	50	1,500	Eurasia & North Africa
Cichorieae Dumort	75	1,000	Eurasia
Eupatorieae Cass.	50	2,050	Tropical N. & S. America
Helenieae Benth. & Hook.	60	600	N. America
Heliantheae Cass.	150	2,000	N. & S. America
Inuleae Cass.	300	2,000	N. & S. America
Mutisieae Cass.	55	500	S. America
Senecioneae Cass.	50	2,000	Cosomopolitan
Veronieae Cass.	50	1,400	N. & S. America, Africa

1/ Data from Bailey Hortorium Staff 1976.

Table 4. -- Distribution of principal Anthemideae genera.[1/]

Genus	Number of Species	Distribution
Achillea L.	80	Eurasia
Anacyclus L.	20	Mediterranean area
Anthemis L.	100	Mediterranean area & Near East
Artemisia L.	200	Mostly temperate N. Hemisphere, a few S. America and S. Africa
Athanasia L.	40	S. Africa
Chrysanthemum L.	150	Mostly Eurasia, a few in S. Africa
Cotula L.	60	S. Hemisphere, mostly New Zealand
Eriocephalus L.	30	S. Africa
Matricaria L.	35	Eurasia, S. Africa, Western N. America
Tanacetum L.	50	Eurasia
Tripleurospermum Schultz-Bip.	25	Europe, W. Asia
Ursina Gaertn.	40	S. Africa

1/ Data from Bailey Hortorium Staff 1976

Genus *Artemisia* of the tribe *Anthemideae*

Artemisia is a well-defined genus. Attempts to establish other genera by segregation have not been successful (Hall and Clements 1923, Holmgren *et al.* 1976). Its closest relatives are the large Old World genus *Tanacetum* and the small western North American genus *Sphaeromeria* (Hall and Clements 1923, Holmgren *et al.*1976). *Artemisia* probably had its origin in Eurasia because it is most diversified there (Hall and Clements 1923, Beetle 1960, Polyakov 1961, McArthur and Plummer 1978). Many of its close relatives are found there (Table 4). The North American members of *Artemisia*, including the sagebrushes, are likely derivatives of subgenus *Artemisia* and subgenus *Dracunculus* plants that bridged Beringia from Asia to North America. Some species, such as *A. frigida* and *A. dracunculus* naturally occur in both areas. Axelrod (1950, 1958, 1975) gave *Artemisia* little prominence in geologically earlier North American floras.

Section *Tridentatae* of the genus *Artemisia*

This group of plants is accepted as a natural assemblage (Ward 1953, Beetle 1960) alghough its exact limits remain in doubt (Figure 1, Holbo and Mozingo 1965, Geissman and Irwin 1974, Beetle *in press*). The *Tridentatae* are distinguished by their woody habit, floral morphology, stem anatomy, plant chemistry, and chromosomal karyotype (Moss 1940, Kelsey *et al.* 1973, Giessman and Irwin 1974, McArthur and Plummer 1978). They likely arose *in situ* from the more primitive subgenus *Artemisia* in North America when a vacillating climate repeatedly gave them opportunity to fill large new niches (McArthur and Plummer 1978). Hall and Clements (1923) and Hanks *et al.* (1973) thought the *Tridentatae* derived from *A. bigelovii* or *A. bigelovii*-like stock. *A. bigelovii* was included in section *Abrotanum* (subgenus *Artemisia* by Rydberg (1916), Hall and Clements (1923), and Ward (1953) since many flower heads include ray as well as the usual disc flowers (Table 1). However, each of these monographers was careful to point out *A. bigelovii's* closeness to *Tridentatae* in leaf morphology and growth habit. Other investigators have shoen similarities in phenolid and terpenoid chemistry (Hanks *et al.* 1973, Geissman and Irwin 1974) and stem anatomy (Moss 1940). *A. bigelovii* grows in the southeastern quarter of section *Tridentatae's* present distributional range (McArthur and Plummer 1978). If it or an early ally were the ancestral stock of *Tridentatae*, then the section probably reached its present distributional limits from an arid southern source. Winward (1975) and Beetle (personal communication), on the other hand, argue that the modern *Tridentatae* evolved from a mesic ancestor, possibly from *A. tridentata* ssp. *vaseyana*. This taxon is more common at northern latitudes and higher elevations.

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AUTECOLOGY OF SELECTED WOODY SAGEBRUSH SPECIES[1]

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Abstract

For the Section Tridentatae of Artemisia the southern A. bigelovii is rejected as either primitive or the progenitor. Instead the mesophytic mountain species, A. rothrockii, A. cana subsp. viscidula, and A. tridentata subsp. vaseyana are thought to be more nearly representative of the original matrix. Other species and subspecies are edaphic adaptations to increasing drought.

Classification is the first step in the autecological studies of sagebrush and the most important. If we cannot agree on the correct identification of populations we have no basis for answering questions about origin, dominance, invasion, and management.

Range Manager's Field Notes

From the range manager's point of view, the proper identification of sagebrush is both demanding and rewarding. Field studies show that most stands are relatively uniform in respect to:

a) production of sesquiterpene lactones, or other chemicals (Hanks et al., 1973);

b) growth form, including ability to layer (Ward, 1953);

c) color, often a function of pubescence (Beetle, 1960);

d) phenology (McArthur et al., 1978);

e) edaphic relationships (Thatcher 1959, Robertson et al. 1966, Zamora 1968);

f) insect depredation (Fronk et al. 1964, Gates 1964);

g) palatability (Sheehy, 1975).

Consistency of stand is characteristic of all the recognized species and subspecies. For 80 to 90 percent of their areas identifying characteristics are so consistent as to require some sort of taxonomic designation be given. The present field classification used by range managers and based on these prevalent stands, is not influenced by the presence, in limited areas, of integration or of hybrids (Beetle 1960, Passey and Hugie 1962, Holbo and Mozingo 1965, Brunner 1972, Morris et al. 1976, Winward and Tisdale 1977).

Herbarium classifications are based on the samples deposited therein which may be more representative of oddities or hybrids than they are of populations.

Admittedly, if a species definition is based on finding integration (no matter how incidental) or of finding gene interchange, or of finding hybrids (no matter how little they influence the composition of the total population) then the taxonomic designations are going to be different than those based on field studies emphasizing predominant characteristics only (Beetle 1971).

Paleobotanical Origin

Sectional treatments of Artemisia have been based on the relative functionality of the ray and disk flowers. Apparently, under the influence of Bessey (1897) all the plants with the most complete (i.e. the most functional flowers, both ray and disk) were considered primitive without regard to growth form. Not only Hall and Clements (1923), but also Ward (1953) considered A. bigelovii as primitive. Beetle (1960) suggested that one of the progenitors of Artemisia arrived from the Old World in the Cretaceous. The reasoning was that the greater presence and diversity of woody species in the Old World suggested this as a place of origin, and the segregation of both species and subspecies seemed to suggest a long time period.

Artemisia is a genus of the Compositae. This

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johnny-come-lately family is now well represented in the fossil record. According to Raven and Axelrod (1974) "No fossil pollen of the vast family Asteraceae is known prior to the uppermost Oligocene, despite extensive search, and pre-Miocene records are exceedingly few. ****No Asteraceae have what appears to be a distribution achieved by direct migration between Australia and southern South America, suggesting with other evidence no more than a mid-Oligocene age for the family. The migration of Asteraceae, consisting of many very readily dispersed genera, must therefore be seen in the light of present geography. Primitive Heliantheae and Mutisieae, the most generalized tribes, are concentrated in northern South America, which may be a likely place of origin for the family. Considering that the family is in the Lower Miocene in New Zealand, northern South America, Nigeria, and eastern Asia, and rapidly increases in abundance in all areas, and that the tribe Cichorieae appears in the Upper Miocene in nearly all areas that have been sampled, dispersal must have been extremely rapid. Asteraceae have rapidly produced many genera and species in response to the worldwide expansion of semiarid and subhumid habitats in Neogene time and subsequently".

Raven and Axelrod (1974) have suggested that the origin of family Compositae was mid-Oligocene and very possibly in the New World. In the light of this evidence, the time schedule for origin and dispersal of species of the Section Tridentatae must be revised and some representatives of the genus Artemisia must spread from the New World to the Old World. Here is an obvious state-of-the-art confusion.

On the other hand, the "response to the worldwide expansion of semiarid and submumid habitats in Neogene time and subsequently", which Raven and Axelrod describe for the family very well, could also be equally descriptive of the Section Tridentatae of Artemisia.

The present thought is that during plural periods in the past a mesic form of sagebrush, one that layered rather easily, and one that had a tendency to woody stems, achieved widespread distribution throughout the West without regard to the continental divide as a barrier.

Whether this prototype led to the derivation of some of the more isolated and unique shrubby species such as A. filifolia, A. pygmaea and A. palmeri remains to be determined but seems to be a distinct possibility. However, a single progenitor does not seem to have been responsible for both the Section Tridentatae and all the other alpine dwarfs, plains biennials, and forest margin herbaceous perennials.

Distribution

The Section Tridentatae of Artemisia is without question a group characteristic of the Great Basin. The most primitive species, A. rothrockii, and its most immediate derivatives, A. cana subsp. viscidula and A. tridentata subspecies vaseyana occupy the mesic mountain habitats scattered throughout and surrounding the Great Basin, and would seem to owe their fragmented range to the development of the Great Basin.

Increasing aridity associated with Great Basin origin then led to the evolution of five types which occupy varied edaphic situations within the Basin proper:

1) A. nova - shallow soils

2) A. longiloba - tight soils

3) A. rigida - scab lands

4) A. tridentata subsp. tridentata - recent alluvium of some depth

5) A. arbuscula subsp. arbuscula - glacial tills

Furthermore, the development of the continental divide seems to have led through geographic isolation to the separation of 1) Artemisia cana subsp. cana from A. cana subsp. bolanderi, 2) A. tripartita subsp. tripartita from A. tripartita subsp. rupicola.

Disclimax Invasion or Edaphic Climax

Vale (1975) has summarized the written record about the so-called "presettlement vegetation" in the sagebrush-grass areas of the Intermountain West. He concluded "the major area of the Intermountain West was covered, not by grass, but by thick stands of brush, when the first Europeans began probing those unknown regions". He further reaches from his Department of Geography position at the University of Wisconsin the same conclusions that many range managers have reached from more immediate observations. To quote again from Vale (1975) "The original condition of the range has implications for management. As brush was abundant in times prior to livestock grazing, its dominance of the vegetation today cannot always be considered evidence of overgrazing. Moreover, attempts to eradicate brush and encourage pure stands of grass cannot be justified in terms of reestablishing the 'natural' plant cover. Grazing has caused an increase in the density of brush in many areas, but woody shrubs were an important, perhaps a dominant, component of the pristine ranges of the semiarid west".

Sagebrush species and subspecies behave on the range as increasers. As such they occur as shrub dominants, or sometimes in savanna situations, as co-dominants and exhibit such a remarkable sensitivity to the substrate that they represent in all cases a community which is an edaphic climax.

Conclusions

What is the state of the art regarding the autecology of the Tridentatae of Artemisia?

1) Data from various unrelated research problems such as habitat, chemistry, insect vulnerability, and the like, are strengthening rather than weakening the present taxonomic dispositions within the Section.

2) The proper limits of the Section within the overall framework of Artemisia are not yet clearly established -- e.g. the inclusion or exclusion of Artemisia filifolia, A. pygmaea, A. palmeri, and others.

3) A time schedule of evolutionary origin coordinated with the fossil evidence and geologic history is very illusive.

4) Mesophytic and layering mountain forms of sagebrush are the most primitive (see Table 1).

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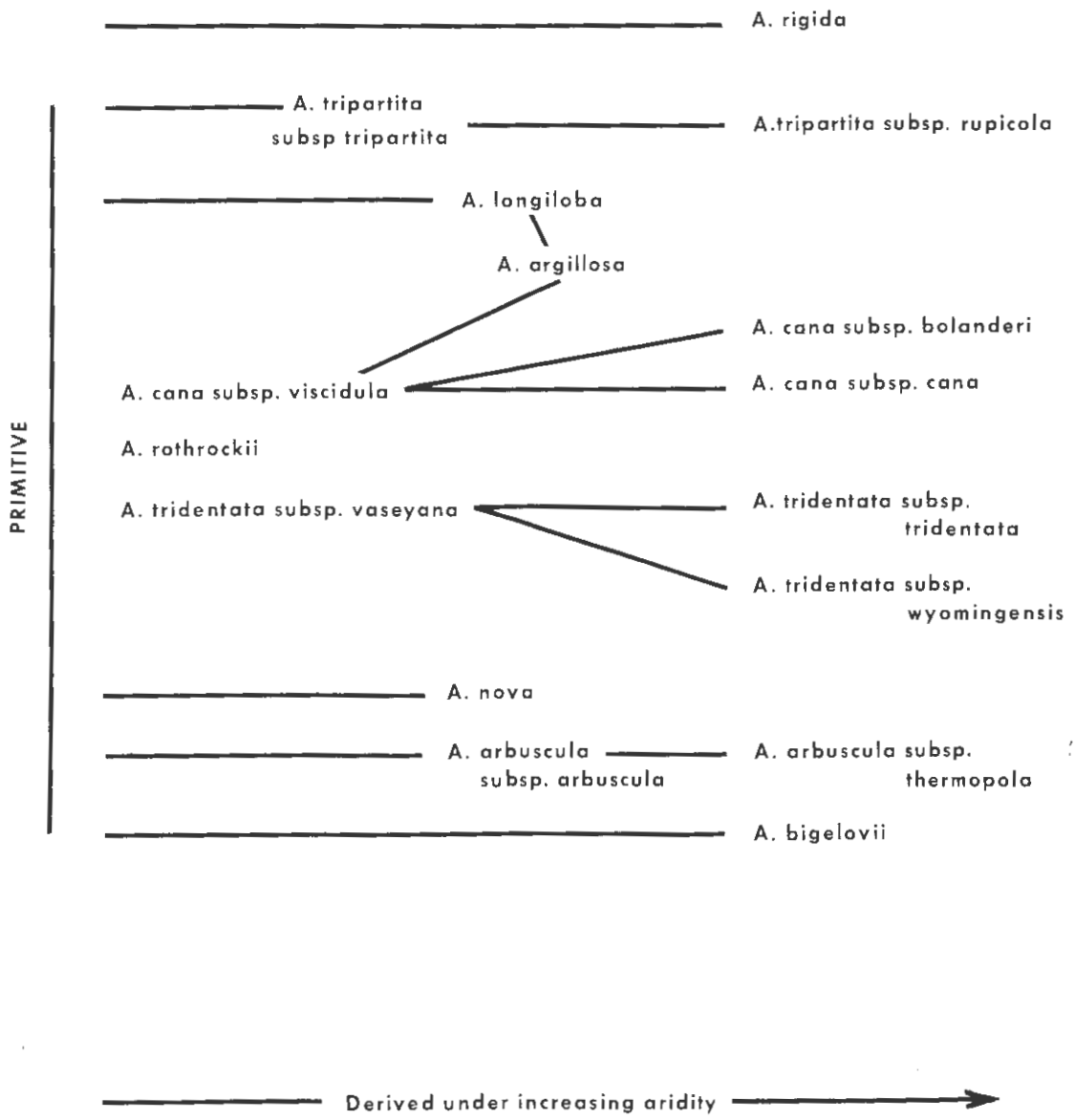
ARTEMISIA # TRIDENTATAE



Basic Synecological Relationships of the Columbia River Sagebrush Type

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INTRODUCTION

The Columbia River sagebrush region includes more than 31.8 million hectares (78 million ac) in Idaho, Oregon and Washington (Beetle 1960). Beetle's estimate appears high as the earlier estimate (USDA/FS 1936) for the entire sagebrush region was 39 million hectares (96.5 million ac). More recent estimates indicate that Idaho and Washington have less than 15 million hectares (Tisdale et al. 1969, Daubenmire 1970), and Oregon's sagebrush area is 25 percent less than Idaho's (Beetle 1960). More recent estimates indicate that the total area for the Columbia River sagebrush region is about 20 to 22.5 million hectares (50 to 55 million ac). This is nearly 30 percent of the area of the entire sagebrush region in the 11 western states (Beetle 1960).

PHYSICAL FACTORS

The environment in which sagebrush species grow varies tremendously from one end of the region to the other. The elevational range for the region is from less than 250 m (800 ft) along the Columbia River in Washington (Daubenmire 1970) to more than 3300 m (10,000 ft) in Idaho (Schlatterer 1972). Most precipitation comes during the winter, in the form of snow and freezing rain. Precipitation as low as 150 mm supports woody *Artemisia* in Washington (Daubenmire 1970), but in Idaho the lower limit is near 200 mm (Tisdale et al. 1969). The upper precipitation limit is about 550 mm before sagebrush gives way to forest. The pattern shifts toward a more continental trend as one travels from west to east. Increase in frequency of summer precipitation is especially noticeable in eastern Idaho.

Soils are of diverse nature as indicated by the wide variety of parent materials involved. Except for the channeled scablands, the Columbia Basin of Washington and the Snake River Plains of Idaho are underlain by the Columbia River Basalt formation and covered by moderate to deep deposits of loess (Tisdale et al. 1969, Daubenmire 1970). The scablands, a vast area in the Columbia Basin, was stripped of its loess mantle by a massive glacial flood, exposing the once-covered basalt flows (Franklin and Dryness 1969, Daubenmire 1970, USDI/GS-1973). The terrain of the Columbia Basin and the Snake River Plains is rolling to hilly.

In the high plains of Oregon, the parent material is highly diverse and includes alluvial and lacustrine deposits as well as basalt, andesite, and tuff, all of fairly recent origin (Eckert 1957, Franklin and Dryness 1969). The Owyhee uplands extend into southwestern Idaho and contain much rhyolite and basalt. Except for the mountain mass of granite along its northeastern perimeter, the Owyhee plateau is predominately of silicic volcanics of welded tuff and rhyolites, with mixtures of basalt flows that are older than those that underlie the Snake River Plains (Tisdale et al. 1969).

To the north of the Snake River Plains is the massive Idaho batholith formation, a granitic intrusion that develops well-drained, highly erosive, coarse textured soils. Monzonite is a common rock type in the batholith. To the east of the batholith and extending southward into Utah, the mountain ranges are primarily of sedimentary origin, particularly limestone. The physiography is typically basin and range with the mountain alignment being north-south on both sides of the Snake River Plains. The narrow valley floors consist primarily of huge overlapping alluvial fans that extend deeply to the center of the valley from both sides. Precipitation in these high dry valleys is often below 150 mm due to the rain shadow effect.

WOODY SAGEBRUSH SPECIES

This extensive and varied region supports a number of woody *Artemisia* species. Twelve species and subspecies occupy 99 percent of the Columbia River sagebrush region (Beetle 1960, Beetle and Young 1965, Winward 1970, Winward and Tisdale 1977) of which only five occur in appreciable amounts in all three states. The species and subspecies common to Idaho, Oregon and Washington are: *A. tridentata, A. vaseyana, A. wyomingensis, A. rigida,* and *A. arbuscula.* Those that are restricted to individual states are: *A. spiciformis* in Idaho; *A. cana* subsp. *bolanderi* in Oregon; none is restricted to Washington. *Artemisia tripartita* is lacking in Oregon but occurs in both Idaho and Washington. *Artemisia longiloba, A. nova, A. 'xericensis'* (Type 'X' in Winward and Tisdale 1977), and *A. cana* subsp. *viscidula* occur in Idaho and Oregon.

A. tridentata Complex

Prior to Beetle's (1960) work, the species *A. tridentata* included nearly all sagebrush species that had a stature of 50 cm or greater. The distributional range of this species was extremely broad, growing in areas where the precipitation was as low as 150 mm at 250 m in elevation to subalpine condition with precipitation in excess of 550 mm and elevations as high as 3500 m. The recognition and identification of two subspecies (Beetle 1960) and later of a

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third in the *A. tridentata* complex (Beetle and Young 1965), helped tremendously in understanding the distribution of major sagebrush communities in relation to environment.

Except for Winward and Tisdale's (1977) distributional map of *A. wyomingensis* and *A. tridentata* in Idaho, there is little information concerning the extent of these subspecies. There is some difficulty in field identification because of interbreeding and the broad continuous variation in morphological and physiological properties including palatability, shrub height and form, leaf shape and size and response to disturbance (Hanks et al. 1971, Brunner 1972, Winward and Tisdale 1977).

SAGEBRUSH DISTRIBUTION

In the Pacific Northwest region, we find that some sagebrush species tend to occur in vegetation units that are confined to the northern or southern half of the region, and others occur in restricted sectors. For example, *A. wyomingensis* occurs extensively in southern Idaho and adjacent southeast Oregon, but not in the Columbia Basin to the north. Interestingly, this subspecies is lacking in the northern Great Basin and recurs in the southern half of Utah and Nevada where the climate is warmer and drier (McArthur and Pope 1975, West et al. 1975).

Artemisia tripartita has an interesting distribution pattern. It is confined primarily to eastern Idaho, western Wyoming, Montana and Washington (Beetle 1960). It does not extend south into Utah and Nevada nor west into Oregon.

Artemisia rigida has basically a northern distribution, being replaced by *A. arbuscula* in the south on similar soils. *Artemisia rigida*, a deciduous dwarf species, is well adapted to the scabland soils in Washington (Daubenmire 1970) and is the only woody *Artemisia* that occurs in the Palouse grasslands.

Artemisia nova is near its northern limit as a vegetation type in eastern Idaho and is restricted to limestone derived soils. This species is absent in southwestern Idaho, probably because limestone is lacking, whereas its absence in Washington is probably due to lack of limestone derived soils and/or short day-lengths in the winter.

Artemisia arbuscula occurs in all three states. Its dwarfed stature is in marked contrast to the height of *A. tridentata* or *A. vaseyana*. This species is found in the higher precipitation areas, often forming extensive stands where soil is shallow to bedrock. In earlier range inventories, this species was often mistaken for the more palatable *A. nova*.

SAGEBRUSH-SOILS RELATIONS

The major communities of the Columbia River sagebrush type have been identified and described by a number of ecologists. Their efforts have been presented in publications, unpublished theses and reports (Anderson 1956, Eckert 1957, Culver 1964, Fosberg and Hironaka 1964, Hugie et al. 1964, Franklin and Dryness 1969, Tisdale et al. 1969, Daubenmire 1970, Winward 1970, Dealy 1975, Hauxwell 1977, Hironaka 1977). Numerous studies dealing with the autecological and the management aspect of sagebrush vegetation also include synecological information, but are not included in this paper.

The classification of the sagebrush vegetation based on the habitat type concept permits discussion of this varied vegetation from a polyclimax approach because a climatic climax or zonal approach is not readily applicable. Edaphic considerations are quite important in the distribution of habitat types in the sagebrush region.

A nice orderly sequence of sagebrush habitat types based on a moisture/temperature gradient does not exist. Although there is a general tendency, there are many exceptions. The distribution of habitats in this region is controlled by edaphic factors as much as it is by climate. Furthermore, changes in the understory do not necessarily coincide with overstory change. Nor does the understory composition always abruptly change with a change in sagebrush cover.

The general distribution of sagebrush in the Pacific Northwest is related to soil moisture, temperature, depth and parent material. The overall tendency is for *A. tridentata* to occupy the deep soils, generally with minimal development in the low to moderate precipitation zone, whereas it gives way to *A. wyomingensis* in soils of moderate depth in the low to moderate precipitation zone at the lower elevations. As moisture conditions improve and temperatures moderate, *A. vaseyana* dominates and gives way to *A. spiciformis* on deep soils at high elevations. The relationship of *A. 'xericensis'* is that it dominates in areas of moderate to high precipitation but of low elevations where temperatures are high. As the elevation increases, *A. 'xericensis'* yields to *A. vaseyana*. The extent of *A. 'xericensis'* in Oregon has not been reported. This species does not occur in Washington.

The ecological status of *A. tripartita* remains a puzzle. Its position along the moisture gradient overlaps with the upper portion of *A. wyomingensis* and the lower portion of *A. vaseyana*. It occurs in eastern Washington and eastern Idaho and appears not to be associated with any particular kinds of soil (Hauxwell 1977).

On shallow soils, dwarf sagebrush species replace the tall species of *Artemisia*. The dwarf species are typically less than 30 cm in height. Among the dwarf sagebrush species, *A. nova* occupies the lowermost position along the moisture gradient and is restricted to calcareous or limestone derived soils in the drier areas. It grows in areas where the precipitation is as low as 200 mm, but may also occur in areas where the precipitation is as high as 300 mm and where soils are derived from limestone. In drier situations salt desert shrub vegetation replaces the *A. nova* communities.

Where *A. arbuscula* is in the same locality as *A. nova*, the former consistently occurs in a cooler and higher moisture situation than the latter, even though the difference in moisture may be only a few centimeters. *Artemisia arbuscula* is found in shallow soils in eastern Idaho where the precipitation is less than 250 mm.

While the association between *A. nova* and limestone derived soils is extremely strong in Idaho, *A. arbuscula* is not so restricted. In the Owyhee uplands, the high lava plains of Oregon and the western edge of the Columbia Basin (Beetle 1960), *A. arbuscula* occurs on shallow non-calcareous soils in areas where precipitation ranges from 300-500 mm. The soils that support this *Artemisia* species under these conditions are shallow, strongly-developed, claypan soils. These soils are supersaturated during the spring snow melt period and the plants are under considerable moisture stress during the summer (Eckert 1957, Fosberg and Hironaka 1964). The bimodal response of *A. arbuscula* to two extremely different habitat conditions is not understood. It is possible that we are dealing with two different subspecies or ecotypes.

Artemisia longiloba occurs in habitats similar to those which support *A. arbuscula*. Both occur on shallow soils that have strong claypan development. At times the two species are found in the same stand.

The distribution of *A. rigida* overlaps with *A. arbuscula*, but the former predominates in Washington and northeastern Oregon. The habitats are somewhat similar, but *A. rigida* occupies soils that are generally more shallow and rocky. It appears that *A. arbuscula* requires greater soil depth. Precipitation in the area is quite high,

generally in excess of 350 mm. *Artemisia rigida's* deciduous characteristic appears to provide this species with an ecological advantage over *A. arbuscula* in the higher latitudes.

INVASION BY SAGEBRUSH

There is no evidence that an extensive grassland steppe was present in southern Idaho and adjacent Oregon and that invasion by sagebrush became widespread since the advent of livestock grazing, as suggested by Stoddart et al. (1975). Evidence of a palouse grassland in the sagebrush steppe such as that reported by Stoddart (1941) has not been verified in southern Idaho. The numerous species and subspecies of *Artemisia* that occur in relatively monospecific stands indicate that they are well adapted to the habitats they presently occupy – strong evidence that adaptation was established well before the advent of livestock grazing in the west.

VEGETATION CLASSIFICATION

The habitat type approach is one of many ways to classify vegetation (Shimwell 1971, Mueller-Dombois and Ellenberg 1974). The habitat type (ht) is defined as the aggregate area that supports, or until recent time supported, and presumably is capable of supporting again, the same climax vegetation. The description and nomenclature in naming the habitat type are generally based on the dominants in the climax vegetation (Daubenmire 1968).

One should be aware that a climax community includes considerable variability. The species composition of the climax dominants is basically similar from area to area, but there is considerable variation as to amount and importance of the individual species. Considerable variability in productivity may be encountered because of soil differences from one geographic area to another, while the vegetation retains the same basic climax characteristics. Different soils are capable of supporting the same climax vegetation because of factor compensation (Daubenmire 1968).

Difference in productivity is sufficient ground to recognize separate range sites (and ecological sites) even though species composition may be similar (USDA/SCS 1975). With the habitat type approach, differences in productivity often relegate such communities to phase status and are identified by the occurrence of a selected lesser species of high fidelity (Pfister et al. 1977). There has been no uniform usage of the phase level in habitat type classification, however.

SAGEBRUSH HABITAT TYPES

A list of the major habitat types that occur in the Columbia River sagebrush region is presented in Table 1. One should be reminded that studies of sagebrush vegetation conducted prior to 1960 (Ward 1953) did not recognize subspecies in the *A. tridentata* complex. Subspecies *A. vaseyana* was distinguished in 1960 (Beetle 1960), and it was not until the mid-1960s that subsp. *A. wyomingensis* was distinguished from subsp. *A. tridentata* (Beetle and Young 1965).

Some of the same habitat types found in the Pacific Northwest may be found in Montana, Wyoming, Nevada and British Columbia, Canada (Marchand 1964, Zamora and Tueller 1973, Mueggler and Handl 1974, Brodahl 1977). Apparently identical habitat types which occur in widely separated areas may be only superficially alike. This similiarity may reflect the dominant and co-dominant species, which are used in naming the habitat type. Many of the lesser species do not have widespread distribution and are of lesser importance than the dominants in the classification. The basic assumption, which does not always hold true, is that dominant species have greater influence in the community than the lesser species, and that their influence is similar wherever they have a dominant role.

Table 1. List of sagebrush-grass habitat types reported for Idaho, Oregon and Washington. The nomenclature recognizes, for the most part, important members of the overstory and understory species of the climax community. There is no significance to the order of presentation.

Dwarf Sagebrush Group

1. *A. arbuscula/Agropyron spicatum* (I, O, W)
2. *A. arbuscula/Festuca idahoensis* (I, O, W)
3. *A. arbuscula/Poa sandbergii* (I)
4. *A. longiloba/Festuca idahoensis* (I, O)
5. *A. nova/Agropyron spicatum* (I)
6. *A. nova/Festuca idahoensis* (I)
7. *A. rigida/Poa sandbergii* (I, O, W)
8. *A. thermopola/Festuca idahoensis* (I)

Big Sagebrush Group

1. *A. spiciformis/Bromus carinatus* (I)
2. *A. spiciformis/Carex geyeri* (I)
3. *A. spiciformis/Festuca idahoensis* (I)
4. *A. tridentata/Agropyron spicatum* (I, O, W)
5. *Stipa thurberiana* phase (O)
6. *Festuca idahoensis* phase (O)
7. *A. tridentata/Elymus cinereus* (I, O, W)
8. *A. tridentata/Festuca idahoensis* (I, O, W)
9. *A. tridentata/Poa sandbergii* (O, W)
10. *A. tridentata/Stipa comata* (I, W)
11. *A. tripartita/Agropyron spicatum* (I, W)
12. *A. tripartita/Festuca idahoensis* (I, W)
13. *A. tripartita/Stipa comata* (I, W)
14. *A. 'xericensis'/Agropyron spicatum* (I)
15. *A. 'xericensis'/Festuca idahoensis* (I)
16. *A. vaseyana/Agropyron spicatum* (I, O)*
17. *A. vaseyana/Festuca idahoensis* (I, O)
18. *A. vaseyana/Stipa comata* (I)
19. *A. vaseyana/Symphoricarpos oreophilus/A. spicatum* (I)
20. *A. vaseyana/Symphoricarpos oreophilus/Festuca idahoensis* (I)
21. *A. vaseyana/Symphoricarpos oreophilus/Carex geyeri* (I)
22. *A. viscidula/Festuca idahoensis* (I)
23. *A. wyomingensis/Agropyron spicatum* (I, O)*
24. *A. wyomingensis/Poa sandbergii* (I)
25. *A. wyomingensis/Sitanion hystrix* (I)
26. *A. wyomingensis/Stipa thurberiana* (I)

* Probably in Washington, also.

The distribution of the major understory species is generally independent of the sagebrush species, but at times there is coincidence. The major perennial grass and grass-like species include: *Poa sandbergii, Stipa thurberiana, Agropyron spicatum, Festuca idahoensis, Stipa comata, Bromus carinatus* and *Carex geyeri.*

Poa sandbergii occurs in most of the habitat types. It is the dominant understory species in the *A. tridentata/Poa sandbergii* ht (Daubenmire 1970, Franklin and Dryness 1974) in the dry, hot portion of the Columbia Basin and in the *A. wyomingensis/Poa sandbergii* ht in Idaho (Hironaka 1977). The primary understory member under *A. rigida* is *Poa sandbergii* (Hall 1967, Culver 1964, Daubenmire 1970, Hironaka 1977).

Stipa thurberiana is the dominant understory species in the *A. wyomingensis/Stipa thurberiana* ht (Tisdale et al. 1969, Hironaka 1977). The habitat type is unique to the Snake River Plains of Idaho and contains no *Agropyron spicatum*. This *Stipa* species occurs in the *A. tridentata/Agropyron spicatum* ht *Stipa thurberiana* phase (Eckert 1957) and is occasionally found with *A. longiloba* and *Festuca idahoensis* (Hugie et al. 1964, Zamora and Tueller 1973).

The most widespread of the understory grasses is *Agropyron spicatum*. It occurs as a dominant understory species with all sagebrush species except *A. rigida*, *A. cana* subsp. *viscidula* and *A. spiciformis*. This species probably includes much ecotypic variation without morphological expression for taxonomic separation. Presently this species is dominant with the following shrub series: *A. wyomingensis*, *A. tridentata*, *A. tripartita*, *A. vaseyana*, *A. arbuscula*, *A. nova* and *A. vaseyana/Symphoricarpos oreophilus*. In areas where *Festuca idahoensis* is in the same locality, *Agropyron spicatum* occupies the warmer and drier habitats. The *A. vaseyana/Symphoricarpos oreophilus/Agropyron spicatum* habitat type is unique in that it is located at high elevations extending upward to 2500 m (8000 ft) on granitic soils with *Symphoricarpos* or other mountain shrub species, such as *Ribes cereum*, *Prunus virginiana* or even *Amelanchier alnifolia* and lacks *Festuca idahoensis*. This habitat type is confined to the southerly slopes. At higher elevations the *Agropyron* is replaced by *Carex geyeri*.

Festuca idahoensis is restricted to the cooler mesic areas. It is commonly found as an important member, if not the dominant, under *A. tridentata*, *A. spiciformis*, *A. tripartita*, *A. vaseyana*, *A. arbuscula*, *A. longiloba*. It occurs with neither *A. wyomingensis* nor *A. rigida*. It has been found in restricted situations with *A. 'xericensis'* and *A. nova*. *Festuca idahoensis* does not appear to thrive on granitic or limestone soils unless compensated with additional moisture. At low elevation, warm temperatures restrict its distribution.

Stipa comata is restricted to sandy (Pearson 1965, Winward 1970) or excessively drained soils. It occurs with all of the big sagebrushes except *A. spiciformis*. It grows with *A. nova* but generally not with *A. arbuscula* or the other dwarf sagebrushes.

Bromus carinatus is often found in but not restricted to *A. spiciformis* communities. It does not play an important role in the *A. vaseyana* series.

At present the status of *Stipa columbiana* and *Stipa lettermani* is unclear. There is evidence that these species may be products of past disturbance and are seral in nature rather than dominant members of climax vegetation in the Columbia River sagebrush region.

FUTURE NEEDS OF SYNECOLOGICAL RESEARCH

The classification of this vast region by habitat type is but an initial step in the better understanding of these lands. The habitat types give an idea of the vegetational potential of each area. What is needed after the habitat types are determined is a unified acceptable method of classifying the current communities within each habitat type. Alone, the habitat type classification is not very useful. Neither would the classification of seral communities be meaningful unless placed within the framework of the habitat type. Combined information for each habitat type and the attendant seral communities would permit one to interpret where a particular vegetation is in relation to its potential. It would also suggest the probable secondary successional pathway of the current vegetation. Since all the seral communities in a habitat type are related to a single climax vegetation, the seral communities are also related to one another. This helps to determine not only the feasibility of changing a particular seral community to another community by management or manipulation, but also whether such a change is realistically attainable.

In conjunction with mapping of habitat types and their attendant seral communities, classification and mapping of soils should also be completed. The management of rangelands is not based on vegetation alone nor on soils alone; the two need to be considered together – as an ecosystem. The information gained from soils would help greatly in subdividing the habitat types into areas of similar productivity.

The development of a seral vegetation classification scheme within habitat types would provide a sound base for an information storage and retrieval system that is not presently available. Land managers have been unable to capitalize on the experiences of their predecessors. Lacking an acceptable classification scheme for seral communities and their respective potential vegetation, there was no way for them to document their experiences with respect to various kinds of vegetation. This I believe should be given serious consideration if we hope to be progressive in our approach to better land management.

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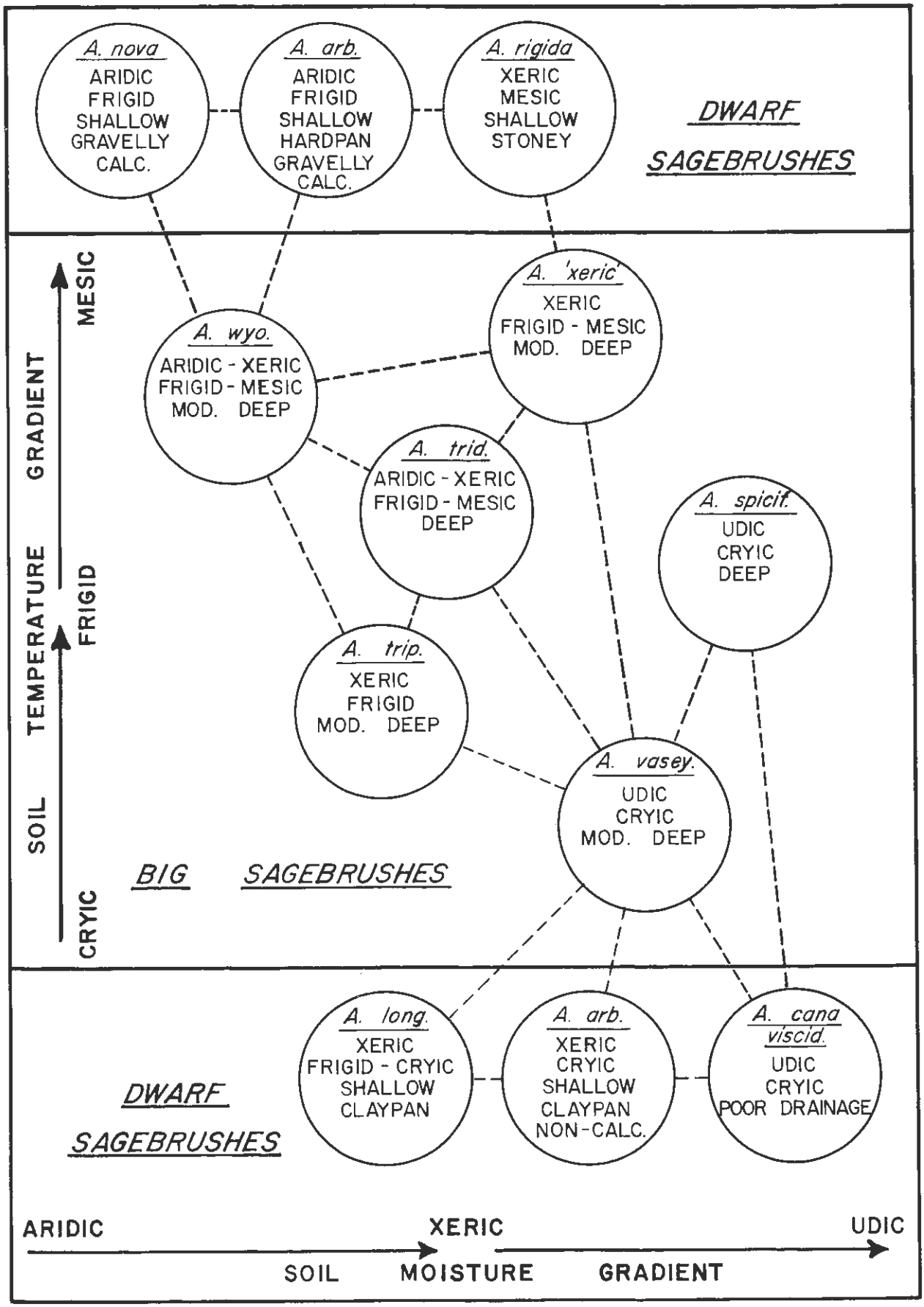
A. nova
ARIDIC
FRIGID
SHALLOW
GRAVELLY
CALC.
A. arb.
ARIDIC
FRIGID
SHALLOW
HARDPAN
GRAVELLY
CALC.
A. rigida
XERIC
MESIC
SHALLOW
STONEY
DWARF
SAGEBRUSHES
MESIC
SOIL TEMPERATURE GRADIENT
FRIGID
CRYIC
A. wyo.
ARIDIC - XERIC
FRIGID - MESIC
MOD. DEEP
A. 'xeric'
XERIC
FRIGID - MESIC
MOD. DEEP
A. trid.
ARIDIC - XERIC
FRIGID - MESIC
DEEP
A. spicif.
UDIC
CRYIC
DEEP
A. trip.
XERIC
FRIGID
MOD. DEEP
A. vasey.
UDIC
CRYIC
MOD. DEEP
BIG SAGEBRUSHES
A. long.
XERIC
FRIGID - CRYIC
SHALLOW
CLAYPAN
A. arb.
XERIC
CRYIC
SHALLOW
CLAYPAN
NON-CALC.
A. cana
viscid.
UDIC
CRYIC
POOR DRAINAGE
DWARF
SAGEBRUSHES
ARIDIC
XERIC
UDIC
SOIL MOISTURE GRADIENT

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BASIC SYNECOLOGICAL RELATIONSHIPS OF SAGEBRUSH-DOMINATED LANDS IN THE GREAT BASIN AND THE COLORADO PLATEAU

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Introduction

Previous chapters in this volume have dealt with the evolution, taxonomy and autecology of woody *Artemisia* in western North America. A major purpose of this chapter is to describe the role that sagebrush play in plant communities of the Great Basin and Colorado Plateau. Vegetation where sagebrush is a key element will be related to environmental gradients. Successional dynamics will be considered. Finally, the knowledge of variations in plant community distribution, composition, environmental controls and successional status and change will all be related to management needs for these ecosystems.

Sagebrushes of the Great Basin and Colorado Plateau

Sagebrushes are a morphologically complex group and have thus been classified differently by various taxonomists. Because different approaches and thus names have been used at various times, one has to be cognizant of the taxonomic permutations used (synonomy) and attempt to translate them to their modern equivalents in order to synthesize information, as is the aim of this paper. I share the taxonomic views of Hanks et al. (1973) at the section level and the sub-specific designations for *A. tridentata* used by Winward and Tisdale (1977). These less inclusive taxonomic designations are more useful to the ecologist and wildland manager than the older labels that included greater morphological and ecological variation. This is so because more indicator significance can be read using the more recently derived taxonomic designations, particularly if chromatographically-assisted identifications are made (West et al. 1978).

The major *Artemisia* taxa present in the Great Basin and Colorado Plateau (using Hunt's (1974) definition of these areas) are listed in Table 1. The listings also attempt to rank these taxa in order of abundance. There are no basic differences in the major sagebrushes between the two regions. It is only with the less important sagebrushes and other taxa that differences emerge. Only the Colorado Plateau has *A. bigelovii*, but lacks the *A. arbuscula* and *A. longiloba* prevalent in the Great Basin.

The distribution of sagebrush-dominated vegetation is given in Figure 1. The area was planimetered and the resultant absolute areas and percentages of the Great Basin and Colorado Plateau physiographic provinces covered by *Artemisia*-dominated vegetation indicated in Table 2. Even though the absolute and relative areas, especially in the Great Basin, are huge, the estimates may be considered conservative. The map of Branson et al. (1967) doesn't include those portions of the salt desert shrub, juniper-pinyon woodland, montane and subalpine zones where sagebrush may also occupy considerable acreages.

As the map shows, sagebrushes occupy areas over a wide array of latitudes and longitudes. The altitudinal variation is also considerable. Figure 2 attempts to show the usual elevational and soil moisture separations of the major taxa in the center of the two physiographic provinces under consideration here. Since altitude correlates strongly with temperature and moisture, this diagram indicates some of the relative indicator value these species have for climatic favorableness.

The lower elevations are colder in winter because of the common occurrence of temperature inversions. The lower, valley bottoms are also hottest in summer. The mid-elevations have the least temperature extremes (Billings 1954). The uppermost distributions of sagebrush usually involve slopes that are exceedingly windswept, steep, rocky or otherwise effectively drier than the surrounding sites with more normal soils occupied by zonal vegetation.

The soils that sagebrushes occupy grade from aridisols toward molisols and alfisols. It is only on sites above the salt-affected soils of the salt desert shrub zone that sagebrushes may be considered climatic climax dominants, if fire is excluded as a factor of climate. The least salty, and comparatively most mesic sites within the salt desert shrub zone frequently have *Artemisia nova*, *A. spinescens*, and *A. pygmea*-dominated communities. The major *Artemisias*, particularly the *A. tridentata* complex, will not tolerate soil salinities higher than 18 mmho/cm^3 (Gates et al. 1956). Salinity in soil profiles where sagebrush dominates usually averages less (Branson et al. 1976). Therefore, the upland positions, in desert valleys and mountain foothills, is where the majority of sagebrush-dominated

Table 1. Major taxa of woody *Artemisia* found in the Great Basin and Colorado Plateau.

Great Basin	Colorado Plateau
A. tridentata wyomingensis	*A. tridentata wyomingensis*
A. tridentata vaseyana	*A. tridentata vaseyana*
A. tridentata tridentata	*A. tridentata tridentata*
A. nova	*A. nova*
A. arbuscula	
A. longiloba	
A. spinescens	*A. spinescens*
	A. bigelovii

Table 2. Area of sagebrush-dominated vegetation in the Great Basin and Colorado Plateau. Derived from Branson et al. (1967) via dot grid placed on enlarged version of Figure 1.

	Total Area (ha x 10^6)	Total Area in Province with Sagebrush-Dominated Vegetation (ha x 10^6)	Percentage of Province Covered by Sagebrush-Dominated Vegetation
Great Basin	42.8	19.5	45.6
California		1.3	
Oregon		1.5	
Nevada		12.6	
Idaho		1.9	
Utah		2.2	
Colorado Plateau	26.3	3.0	11.5
Utah		0.4	
Arizona		2.0	
Colorado		0.5	
New Mexico		0.1	

vegetation is found. The salinity of soil derived from marine shales in the Colorado Plateau has apparently caused restriction of sagebrush to less area than climate alone would allow (West 1969). In many portions of the Colorado Plateau the sagebrush zone is missing entirely, with salt desert shrub vegetation occupying the shale-derived soils and juniper-pinyon woodlands beginning immediately where sandstone or limestone derived soils begin.

At higher (and thus wetter) elevations in both the Great Basin (Zamora and Tueller 1973) and Colorado Plateau (Robertson et al. 1966, Van Pelt 1978), sites with slopes, exposure, and micro-climate and/or edaphic features that make them droughty, cold air sinks and/or free from fire, frequently have sagebrush-dominated communities inplace of the surrounding zonal vegetation on more normal soils.

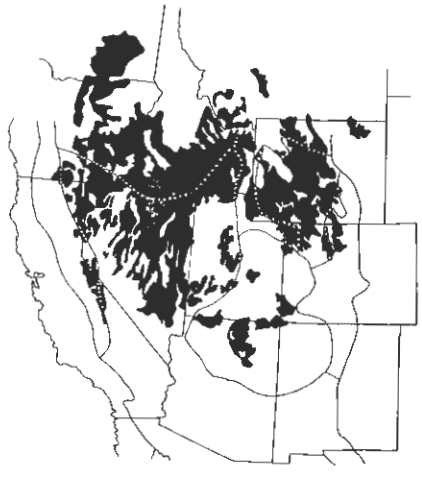

Figure 1. Map of sagebrush dominated vegetation in the western United States (derived from Branson et al. 1967). Superimposed boundaries of the Basin and Range and Colorado Plateau physiographic provinces following Hunt (1974).

Figure 2a.

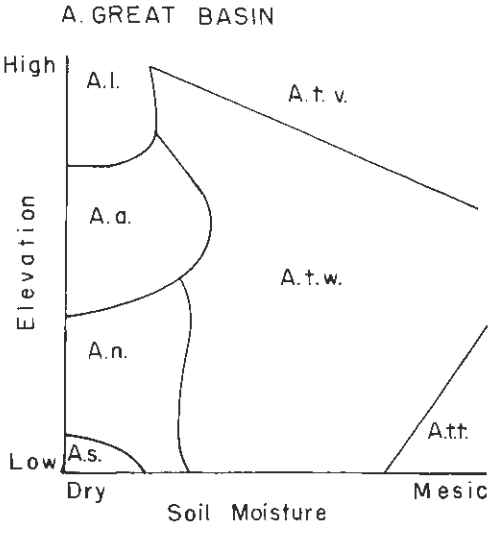

Figure 2b.

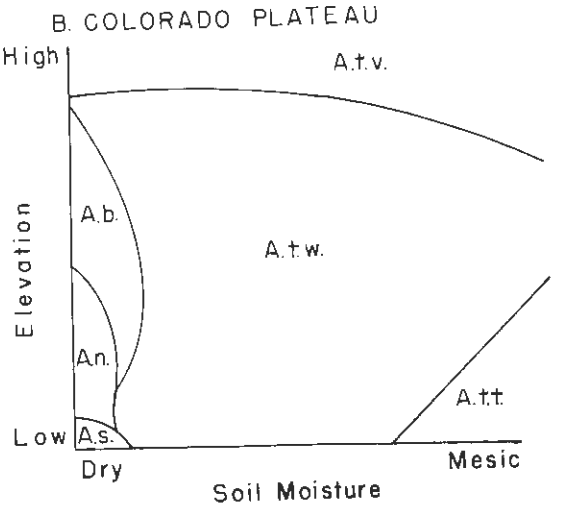

Figure 2. Ordinations' of major sagebrush taxa against gradients of elevation and effective moisture. A.♀ = Artemisia longiloba etc., as derived from Table 1, using the first letters of the genus, species and subspecies names.

Associated Species

The associates of sagebrushes vary largely in response to climatic differences in these regions (Daubenmire 1978). Table 3 is an abbreviated list of major species in *A. tridentata*-dominated plant communities in lowlands at several widely-separated sites in the Great Basin and Colorado Plateau. Figure 3 shows climatic diagrams for the nearest climatic stations with somewhat comparable conditions of elevation, slope, exposure, etc.

We see an increase in warm season grass understory of southern floristic affinity where the summer precipitation becomes more important in the southeastern Great Basin and Colorado Plateau. Cool season grasses derived from northern forests are more important to the west and north. The greatest differences between provinces and sites exist with the normally higher diversity of forb associates. Problems in consistently identifying species in the major forb genera prevent us from definitively discussing this aspect of floristic variation here.

Further understanding of variation in sagebrush-dominated vegetation requires consideration of more than just physical environmental factors. Of considerable importance are the effects of fire and animals. Only when these elements are added can we understand successional dynamics within the type.

Changes in Vegetation

During the pluvial intervals of the Pleistocene Epoch much of the present areas dominated by sagebrush was probably covered by pinyon and juniper trees (Wells and Berger 1967, Axelrod 1976, Taylor 1977 and 1978, Spaulding and VanDevender 1977, Mehringer 1977). A general climatic warming began in the Holocene Epoch starting 10,500 years before present. The trees retreated extensively, particularly during the drier, hotter xerothermic (hypsithermal) interval approximately 4,000 to 7,500 years before present. At that time sagebrushes probably became even more widespread, coming to occupy the mountain tops of the Great Basin that were bereft of a significant montane forest component.

The importance of the horizontal geological strata of the Colorado Plateau and their role in soil development probably complicated some of these movements in the Colorado Plateau. Edaphic and topographic compensations for climate were probably as important then as now (Spaulding and VanDevender 1977).

The proportion of sagebrush with herbaceous components has probably always varied with site conditions (Christensen and Hutchinson 1965, Vale 1975, Frishknecht 1976, Daubenmire 1978). Sagebrushes can be expected to have greater abundance on the more xeric sites since the shrubs are more adapted to enduring drought and drawing on deep moisture storage. The lower fuel volume on more xeric sites also lessens the chances of fire. Wright et al. (1978) speculate that a fire frequency of around 50 years probably prevailed under pristine conditions. Since none of the major *Artemisia* of the Great Basin can resprout after fire, frequent fire may well have favored dominance by herbaceous species on the more mesic sites within the sagebrush grass zones. It would be over generalizing to say that all sites presently having sagebrush dominance were once grass-dominated since each site has its own unique successional pattern (Whittaker 1974).

Table 3. Major perennial plant species at representative lowland locations within sagebrush-dominated areas of the Great Basin and Colorado plateau. Sites ordered from northwest on right-hand side of the table to southeast on left-hand side. Location of sites described on next page.

Species	Sites 1	2	3	4	5	6	7	8
Shrubs								
Artemisia tridentata	X	X	X	X	X	X	X	X
Chrysothamnus visiciflorus	X	X	X		X			X
Eriogonum microthecum	X				X			
Gutierrezia sarothrae	X			X			X	X
Prunus andersonii	X							
Purshia tridentata	X							
Tetradymia canescens	X							
Tetradymia glabrata	X							
Leptodactylon pungens		X						
Chrysothamnus nauseosus				X		X		
Ephedra viridis			X					X
Ephedra nevadensis			X					
Grayia spinosa		X			X			
Ceratoides lanata					X			
Atriplex canescens					X			
Succulents								
Opuntia polycantha		X		X	X	X	X	X
Grasses								
Agropyron spicatum	X	X						X
Bromus tectorum	X	X						
Oryzopsis hymenoides	X	X	X		X		X	
Poa canbyi	X							
Poa secunda	X	X					X	
Sitanion hystrix	X	X	X			X	X	X
Stipa thurberiana	X	X						
Elymus cinereus		X						
Stipa columbiana				X				
Bouteloua gracilis				X	X		X	X
Agroypron smithii				X				
Poa longiligula				X			X	
Hilaria jamesii					X	X		X
Sporobolus airoides					X			X
Sporobolus cryptandrus					X		X	X
Stipa speciosa					X		X	
Stipa comata								
Forbs								
Astragalus spp.	X	X						X
Calochortus spp.	X							
Castelleja spp.	X						X	
Caenactis douglasii	X	X						
Crepis acuminata	X			X				
Epilobium paniculatum	X	X						
Lomatium spp.	X						X	
Mentzelia albicaulis	X			X				
Penstemon spp.	X						X	
Phlox gracilis	X						X	
Viola beckwithii	X			X				
Zygadenus paniculatus	X							
Phlox diffusa		X	X					X
Lupinus candatus		X		X				
Erigeron pumilis		X						
Cryptantha jamesii		X						
Polygonum nuttallii				X				
Aster specious			X	X				X
Gilia spp.							X	
Erigeron spp.							X	
Townsendia spp.							X	
Sphaeralcea spp.			X		X		X	X

Key to Site Locations in Table 3. Corresponding climatic stations in Figure 3 shown in parenthesis.

1. Sites No. 1 and 2, Carson Valley near Reno, Nevada, Billings et al. 1954. (Reno)
2. *Artemisia tridentata/Poa secunda/Phlox diffusa* community, Coils Creek, Eureka County, Nevada, Blackburn et al. 1969. (Eureka)
3. *Artemisia tridentata/Hilaria jamesii* association, Hot Creek Valley, Nye County, Nevada, Tueller et al. 1972. (Rattlesnake Hwy. Sta.)
4. Exclosures near Duchesne, Duchesne County, Utah, Dastrup 1963. (Duchesne)
5. Cedar Mesa relict area, Canyonlands National Park, Utah, Van Pelt 1978. (Monticello)
6. Experimental watershed paddocks, Badger Wash, near Fruita, Mesa County, Colorado, Branson et al. 1976. (Fruita)
7. *Artemisia* site, Fishtail Mesa, Grand Canyon National Park, Arizona, Jameson et al. 1962. (Grand Canyon)
8. Inside fenced highway, (N.M. 197) near Rio Puerco, Sandoval County, New Mexico, Dahl et al. 1976. (Cuba)

The acquisition of horses by Indians, after their reintroduction by the Spanish, may have begun tipping the balance toward brush dominance on many sites. The major changes, however, occurred following settlement of the Intermountain West by Whitemen and their much larger numbers of all types of livestock (Pickford 1932). Some virgin lands or lands with only winter sheep use remained up until recently because of water distribution problems. It is difficult to find the topographic circumstances that have preserved relict areas. These sites are not always comparable to the majority of sites under current sagebrush dominance, making the generality of these interpretations difficult (Tueller and Blackburn 1974, Passey and Hugie 1962).

Figure 4 outlines some of the main pathways by which succession progresses on major lowland sagebrush-grass sites in the Great Basin and Colorado Plateau. Not all possible pathways could be shown.

The major change that came about with unrestricted livestock use of sagebrush-grass range was the rapid loss of the herbaceous species and the dominance of brush and exotic annuals (Hull 1976). The switch over came within 10-15 years because the native herbaceous species were so sensitive to utilization during the growing season (Stoddart 1946, Daubenmire 1978). The exotic annuals on the other hand were preadapted to the environment (Evans and Young 1972). The Eurasian annuals likely possessed genotypes which were selected by centuries of heavy ungulate grazing (Young et al. 1972). The native plants, perennial or annuals, apparently did not evolve under these kinds of pressures. Whether such pressure was lacking prior to the late Pleistocene extinction of the megafauna (Mehringer 1967) is a moot point.

Nearly all the perennials found in this flora are relatively long-lived and replace themselves only at infrequent intervals (West et al. 1978). The exotics (*Bromus*, *Taeniatherum*) produce seed every year and can grow root systems at colder soil temperatures (Harris 1967 and 1977) or flourish in the summer (*Lepidium*, *Salsola*, *Halogeton*) when the native grasses and forbs are aestivating, and thus gain competitive advantage over the native herbaceous species. The shrubs, on the other hand, are so plastic, long-lived and competitive that they could quickly fill the vacancies by increasing and maintaining their average size (West et al. 1978). Mere reduction in livestock numbers following implementation of federal grazing laws did little to reverse these changes on most sites (Robertson 1971, McLean and Tisdale 1972, Harniss and West 1973, Young et al. 1976a, Westoby and Rice 1978).

Range managers have had to rely on mechanical and chemical methods of reducing the brush and planting of exotic perennial grasses to increase livestock carrying capacities on these ranges. Seedings of native grasses will not stand heavy use, therefore crested wheatgrasses have been regarded as a panacea. There are many more possibilities for other even more productive and better adapted genotypes of this grass, as well as other species from Eurasia (Asay 1975).

Until recent increases in costs of mechanical and herbicidal treatments, there has been reluctance in using prescribed burning to simulate nature's way of maintaining more herbaceous cover during pristine conditions (Beardall and Sylvester 1976). The exotic annuals, particularly cheatgrass brome (*Bromus tectorum L.*) are promoted by fire. A never ending spiral of decline in site quality can result with frequent fire on cheatgrass-covered sites (Young and Evans 1973, Young et al. 1976b). With the availability of herbicides to impede annuals (Evans and Young 1977), perhaps more widespread use of fire in place of shrub-killing herbicides or tillage will not be made to prepare the sites for planting of perennial grasses.

Conclusion

I hope that it will now be easy for you to see why an understanding of basic synecological relationships in sagebrush-dominated ecosystems will be helpful, indeed necessary, for better management of these rangelands. The projection of responses to a management plan will be much more accurate if the manager will recognize plant community and site differences and stratify his planning by them. Each situation is unique, but some major differences between sites can be read from a close examination of the vegetation and soils involved. By relating the successes or failures from management action on the same or similar sites, problems can be avoided and good returns from public expenditures assured. More synecological analysis and synthesis would make possible even higher degrees of predictability of success in management actions taken in our sagebrush-dominated ecosystems.

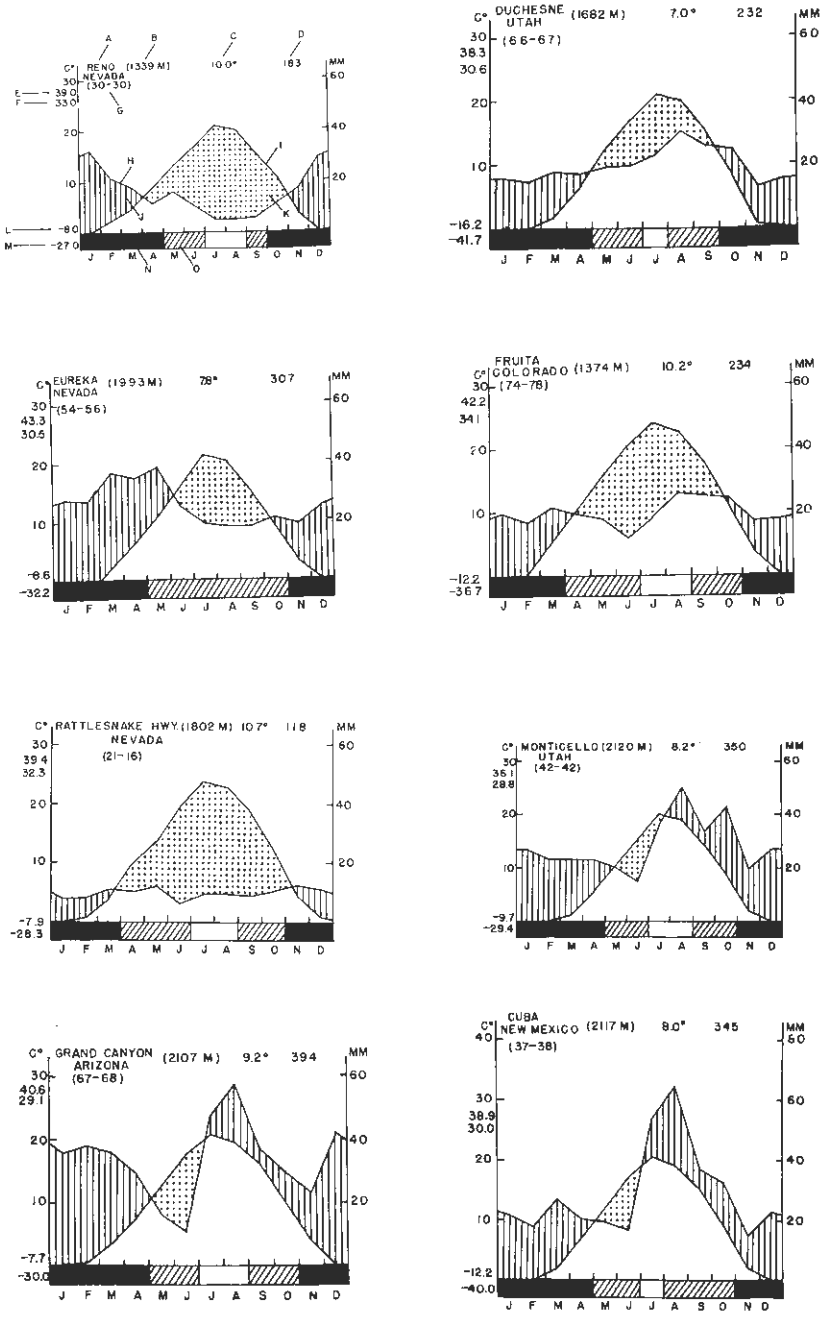

Figure 3. Climatic diagrams, constructed from U.S. Weather Bureau Service data as suggested by Walter (1963), for representative lowland stations in or near where *Artemisia tridentata* is known to dominate the native vegetation (Table 3). Key to data is given below.

A = station name
B = altitude (meters)
C = mean annual temperature (°C)
D = mean annual amount of precipitation (mm)
E = absolute maximum temperature (°C)
F = mean daily maximum of hottest month (°C)
G = number of years observation (first = temp., second = ppt.)
H = monthly means of precipitation
I = monthly means of temperature
J = humid period (lined)
K = arid period (dotted)
L = mean daily minimum temperature of the coldest month (°C)
M = absolute minimum temperature (°C)
N = months with mean daily minimum temperature below 0°C.
O = months with an absolute minimun below °C.

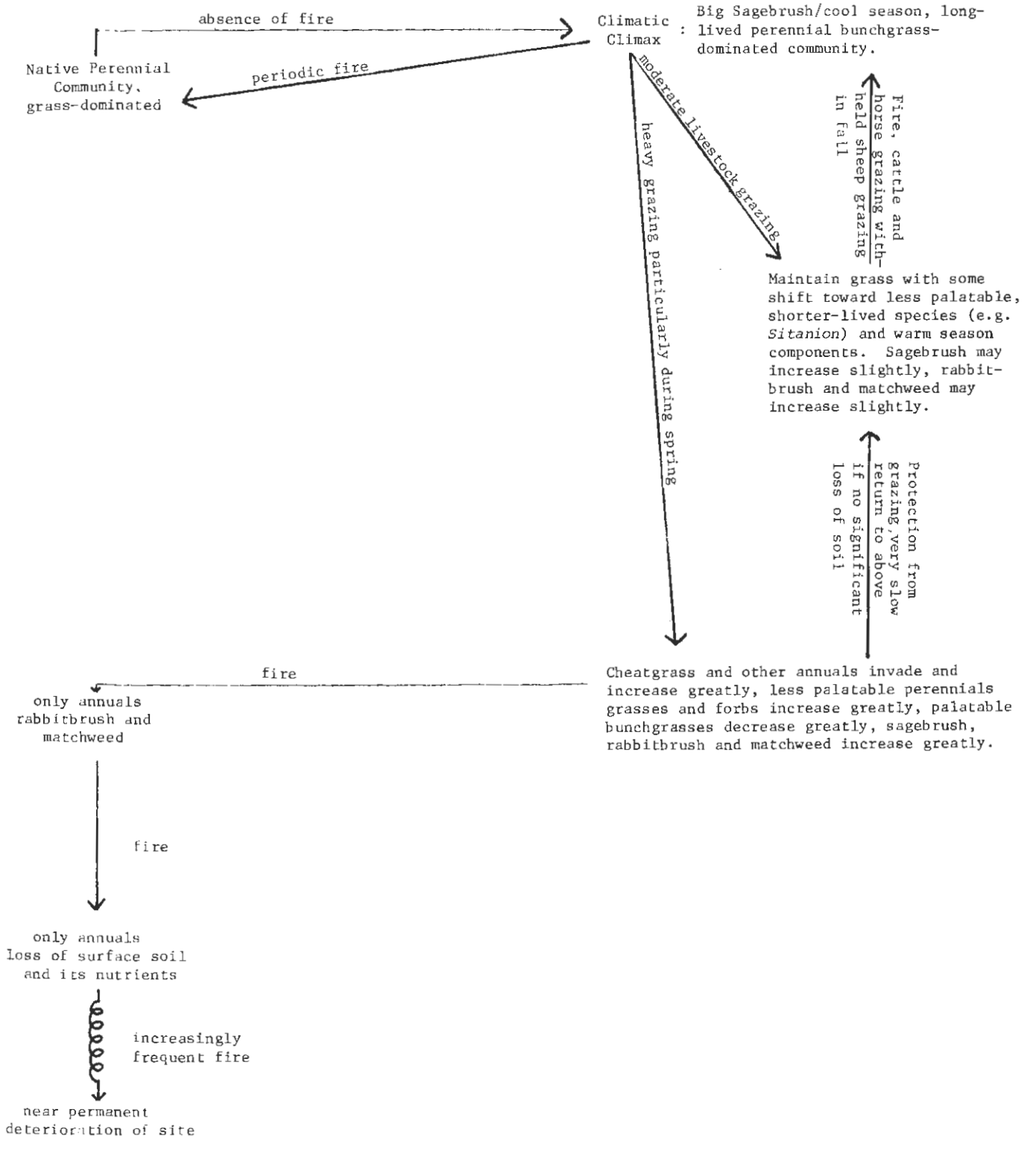

Figure 4. Major pathways of succession on important lowland sagebrush-grass sites in the Great Basin and Colorado Plateau.

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BASIC SYNECOLOGICAL RELATIONSHIPS OF THE SAGEBRUSH TYPES ON THE HIGH PLAINS OF MONTANA, WYOMING AND THE DAKOTAS

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Introduction

The northern Great Plains, at their western margin, join the foothills of the Rocky Mountains from about the Wyoming-Colorado border north to near Edmonton, Alberta, covering approximately 400,000 square miles (Figure 1). To the east, north and south the Plains are bounded by transitional zones created by differences in climate, soils and vegetation. But the distinct western barrier formed by the Rocky Mountains, in relation to prevailing winds, largely determines the climate of the Plains, and thus the development of soils and vegetation.

Figure 1. The northern Great Plains, as outlined by Lodge (1970).

Climate in the northern Great Plains is erratic, marked by extremes, and punctuated by drought. Average precipitation is highly irregular as well, ranging from as little as 10 inches in the west to more than 20 inches in the east. Precipitation also increases from south to north. About half of the yearly precipitation falls as rain during the three-month period May to July; about three-fourths arrives during the growing season April through September. Summer thunderstorms of high intensity are common. The remaining portion comes mostly as snow, often in the form of blizzards, and is further relocated by winter winds. Temperature extremes, near-constant winds, and high evaporation and sublimation rates make the effective fraction of yearly precipitation even smaller. Thus vegetative growth in the northern Great Plains depends on spring and summer rains to initiate growth and replenish soil moisture.

This general climatic pattern is interrupted only once. In central Wyoming a low spot in the Continental Divide (Marwitz and Rogers 1976) allows air masses from the Great Basin to flow into the Plains, especially during fall and winter (Figure 2). The resulting mix of air masses in northeastern Wyoming, bounded by the Black Hills and dissipating northward into Montana and North Dakota, is reflected by the presence of Great Basin plants, which are adapted to an environment where the bulk of yearly precipitation is received as winter snow, and the growing season is warm and dry. This local or regional 'tension zone' between Great Plains and Great Basin floristic elements tends to be plastic: dry cycles favor the eastward extension of Great Basin plants, while wet cycles work in an opposite direction (Rudd 1951, Stevens 1920).

This paper examines the distribution and ecological relationships of shrubby members of the genus Artemisia in the northern Great Plains.

The Physical Setting

The landform of the northern Great Plains is dominated by rolling and rounded hills with gentle slopes, studded occasionally with rough breaks or badlands, ephemeral lake bottoms and drainages, and

moist stream-channel areas (Figure 3). About 70% of the total land area (Wight 1976) supports mixed prairie vegetation, merging into tallgrass prairie to the east, fescue grassland to the north, and short-grass prairie to the south. Lodge (1970) estimated that about 125,000 square miles are cultivated for wheat and other small grains. A substantial additional acreage of native range has been put into cultivation at some time in the past and subsequently abandoned. These land resources support some 12 million animal units of cattle and sheep (Lodge 1970), the major industry in the northern Great Plains.

The major forage species best adapted to these conditions include both cool-and warm-season grasses such as western wheatgrass (Agropyron smithii), blue grama (Bouteloua gracilis), prairie junegrass (Koelaria cristata), and needleandthread (Stipa comata). The upland sedges, threadleaf sedge (Carex filifolia) and needleleaf sedge (Carex eleocharis), are important forage species as well. A variety of associated forbs, plains pricklypear (Opuntia polyacantha), and several major shrubs, among them rose (Rosa spp.), skunkbush sumac (Rhus trilobata), wax currant (Ribes cereum), rubber rabbitbrush (Chrysothamnus nauseosus), silver sagebrush (Artemisia cana), and big sagebrush (A. tridentata), are included in the mixed prairie type.

The Historical Setting

The existence of a low-level crossing of the mountains in central Wyoming concentrated all early east-westward travel on the Oregon, California and Mormon Trails. Thus the gradual change in elevation, climate and vegetation as travellers approached the mountains from the east is well documented. Of particular note is the abrupt transition from mixed prairie in western Nebraska to a type dominated by big sagebrush (Artemisia tridentata) past Fort Laramie. A prominent example is Fremont's 1842 comments as he explored the Oregon Trail just ahead of the flood of emigrants (in Smucker 1856):

> With the change in the geological formation on leaving Fort Laramie, the whole face of the country has entirely altered its appearance. Eastward of that meridian, the principal objects which strike the eye of a traveler are the absence of timber, and the immense expanse of prairie, covered with the verdure of rich grasses, and highly adapted for pasturage. Wherever they are not disturbed by the vicinity of man, large herds of buffalo give animation to this country. Westward of Laramie river the region is sandy, and apparently sterile; and the place of the grass is usurped by the artemisia and other odoriferous plants, to whose growth the sandy soil and dry air of this elevated region seem highly favorable.

In the same general area at the height of western migration, Stansbury (1852) observed:

> Artemisia was almost the only vegetation, and great difficulty was experienced in obtaining enough grass to subsist our animals. The soil appears very barren, more from the absence of moisture than from the character of its constituents; as even the alluvial bottoms exhibit the same destitute and naked features.

Fifty miles further on after leaving the North Platte River, Stansbury reported:

> The country, all the way from the crossing of the Platte, is a dry, sterile, and dreary desert.

That 'dry, sterile, and dreary desert' was to surround Stansbury for the remainder of his journey to and from the Valley of the Great Salt Lake until on the return trip over the Overland Trail, entering the Laramie Plains in southeastern Wyoming, he noted simply: "Artemisia has entirely disappeared."

Thus it seems clear historically that in the eastern Wyoming portion of the northern Great Plains, sagebrush was an important component of the vegetation.

Distribution of Sagebrush in the Northern Great Plains

The Section Tridentatae of Artemisia, as described by Beetle (1960), with an important addition by Beetle and Young (1965), contains 19 taxa: 11 species, 6 subspecies and 2 forms. The Section is of mountain origin and Great Basin adaptation, as outlined by Beetle in a companion symposium paper. Hence a majority of the species are adapted to more xeric conditions south and west of the northern Great Plains; the Section is represented in the mixed prairie by only two species. Wyoming big sagebrush (A. tridentata ssp. wyomingensis) is a dwarf shrub of up to 1 ft., growing on dry, shallow-soil sites at elevations around 5,000 feet (Figure 4). Silver sagebrush (A. cana ssp. cana) is an erect, freely branching shrub of up to 5 ft., growing on well-watered, deep soils throughout the region, especially along stream bottoms and drainageways (Figure 5).

The foothills and mountain valleys rimming the northern Great Plains to the west support several other species, notably mountain big sagebrush (A. tridentata ssp. vaseyana), mountain silver sagebrush (A. cana ssp. viscidula), Wyoming threetip sagebrush (A. tripartita ssp. rupicola), and black sagebrush (A. nova). These are all confined, however, to more mesic sites at higher elevations than are typical of Great Plains species. Distribution and site relationships are presented by Thatcher (1959), Fisser (1962), Jorgensen (1958), Butler (1972), and Morris et al. (1976).

Silver Sagebrush (A. cana ssp. cana)

Silver sagebrush occurs rather sparsely but widely throughout the northern Great Plains. Ellison and Woolfolk (1937) observed that "Artemisia cana, although to be found growing on the uplands, is most abundant in coulees and bottoms." Thus typical habitats are loamy to sandy, well-drained soils of the uplands, and the alluvial flats and terraces of valley bottoms.

The shrub is distributed generally over the eastern plains of Wyoming and Montana, and over the western portions of the Dakotas and Nebraska (Figure 6). In the dissected badlands of the Little Missouri River, A. cana dominates the alluvial deposits of the valley floors (Hazlett and Hoffman 1975). Coupland (1950, 1961) notes A. cana as the most abundant shrub, after species of Rosa, in the mixed prairie of Saskatchewan, while Moss (1955) observed its local dominance of some of the drier lowlands in Alberta. Breitung (1954) called it 'occasional on dry, exposed hillsides' in the Cypress Hills, but Dirschl (1962) regarded it as abundant on sandy terrain, steep arid slopes, and alluvial deposits. Hubbard (1950) found A. cana reaching a maximum development on light, well-drained soils in southwestern Saskatchewan, so much so that it was useful as a soil indicator.

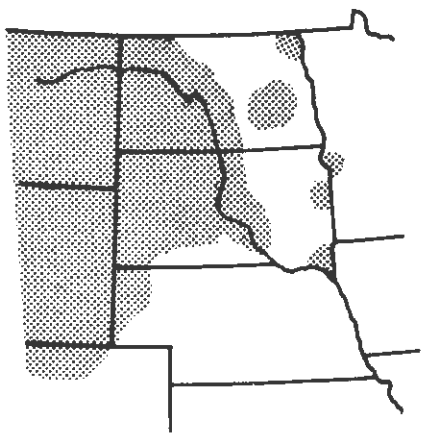

Figure 6. Distribution of silver sagebrush (A. cana ssp. cana) in the U.S. portion of the northern Great Plains (after Great Plains Flora Association 1977).

In sum, silver sagebrush is a familiar component of northern Great Plains flora, usually occurring on deep loam to sandy soils of river terraces primarily, and of uplands secondarily.

Wyoming Big Sagebrush (A. tridentata ssp. wyomingensis)

The northern Great Plains contain the northern and eastern limits of big sagebrush distribution. Because big sagebrush is particularly adapted to an environment where the bulk of yearly precipitation is received as winter snow, and the growing season is warm and dry, it is at a competitive disadvantage with plants adapted to a warm and wet growing season. As a result the shrub is confined to the drier sites, generally within the zone of Great Basin climatic influence in the lee of the Rocky Mountains, or to sites where local edaphic conditions produce a favorable growing medium (Shantz 1923).

North Dakota. The northeastern limit of A. tridentata distribution occurs in the western state-line counties south of the Missouri River (Figure 7). Where A. cana occupies valley floors of the Little Missouri badlands, A. tridentata dominates the higher benches and terraces (Hazlett and Hoffman 1975). On the buttes of the badland area, both A. cana and A. tridentata occur in slight amounts on relict mesa tops, but both are far more abundant on the eroding slopes and margins of the mesas and on the grazed valley floors (Quinnild and Cosby 1958). Big sagebrush rarely occurs on scoria buttes, but is found as occasional plants on the steep sides of clay buttes (Whitman and Hanson 1939, Ralston 1960). Where moisture relations are more favorable on the tops of buttes, or on areas receiving runoff from surrounding slopes, big sagebrush can be abundant.

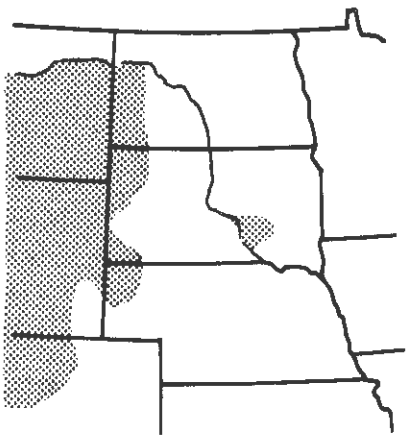

Figure 7. Distribution of big sagebrush (A. tridentata ssp. wyomingensis) in the northern Great Plains (after Great Plains Flora Association 1977).

South Dakota. Wyoming big sagebrush is confined to the northwest corner of the state along the state line (Baumberger 1977), in a continuation of the Little Missouri distribution found in North Dakota. It is largely absent on the uplands, but is abundant on the lower terraces of the valleys and badlands, primarily on alkaline, medium to heavy-textured soils.

An extreme eastern limit to the big sagebrush distribution may be reached in the isolated patches found along the Missouri River. South of the Black Hills along the western reaches of the Cheyenne River, big sagebrush occurs again on lower terraces of valleys and stream bottoms, and in badland areas; portions of the distribution curl into the extreme northwest corner of Nebraska. This population may represent an isolated occurrence of A. tridentata ssp. vaseyana (Johnson and Nichols 1970).

Montana. Wyoming big sagebrush is the common subspecies on the plains of southcentral and southeastern Montana, generally south of the Missouri River. It is definitely associated with medium to

heavy-textured soils, river breaks, and badlands (Ross and Hunter 1976). It is noticeably absent, except for scattered plants, on coarse-textured soils. The result is a mosaic of range sites with a varying amount of big sagebrush as an important component. As Morris et al. (1976) point out, "the extent and density of this shrub in eastern Montana is influenced by the grazing history and farm abandonment, as it is elsewhere. Consequently, consideration of the successional status of vegetation or plant communities dominated by this subspecies is uncertain and cannot be generalized." It is likely that some of the range sites -- badlands and rough breaks in particular -- were dominated historically by the shrub. There is evidence, however, that much of its present distribution may represent a grazing disclimax (Ross et al. 1973).

Wyoming. Virtually the entirety of the northern Great Plains in Wyoming, except for the southeastern shortgrass prairie, is given over to mixed prairie vegetation with a strong component of Wyoming big sagebrush. The basins of the Powder, Belle Fouche, Cheyenne and a large part of the North Platte River support extensive stands of the shrub, ranging from dense fields to scattered plants. Here as elsewhere, variations in soil, physiography, and land use find expression in differing densities of big sagebrush. The historic evidence, however, and the major physiographic features permitting Great Basin climatic influences to intrude upon northeastern Wyoming, lend weight to the idea that Wyoming big sagebrush occupies a more dominant role here than elsewhere in the northern Great Plains. It is often noted that vegetation in northeastern Wyoming is consistent with mixed prairie elsewhere except for the greater abundance of big sagebrush.

Site Characteristics of Sagebrush in the Northern Great Plains

As pointed out by Ries (1973), the physical aspects of the environment controlling growth of plants are radiant energy, concentration of carbon dioxide and oxygen, water, mineral nutrients and temperature. Because these factors are difficult to measure, indirect expressions of their integration are often used, e.g., landform, slope and aspect, soils and water relations. The features discussed here are based on these indirect factors.

Silver Sagebrush

The affinity of silver sagebrush for coarse-textured, well-drained soils is widely documented. Coupland's (1950) evaluation of the ecology of mixed prairie in Canada showed that A. cana had a frequency of 26 percent in the Bouteloua-Stipa faciation, 3 percent in Bouteloua-Agropyron, only a trace in Stipa-Bouteloua, and absent entirely in the Agropyron-Koelaria faciation. The Bouteloua-Stipa faciation occurred on areas of medium- to coarse-textured soil in the drier parts of the brown soil zone, on areas of coarse texture in the moister parts, and on exposed locations. This definite site preferance, together with height ranging from a few inches on heavy soils to about 2 feet on sandy soils, makes A. cana an indicator of excessive drainage.

This relationship was supported by Hubbard's (1950) data, which listed A. cana as the most important shrub in the shortgrass association of the mixed-grass formation in southwestern Saskatchewan. Its decided preferance for light, well-drained soils is indicated by the percent density of total ground cover made up by the plant:

Fine sandy loam	0.80
Light loam	0.12
Loam	0.30
Clay loam	-0-
Heavy loam	-0-

In the North Dakota badlands, Hanson and Whitman (1938) observed that A. cana grew in dense or open stands, commonly 3-4 ft. tall, on flats along the streams and in valleys. The type was subject to flooding, erosion and deposition, hence stratification and heterogeneity were conspicuous in the alluvial profiles. Frequency of silver sagebrush averaged 48 percent; major herbaceous dominants were western wheatgrass (88), blue grama (41), and green needlegrass (Stipa viridula) at 34 percent. In areas subject to frequent flooding, only western wheatgrass and silver sagebrush appeared to thrive. On terraces the type appeared to be a successional stage where soil moisture was usually available in the subsoil throughout the season. In addition, silver sagebrush is associated sparsely with upland (Potter and Green 1964) and butte communities.

Silver sagebrush commonly occurs as the dominant shrub on sand dunes in the Powder River Basin of Wyoming, thus underlining a well-established relationship.

Wyoming Big Sagebrush

Site relationships for Wyoming big sagebrush are neither as clearcut nor as well understood as those of silver sagebrush. A typical study (Ries et al. 1976) found Wyoming big sagebrush occurring in three major vegetation types of the Powder River Basin in Wyoming. The largest and most diverse type occupied rolling uplands of clay loam soils, dominated by big sagebrush, blue grama, needleandthread, and plains pricklypear. A smaller area of fine-textured loamy soils supported a typical big sagebrush blue-grama association. Steeper slopes of shallow soils supported a big sagebrush-blue grama-western wheatgrass type. All three associations were in a stable state of disclimax (high fair range condition) due to historical grazing pressure. Similar patterns emerged from an earlier study (Hunter et al. 1938). In a northcentral Wyoming study, Nichols (1964) identified two broad categories of communities based on soil moisture relationships: 1) lowland communities situated near the main drainage channels with permanent subsoil moisture at 8-15 feet, and 2) upland communities characteristically situated on residual sandy soils. The sagebrush-rabbitbrush lowland community was located on alluvial deposits of the first terrace adjacent to the stream channel. Basin big sagebrush (A. tridentata ssp. tridentata) occupied 26 percent of the composition and 6.4 percent of the ground cover, silver sagebrush 17 and 2.8 percent, and rubber rabbitbrush 55 and 13.6 percent respectively. Needleandthread, Sandberg bluegrass (Poa secunda), and Indian ricegrass (Oryzopsis hymenoides) were the

major forage species.

The upland community featured a thin (8 percent cover) Wyoming big sagebrush overstory with blue grama, sandberg bluegrass and needleandthread. Soil texture was not considered to be a factor in lowland communities, but the higher permeability of the upland communities was thought to be responsible for sagebrush as an overstory dominant. Sagebrush also occurred within the saltbush (Atriplex gardnerii) community wherever additional moisture was available e. g., around ant hills or in small channels with running water.

In a similar study of the dissected badlands of the Little Missouri River, Hanson and Whitman (1938), supported by Hazlett and Hoffman (1975), found that while silver sagebrush occurred on the alluvial deposits of the valley floors, big sagebrush dominated the higher benches and terraces. Bench and terrace soils tended to be alkaline, medium to heavy textured, and older with distinct profile characteristics. Both species of sagebrush appeared to develop under the influence of a water table within root range for at least part of the growing season. In a study of succession on solonetz soils, Hanson and Whitman (1937) found that A. tridentata appeared to be confined chiefly to the soloth stage or 'steps' where water relationships may be better.

In general, it appears that the major sagebrush community in northeastern Wyoming and southeastern Montana is associated with the heavier soils. The typical community is a shrub-shortgrass (blue grama) type. A further breakdown can be made on the presence of certain mid-grasses as these indicate growing conditions associated with soil texture: western wheatgrass on clayey soils, needleandthread on loamy soils, bluebunch wheatgrass (Agropyron spicatum) on sandy or gravelly soils, and little bluestem (Schizachyrium scoparium) on coarse and calcareous soils (unpublished data collected by J. T. Thilenius, Rocky Mountain Forest and Range Experiment Station).

Abandoned Fields

In response to economic and social trends in the past, a substantial area of the northern Great Plains has been put into cultivation and subsequently abandoned. Secondary succession on such disturbed areas illustrate local and regional site potentials, in progressing through the stages of 1) annual weed, 2) mixed annual-perennial, 3) late annual-perennial, 4) perennial grass, and 5) climax species (de Anda 1977). Reestablishment of the native vegetative community requires a minimum of 40 years under good conditions (Lang 1941, de Anda 1977). The recovered community is typical of northern Great Plains range in eastern Wyoming, except that big sagebrush may be more abundant. This conclusion is supported by longterm range surveys (Lang 1945, 1973) in northeastern Wyoming which showed 1) an increase of shortgrass cover and a decrease of midgrasses on plots open to grazing, but an opposite relationship on protected plots; and 2) a general increase of plains pricklypear and big sagebrush on both open and protected plots. The effects of over grazing and disturbance on big sagebrush density and distribution are also pointed out by Wright and Wright (1948).

Site Evaluation

The relationship of environmental factors to annual forage production was studied by Ries (1973) on seventeen sagebrush-grass sites in Wyoming. Significant simple correlations were found for 19 of 42 environmental variables in relation to annual forage production. Stepwise multiple regression analyses identified six factors as most important to production: fall precipitation, spring precipitation, summer potential evapo-transpiration, percent very fine sands, percent coarse fragments, and percent grass and forb composition. These factors were biologically sound in explaining site production; the multiple regression equation showed a correlation coefficient of .80 and a determination coefficient of .64, statistically significant at more than 95 percent probability.

In a further study of the relationships of vegetative production to 40 physical and chemical soil characteristics, Taha (1977) found that although production relationships for grasses and forbs could be identified, soil factors responsible for big sagebrush production could not be isolated. It was suggested that moisture and nutrients drawn from deep soils not sampled in the investigation might explain the apparent lack of production-soil relationships for big sagebrush.

In a study of phenology in relation to environmental and vegetative production factors, Kleinman (1976) found that stepwise multiple regression analysis of 17 independent variables explained 43 percent of the variation for big sagebrush. The most significant factors were soil moisture at medium depth (15-30 cm), summer precipitation, and maximum air temperature. Other important variables were soil moisture at shallow depth (0-15 cm), soil temperature, fall precipitation, and herbage production. In a related study, Cox (1977) found that soil moisture at shallow depth (0-15 cm) and minimum temperature most influenced the vegetative and reproductive phenology of big sagebrush.

Flesland (1964) studied the salt-desert shrub type of the North Dakota badlands in some detail, following Stevens' (1943) general description. The work represented an addition to Nelson's (1961) examination of woody vegetation types in the area, including big sagebrush. The type was characteristic of very steep slopes (32-45°) undergoing severe erosion, and was most typical of east and south aspects. The communities existed as scattered plots of small size, usually less than 1 acre. Each had a sparse sprinkling of shrubs, big sagebrush the most important, with an average cover of 282 ft^2 /100 yd^2. A scanty suffrutescent layer and a very scattered herbaceous layer formed the remaining vegetation. Salt content of the soils ranged from a low .10 to 1.20 percent, averaging .60. Distribution of shrubs tended to group in minor associations of very small extent; big sagebrush occurred on lighter-textured soils of lowest salt content.

Conclusions

Some broadscale patterns in the distribution and ecological relationships of Artemisia in the northern Great Plains are clear:

1. Wyoming big sagebrush is a regional dominant and a strong climax species in northeastern Wyoming, due to Great Basin climatic influences. The region may be thought of as a vast tension zone between Great Basin and Great Plains vegetation.

2. Big sagebrush occupies a diminishing role as a regional dominant to its northern distribution limits in Montana; dense stands become more discrete and edaphically controlled with broad transition zones to pure grassland.

3. Big sagebrush is clearly an edaphic climax species at its eastern distribution limits in the Dakotas.

4. Silver sagebrush occurs largely east of the Continental Divide as well-adapted and a widely-distributed native shrub. Normally it occurs as scattered shrubs on uplands; greater numbers and sometimes local dominance are achieved in well-watered bottoms.

5. Silver sagebrush is best adapted to well-drained, coarser soils. In most areas its occurrence serves as an indicator of these characteristics. It exhibits a definite preferance for bottoms and drainageways with better water relations, especially where its roots can intersect the water table for at least part of the growing season.

6. Wyoming big sagebrush is best adapted to medium to heavy-textured soils in its area of regional dominance, but it occupies sites with locally favorable conditions as well. In areas of the Plains too dry or too salty for big sagebrush growth, it occurs wherever additional moisture is available. Conversely in other areas too wet for it to compete successfully with mixed prairie vegetation, it occupies sites- rough breaks, badlands-made drier by local conditions.

7. In all areas, except Wyoming and parts of Montana, big sagebrush exhibits the attributes of a plant at the outer reaches of its range- disjunct populations and concentration on sites with favorable soil and moisture conditions. Silver sagebrush, on the other hand, exhibits the properties of a plant well within its established range.

8. Big sagebrush has definite standing as a grazing disclimax (increase in density) through most of its distribution. Overgrazing of the associated herbaceous species would profit sagebrush in the release of competition, and in making the site warmer and drier.

9. Study of site factors for silver sagebrush has not been done, but some study of big sagebrush factors has been completed. There is an emerging consensus on the relation of physical factors to vegetative production and phenology.

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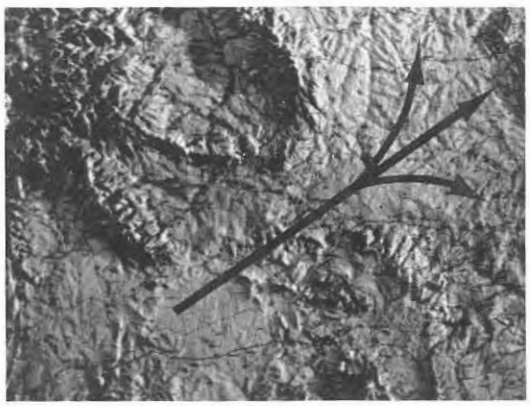

Figure 2. The physiographic features of Wyoming allowing Great Basin air masses to flow into the northern Great Plains.

Figure 4. Wyoming Big sagebrush (A. tridentata ssp. wyomingensis) community in the northern Great Plains of Wyoming.

Figure 3. Powder River Basin in Wyoming, typical of northern Great Plains landforms.

Figure 5. The distinctive long, linear leaves of silver sagebrush (A. cana ssp. cana)

NATIVE FAUNAL RELATIONSHIPS IN SAGEBRUSH ECOSYSTEMS

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Abstract

Sagebrush ecosystems provide food, cover, escape routes, breeding sites, rearing sites, etc., for a variety of animal species. Some of these species inhabit sagebrush habitats year-round, while others utilize them only seasonally. A few animals (e.g., pygmy rabbits, sagebrush voles, Great Basin pocket mice, least chipmunks, sage grouse, Brewer's sparrows, and some insects) are highly dependent on sagebrush communities, whereas the more adaptable species occur in other habitats as well.

Foraging animals may utilize grasses, forbs, and shrubs associated with sagebrush communities, and often the sagebrush species as well. The rodents, leporids, small birds, reptiles, amphibians, and insects supported by sagebrush communitites are important as prey for predatory animals living in and/or adjacent to these areas.

INTRODUCTION

The faunal composition of any sagebrush ecosystem will depend upon the species of sagebrush occurring in the area and the species composition of other vegetation. Percent cover, soil type, and terrain are also contributing factors, as well as associated habitat types. For example, riparian associations within sagebrush communities might result in the presence of animals which would not otherwise occur in the type. Faunal composition may also vary with the intensity of grazing by domestic livestock.

To enumerate all animal species which occur in sagebrush ecosystems and elaborate on their relationships to each other and their environment is not possible in this format. We have attempted to review pertinent literature on the more important species. Not surprisingly, much more information is available on game species than on reptiles, amphibians, invertebrates, and many bird and mammal non-game species.

In this paper "sagebrush" most often refers to big sagebrush *(Artemisia tridentata)*, but "sagebrush communities", "sagebrush habitats", etc., may include many of the other species. Emphasis has been placed particularly on sagebrush ecosystems of the Great Basin area.

MAMMALS

Ungulates

Mule deer *(Odocoileus hemionus)* are closely associated with sagebrush ecosystems in much of their range. Although scarce during prepioneer and early pioneer days, this species built up in large numbers during the second quarter of the twentieth century (Julander and Low 1976). This build-up was concurrent with predator control, limited harvests, and a change in range composition (from grass to browse).

According to Urness (1976), "an extensive literature attests to general abusive rangeland use by livestock over most of western North America from mid-nineteenth century settlement, up to the present in some cases." In the sagebrush-bunchgrass type, heavy grazing resulted in a decline in grasses and an increase in shrubs (Stoddart 1941, Urness 1976). Fire suppression also contributed to the increase in shrubs (Julander 1962). Since mule deer are primarily browsers (Mackie 1970, Kufeld et al. 1973, Tueller and Monroe 1975, Hansen and Reid 1975, Papez 1976, Hansen and Clark 1977), the successional change favoring shrubs permitted the increase in deer densities (Urness 1976).

Shrubs, forbs, and grasses associated with sagebrush are important in mule deer diets. Of 13 important deer range plant communities identified for 8 areas in a Nevada study, 8 were sagebrush types (Tueller and Monroe 1975). Such shrubs as curl-leaf mountain mahogany *(Cercocarpus ledifolius)*, bitterbrush *(Purshia tridentata)*, serviceberry *(Amelanchier alnifolia)*, and others are utilized (Julander 1955, Tueller and Monroe 1975, Papez 1976) at various seasons. Kufeld et al. (1973) reported that forb use is highest in summer, while grasses are used primarily in spring. In some areas, sagebrush itself may constitute a significant portion of mule deer diets, at least seasonally. Mackie (1970) found that big sage was the most important winter forage of deer in a Montana study. Pudney (1972) reported that use of big sage in eastern Nevada was highest in winter and spring, and made up the greatest part of the diet (by percent composition) for the entire year. Hansen and Reid (1975) also reported heavy use of sagebrush by deer during winter and spring in a Colorado study.

The sagebrush zone is important particularly as winter range. In many areas, deer utilize higher elevation range during summer, migrating to the sagebrush zone during winter. According to Tueller and Monroe (1975), the northern desert shrub type is important as deer winter range due to its considerable acreage and general lack of deep snow.

Elk *(Cervus canadensis)* utilize sagebrush-grass communities to some extent, especially during winter. Mackie (1970) found that *Artemisia-Agropyron* areas were used in fall and spring as well as winter. In northern Utah (Kimball and Wolfe 1974) and northwestern Colorado (Hansen and Clark 1977) elk utilized low elevation brush range which included various sagebrush species. Kufeld (1973) reported that big sagebrush was a "valuable" forage during fall and winter in some areas.

Elk are generally dependent upon grasses for forage (Morris and Schwartz 1957, Knight 1970, Hansen and Clark 1977). Mackie (1970) found that elk depended primarily on forbs in the summer and grasses during the other seasons. However, in some areas, the species utilizes browse heavily (Young 1938). In an area supporting both elk and deer, Hansen and Clark (1977) found that big sage was important deer forage, but was utilized only slightly by elk.

Pronghorn antelope *(Antilocapra americana)* are linked closely with sagebrush-grass habitats in the western states. Athough this species reached its greatest numbers in short grassland communities, it was not restricted to these areas, and the Great Basin once supported thousands (Fautin 1946). The diaries of early explorers reveal that antelope were once the common ungulate in sagebrush communities west of the Rockies (Fautin 1946). Before white settlement, pronghorns "were the co-dominant grazing species with bison *(Bison bison)* on the Great Plains and with elk on the Palouse and California Prairies" (Evans and Probasco 1977).

The decline of antelope from about 35 million before white settlement to less than 20,000 in the early 1900s was probably due to a combination of factors. Uncontrolled hunting and habitat reduction (Yoakum 1968), as well as construction of fences and susceptibility to disease (Evans and Probasco 1977), may have contributed to the decline. Since the turn of the century, antelope populations have built up, with greatest numbers in the high plains of Wyoming and Montana. Yoakum (1968) estimated the population in the 1960s at about half a million.

The importance of forbs and browse in the diet of antelope has been mentioned in several studies. In southwestern Utah, Smith et al. (1965) found that major winter foods of captive pronghorns were big sage and black sage *(Artemisia nova)*. These conclusions were later confirmed by field observations (Beale and Smith 1970). Another Utah study revealed that although browse contributed the most to summer diets, with *Artemisia nova*, *A. frigida*, and *A. tridentata* all important, a variety of forbs within the *A. tridentata* type were also used (Smith and Malechek 1974). Severson and May (1967) concluded that antelope in a sagebrush-grass type in Wyoming utilized shrubs primarily, and that pronghorns competed very little with domestic sheep for forage. In Alberta, Mitchell and Smoliak (1971) found the year-long diets of pronghorns to be composed of 51 percent forbs, 35 percent browse, and 14 percent grasses and sedges. These authors concluded that "the role and importance of big sagebrush in the diet of antelopes south of latitude 49°N is assumed by silver sagebrush *(A. cana)* and pasture sagewort *(A. frigida)* in the diets of antelopes in Alberta." In Idaho, Autenrieth and Fichter (1975) found that sagebrush was important not only as forage, but because it furnishes fawning cover.

Bighorn sheep *(Ovis canadensis)* were once numerous in most mountain ranges of the West, as well as the "badlands" of the plains (Buechner 1960). However, with the advent of pioneer settlements, the sheep were eliminated in much of their previous range. The species was over-hunted, and over-grazing by livestock resulted in range deterioration. This habitat shift, which resulted in improved deer habitat in Nevada, brought about a decrease in bighorn numbers (McQuivey 1978). Likewise, bighorn population reductions throughout the West have been blamed on livestock grazing pressure (Packard 1946, Buechner 1960). However, Buechner (1960) speculated that scabies, apparently contracted from domestic sheep, was the greatest contributor to the bighorn's decline.

In Nevada, according to Hall (1946), and Buechner (1960), bighorns were once distributed over most of the State. However, based on petroglyphs depicting bighorn bones at archaeological diggings, historical records, and increased knowledge of sheep habitat requirements, McQuivey (1978) concluded that the populations were not continuous, but rather isolated. Many of these populations were located in mountain ranges where the sagebrush zone currently dominates alluvial fans and foothills. This zone represents the climatic climax of desert areas where annual precipitation usually exceeds 7 in (Cronquist et al. 1972).

Sagebrush-grass communities are still utilized by bighorns in some areas, especially as winter range (Buechner 1960). Rumen analyses of 177 desert bighorns *(O. canadensis nelsoni)* in Nevada since 1956 showed an overall diet composition of 65.3 percent grasses, 28.2 percent shrubs, and 6.5 percent forbs (McQuivey 1978). Big sagebrush was identified as a

preferred shrub. In a Colorado study of Rocky Mountain bighorns *(O. canadensis canadensis)*, grasses and sedges made up 46 percent of the yearly diet, shrubs 45 percent, and forbs 9 percent (Todd 1975). Major food items were fringed sage, sedges, and 4 genera of bunchgrasses.

Predators

Coyotes *(Canis latrans)* are without doubt the most important predator in the sagebrush type. Although this adaptable species is distributed throughout most habitat types in the West, it is closely associated with sagebrush communities in much of its range. Fautin (1946) found that coyotes were more abundant in brush than in more open areas. Based on induced howling response Kauffeld (1977) believed that coyotes in eastern Nevada preferred black sagebrush flats to other habitats. These flats were areas of highest black-tailed jackrabbit *(Lepus californicus)* densities.

Food habits studies in western states (Bond 1939, Sperry 1941, Fitch 1948, Murie 1951, Gier 1968, and Hawthorne 1970) have shown that rabbits and rodents are the most important components of coyote diets. In a Nevada study, jackrabbits were the major food source during all seasons (Kauffeld 1977). Clark (1972) found that jackrabbits in Curlew Valley, Utah, composed 75 percent of coyote winter diets and that the black-tailed jackrabbit cycle was the major factor controlling coyote populations. In a Nevada range where jackrabbits did not occur, rodents, primarily Belding ground squirrels *(Citellus beldingi)* were used most heavily by coyotes (Howanyk 1975). In some areas, coyotes have relied on fruits, berries, and insects (Murie 1951, Meinzer et al. 1975).

Coyote predation on big-game occurs but the extent has not been well established. Cahalane (1947), Young and Jackson (1951), and Robinson (1952) have all reported instances of coyote attacks on mule deer. Knowlton (1976) suggested that, in some cases, coyote predation on deer might be symptomatic of other environmental deficiencies. Coyotes have also been known to prey upon antelope (Thompson 1949).

The diet versatility and relative abundance of coyotes in the West makes this species the principal predator of domestic sheep (Presnall 1948). Questions concerning the extent of sheep predation by coyotes and the effectiveness of coyote control programs have resulted in many studies since the early 1970s. Research in California (Nesse 1973, McAdoo and Klebenow 1978), Nevada (Klebenow and McAdoo 1976, Kauffeld 1977), Utah (Bowns et al. 1973), New Mexico (DeLorenzo and Howard 1976), Idaho (Nass 1976), and Montana (Henne 1975, Munoz 1976) has shown that the extent of depredations is variable from one operation to the next. Type and intensity of predator control, sheep management, and natural prey availability have all been mentioned as variables which influence predation intensity.

Other canine predators in sagebrush communities include the kit fox *(Vulpes macrotis)*, red fox *(V. fulva)*, and gray fox *(Urocyron cinereoargentus)*. According to Fautin (1946), kit foxes range throughout the northern desert biome. Although kit foxes eat rodents of various species, as well as rabbits and insects, Bailey (1931) wrote that kit fox distribution in New Mexico is closely correlated with the occurrence of kangaroo rats *(Dipodomys* spp.). All fox species prey primarily on small mammals and birds, although gray foxes are highly omnivorous (Bailey 1931).

Mustellids occurring in sagebrush communities include the short-tail weasel *(Mustela erminea)*, long-tail weasel *(Mustela frenata)*, badger *(Taxidea taxus)*, spotted skunk *(Spilogale putorius)*, and striped skunk *(Mephitis mephitis)*. These species are all primarily nocturnal. Weasels thrive on rodents, especially pocket gophers *(Thomomys* spp.), and use the burrows of gophers for shelter (Hall 1946). Badgers feed on a variety of prey, including various rodents, reptiles, insects, and eggs (Hall 1946), but burrowing rodents are their primary food source (Hall and Kelson 1957). Skunks are dependent primarily on small animals and insects (Hall 1946), but will also prey on small birds, reptiles, amphibians, and eggs (Evans and Probasco 1977).

Mountain lions *(Felis concolor)* are typically restricted to areas of either dense vegetation or rugged terrain. In some areas of the West, lions are associated with those sagebrush communities which occur in the foothills of rugged mountain ranges. Such areas typically border pinyon-juniper or mountain brush vegetation types and support flourishing deer herds.

Mule deer are a major prey species of lions in the West (Rasmussen 1941, Hall 1946, Hornocker 1976). In an Idaho study, Hornocker (1970) found that lions relied heavily on both mule deer and elk, while use of bighorn sheep was negligible. Hornocker concluded that lions did not limit ungulate populations, but had a dampening effect on prey oscillations.

Although lions have disappeared from some parts of their previous range, some areas have apparently experienced an increase in lion numbers. In Nevada, the species increased in the early 1900s as deer herds increased, and have decreased since the 1960s with a decline in deer numbers (Greenley 1971). Utah has apparently experienced a similar phenomenon. Nappe (1974) speculated that Nevada presently has more lions than when the first white settlers entered the State.

Bobcats *(Lynx rufus)* are typically associated with either rocky or wooded terrain, but are often found in sagebrush communities. Linsdale (1938), and Borell and Ellis (1934), recorded the presence of bobcats in and adjacent to sagebrush communities in central Nevada. According to Gashwiler et al. (1960), bobcats occur in valleys and mountain sections of eastern Nevada and Utah, but are most common in juniper-covered foothills and rocky outcrops.

In an Idaho study, Bailey (1972) found that bobcats depended primarily on jackrabbits and cottontails *(Sylvilagus* spp.) as their food source in an area where sagebrush-grass was the climax vegetation. Cottontails were more vulnerable to predation and were the preferred species. Similarly, Gashwiler et al. (1960) found that leporids, primarily cottontails, were the major foods of bobcats in Utah and eastern Nevada.

Bobcats also prey on gamebirds and big-game species. In a Utah study Beale and Smith (1973) found that bobcat predation was the major cause of fawn losses to antelope on the Desert Experimental Range. Rasmussen (1941) reported that bobcats in the Kaibab Forest take an occasional mule deer fawn, and Dill (1947) documented a bobcat attack on an adult doe.

Prices for bobcat hides have skyrocketed in the past 10 years, with prime furs bringing more than $200 in the western states. The resultant increased pressure on bobcat populations has caused concern about possible over-harvest. Several states have taken actions to afford the cats with some protection (Laycock 1978).

Hares and Rabbits

Five species of lagomorphs may occur in sagebrush ecosystems. Four of these, the white-tailed jackrabbit *(Lepus townsendi)*, mountain cottontail *(Sylvilagus audubonii)*, and pygmy rabbit *(S. idahoensis)*, are considered game animals in most states. Black-tailed jackrabbits are generally unprotected.

All of these species consume green vegetation, and the two jackrabbits can cause considerable damage to hay crops and range vegetation (Bear and Hansen 1966). Twelve black-tailed jackrabbits will consume as much vegetation as one sheep, and 59 as much as one cow (Burt and Grossenheider 1976). In general, studies have shown that *Lepus* spp. are more numerous on deteriorated range than on lightly or unused ranges (Taylor et al. 1935, Phillips 1936, Bear and Hansen 1966). Jackrabbits may exert forces favoring succession toward the climax on moderately deteriorated ranges, and further deplete those ranges having more weeds than grass (Bond 1945).

According to Bear and Hansen (1966), black-tailed jackrabbits are spreading into areas formerly occupied by white-tails in Colorado. The authors found that during spring, summer, and early fall, grasses and forbs were most important in the diet of white-tails. Although shrubs were the most important winter food source, big sage was a least preferred species. Currie and Goodwin (1966) found that black-tailed jackrabbits in Utah utilized big sage during winter, but not until November when the plants were dormant. In Nevada, Gustafson (1974) reported that black-tails fed on sagebrush leaves and bark during winter. Borell and Ellis (1934) reported that white-tails in eastern Nevada were once much more widely distributed.

In a Colorado shortgrass-prairie, Flinders and Hansen (1975) found that desert cottontails were more abundant in areas where moderate grazing had resulted in greater density of shrub cover. In pinyon-juniper woodland Kundaeli and Reynolds (1972) reported that this species increased with shrub density to a point, then decreased. Borell and Ellis (1934) found that mountain cottontails preferred heavy brush along streams and dense sagebrush-rabbitbrush *(Chrysothamnus* spp.*)* flats. Of all the species, pygmy rabbits are possibly the most dependent on sagebrush. These animals inhabit areas of tall sagebrush growing in clumps, and feed primarily on sagebrush (Burt and Grossenheider 1976).

Rodents

A wide variety of rodent species is found within sagebrush ecosystems. Of these, the eurotypic deer mouse *(Peromyscus maniculatus)* is one of the most abundant nocturnal species (Borell and Ellis 1934, Linsdale 1938, Larrison and Johnson 1973, O'Farrell 1973, Howanyk 1975, Kauffeld 1977). Fautin (1946) reported that big sage provided cover and nesting areas for deer mice. Sagebrush voles *(Lagurus curtatus)* are more restricted to sagebrush habitats and require grass for both cover and food (Moore 1943). Another nocturnal species, the Great Basin pocket mouse *(Perognathus parvus)*, was reported in a Utah study to be restricted to sagebrush communities (Fautin 1946). In Washington, Kritzman (1974) reported that, in a big sage habitat, deer mouse density increased with elevation, while pocket mouse density decreased.

Least chipmunks *(Eutamias minimus)* are a common diurnal species closely associated with sagebrush communities. This species was described as being a characteristic mammal of big sage-grass habitat in eastern Nevada (Borell and Ellis 1934). In another Nevada study, Kauffeld (1977) found that least chipmunks were the most abundant diurnal species in sagebrush habitats. We have made similar conclusions in an ongoing study in central Nevada, but have found this species to be spotty in distribution. In western Utah, this species was reported to occur only in the sagebrush community (Fautin 1946).

By combining the results of 4 Nevada studies (O'Farrell 1973, Gustafson 1974, Howanyk 1975, Kauffeld 1977), a total of 28 rodent species is obtained for various sagebrush types. Species diversity of rodent species in sagebrush habitats is dependent upon plant composition and range condition. In reviewing literature, Larrison and Johnson (1973) stated that studies have shown range depletion to favor an increase in deer mice and a decrease in western harvest mice *(Reithrodontomys megalotis)*.

Rodents inhabiting rangelands can cause considerable damage to vegetation, especially during cyclic population highs. Green vegetation, seeds, bulbs, and roots are consumed by various species. In a Utah study, long-tailed voles *(Microtus longicaudus)* girdled and killed big sage and other shrub species (Frischnecht and Baker 1972). Similarly, Mueggler (1967) reported an outbreak of voles *(Microtus* spp.*)* in Montana which killed hundreds of acres of sagebrush by bark stripping. Range damage is not always limited to forage consumed. For example, burrows can accelerate erosion, disrupt irrigation, and cause livestock accidents. Some vegetation is removed and not consumed ("waste cutting"), and den areas are frequently denuded.

Although high rodent populations can be detrimental to range conditions, the same species at lower populations can be beneficial. For example, many rodents, though primarily herbivores, feed upon insects at certain times of year. Other species, such as the northern grasshopper mouse *(Onychomys leucogaster)*, are primarily insectivorous year-round. Some species (i.e., *Dipodomys* spp.*)* "cache" seeds a few centimeters below the soil surface, and many

which are not retrieved by rodents later germinate (LaTourrette et al. 1971, McAdoo et al. 1978). This phenomenon may be important for the propagation of some plants.

Another often-neglected aspect of small mammal-range-livestock interactions concerns the role of rodents in predator diets. Studies have indicated that during periods of natural prey scarcity, predators (particularly coyotes) depend more upon livestock as alternate prey (Presnall 1948, Howard 1974, Howanyk 1975, McAdoo 1975, Kauffeld 1977).

As pointed out by Leopold (1964), serious outbreaks of rodents in the West are sometimes " a direct result of land misuse, particularly over-grazing." He suggests that rodent control is not the cure in such instances, but rather an attempt to relieve a symptom. The role of rodents in sagebrush habitats is complex, and management of these areas will benefit from a greater working knowledge of the intricacies involved.

BIRDS

Upland Game

Few animals and no other game birds are as closely associated with a habitat type as is the sage grouse *(Centrocercus urophasianus)*. All of the requirements for breeding, nesting, rearing, and feeding are found in the sagebrush-dominated environment (Girard 1935, Rasmussen and Griner 1938, Griner 1939, Patterson 1952, Leach and Hensley 1954, Dalke et al. 1963, Rogers 1964, Klebenow and Gray 1968, Klebenow 1969, Peterson 1970, Wallestad 1971, Eng and Schladweiler 1972, Wallestad and Pyrah 1974, Wallestad 1975). In this environment, the interspersed meadows are important feeding grounds (Savage 1968, Oakleaf 1971).

Due to their dependence upon sagebrush-grassland habitat, sage grouse were once found virtually wherever sagebrush occurred. In pioneer times this bird was found in 14 or 15 western states and was considered the leading game bird in 9 states. Settlement, with its inevitable intensification of agriculture, grazing, and hunting led to diminished populations. In the early 1930s it was considered an important game bird only in parts of Montana, Wyoming, Idaho, and Nevada, and by 1937 only Montana retained a regular open season (Rasmussen and Griner 1938). Low populations showed upward trends in the mid-1940s and around 1950 most western states again permitted hunting (Patterson 1952). The most recently available hunter-kill estimates would indicate that the sage grouse is at least maintaining its population sufficiently to be a major game species in 5 states and of secondary importance in 6 more states and 2 Canadian provinces (Johnsgard 1973).

Where agriculture converted wild meadows into domestic hayfields, the bird adapted to the new sources of succulent feed (Eng 1952). This is the only adaptability the species has exhibited. Further changes have occurred, however, to which the bird cannot adapt. Large-scale irrigation has enabled the conversion of extensive areas to irrigated farmland. Industrial and urban development in some places has added to the impact. Much sagebrush has disappeared (Edminister 1954). In remaining sagebrush rangelands, increased dominance by sagebrush has occurred with protection from fire and extensive overgrazing. Sage grouse have not increased proportionately to the increased density of sagebrush. Habitat diversity within the sagebrush environment is necessary to provide for all the needs of the sage grouse (Klebenow 1972).

Better range management of sagebrush-rangelands may lead to increases in sage grouse populations on these ranges. Further conversion of these ranges by agriculture, mining, urbanization, or other practices will reduce the total habitat available for the future.

At one time, great numbers of Columbian sharp-tailed grouse *(Pedioecetes phasianellus columbianus)* inhabited the grassy plains and foothills within the climax sagebrush vegetation of the Great Basin. First described by Captain Lewis of the Lewis and Clark expedition in 1806, the birds were abundant and remained so until 1910-1915 when they disappeared over much of their original range (Hart el al. 1950. Yocum 1952, Buss and Dziedzic 1955). Most commonly, the disappearance of the birds has been related to the destruction of essential habitat by agricultural practices (Jensen 1937, Edminister 1954, Buss and Dziedzic 1955, Jones 1966, Evans 1968). Farming has not been the sole cause of habitat loss, however.

In Nevada, sharp-tailed grouse have not been seen for 20 years or more. Hoffman (1881) and Linsdale (1936) reported them as being in moderate numbers or common in northern Nevada. Ridgeway (1977:599) collected a young female in the upper Humboldt Valley, September 16, 1868, and found the species ". . . abundant in rye-grass meadows at the base of the Clover Mountains." Presently, sharp-tails are considered extinct in the State. The most likely reason for the loss is destruction of habitat by overgrazing and successional change (Nappe and Klebenow 1973).

The mourning dove *(Zenaidura macroura)* is migratory and depends on the sagebrush grassland for life requirements only during the breeding season. It is second to the chukar *(Alectoris graeca)* in number of game birds harvested in Nevada with more than 180,000 birds taken annually (Giezentanner 1973). While more abundant in agricultural areas than in native rangelands, the sagebrush habitat type is an important nesting habitat. Burned areas with no shrub cover are important as late summer feeding areas.

First introduced into the State of Nevada in 1935, the chukar partridge established and has become the number one game bird (Molini 1976). In the southern sagebrush-grassland, it has become an important, although exotic, inhabitant. In the Great Basin, cover is provided by rock outcroppings and associated scattered shrubs. Food is provided primarily by grass and forb leaves and seeds. Water is provided by the springs, seeps, and small perennial and intermittant streams. The arrangement of these habitat components is the factor determining population densities. In some years and in some northern desert shrub habitats, chukar densities may reach 20-50 birds per mi^2.

It was the early introduction of cheatgrass *(Bromus tectorum)* into the western United States that may well have paved the way for the successful introductions and establishment of this Asian exotic

partridge. Overgrazing permitted the invasion of annual Mediterranean grasses under the shrubs as replacements for the weakened native perennials (Billings 1951). Now, in Nevada, where we have extensive stands of cheatgrass, we have some of the best chukar populations (Christensen 1970). Chukar are usually associated with cheatgrass or red-stem filaree *(Erodium cicutarium)* (Galbreath and Moreland 1953, Harper et al. 1958, Mackie and Buechner 1963).

Waterfowl

Sagebrush-grasslands are not noted for their waterfowl production, although marshes exist within the vegetative type that produce significant numbers. For example, Gray's Lake in Idaho, the Ruby Marsh, Humboldt River, and Stillwater Marsh in Nevada are duck-producing habitats of recognized value.

With agricultural development and the increased intensity of grazing management, a new type of waterfowl habitat has become more and more important - created upon land usually without surface water. Irrigation projects and stock ponds are examples.

Water projects such as the Columbia River Irrigation Project in east-central Washington and the development in nearby Yakima Valley have resulted in hundreds of miles of drainage ditches and flooded lands. These areas are excellent places for production of mallards *(Anas platyrhynchos)*, blue-winged teal *(A. discors)*, and cinnamon teal *(A. cyanoptera)*. Densities of breeding ducks may average 15 to 30 per mi^2, and broods 5 to 10 per mi^2 (Jensen and Chattin 1964). Other projects of this type and many more smaller irrigation projects have created waterfowl habitat.

Stock watering ponds have been created by ranchers throughout the West. Their numbers are tremendous, with densities up to 1 per 500 acres or more (Gjersing 1971). Nearly all research on the productivity of these developments has occured in the Great Plains. Blue-winged teal, mallards, pintails *(A. acuta)*, shovelers *(Spatula clypeata)*, and American Widgeon *(Mareca americana)* are the major species produced (Bue et al. 1964). Duck breeding populations vary between an estimate of 3.3 pairs per mi^2 (1.8 pairs per surface acre of water) (Lokemoen 1973), and 7.0 pairs per mi^2 (2.3 pairs per surface acre of water) (Bue et al. 1952). Brood production ranges from 0.79 per acre of stock watering pond (Lokemoen 1973) to 1.5 per acre (Bue et al. 1952).

Non-Game

In rangeland habitats where grazing is the major utilization, the effects on breeding birds are not uniform because grazing varies so much in its local intensity and impact. Alterations in avifauna largely relate to the effects of grazing on vegetation structure and composition. Grassland studies under the International Biological Program have shown that where grazing produced marked changes in vegetation, there were accompanying major shifts in the avian community composition (Weins and Dyer 1975).

Where rangelands are managed under some system of rest and rotation, grazing may be intensified where cattle are confined, and eliminated from the areas from which cattle are excluded. The fencing of these areas sharpens the differences between locally adjacent plant communities and thereby creates a local mosaic of avian communities of differing species composition and structure. Unfenced rangelands grazed moderately will not have these grazing differences and presumably the avifaunas are less changed from the original composition (Weins and Dyer 1975).

In the riparian zone of the sagebrush-grassland, changes in avifauna populations have been related to the loss of portions of the shrub understory (Oakleaf and Klebenow 1975). Comparisons of recent populations with those in 1868 (Ridgeway (1877) revealed the lack or decline of species that normally occupy willow *(Salix* spp.) or bullberry *(Shepherdia argentea)* thickets or dense brush tangles of other shrubs. Birds such as the yellow-throat *(Geothlypis trichas)*, yellow-breasted chat *(Icteria virens)*, Traill's flycatcher *(Empidonax trailli)*, yellow-billed cuckoo *(Coccyzus americanus)*, and others were affected. Intensive, season-long grazing by livestock, coupled with flood control efforts by the Corps of Engineers, have resulted in elimination of the shrub niches needed by the species of birds affected.

Sagebrush control with herbicides that totally eliminated sagebrush resulted in declines of breeding pairs of Brewer's sparrows *(Spizella breweri)* Best 1972). Spraying which produced a partial kill of sagebrush was not followed by a population change of Brewer's sparrows or vesper sparrows *(Pooecetes gramineus)*. Although both species utilized sagebrush for nest cover, vesper sparrows nested on the ground, whereas Brewer's sparrows nested in shrubs. Little other information is available on the impact of sagebrush control on non-game species.

Other song-birds commonly occurring in sagebrush communities include horned larks *(Eremophila alpestris)*, sage thrashers *(Oreoscoptes montanus)*, mountain bluebirds *(Sialia currocoides)*, loggerhead shrikes *(Lanius ludovicianus)*, western meadowlarks *(Sturnella neglecta)*, green-tailed towhees *(Chlorura chlorura)*, lark sparrows *(Chondestes grammacus)*, black-throated sparrows *(Amphispiza bilineata)*, and sage sparrows *(Amphispiza belli)*. In western Utah, Fautin (1946) reported that shrikes, sage thrashers, sage sparrows, and Brewer's sparrows were found only in greasewood *(Sarcobatus* spp.) and sagebrush communties.

Man's impact on birds of prey in sagebrush lands has been analogous to the occurrences in other habitats. Raptors have been affected by predator control, indiscriminate shooting, toxic chemicals, habitat conversion, and other factors such as human disturbance of nestings sites, electrocution, etc. (Snyder and Snyder 1975). Impacts such as these have led to real or suspected population declines, of which the peregrine falcon's *(Falco peregrinus)* near extinction in the West is the most drastic example. The Endangered Species Act of 1973, together with other federal and state regulations, stimulated a flurry of surveys and research projects, such as those by Clark and Oakleaf (1976) and Siebert et al. (1976), to determine the status of raptor species. From these efforts, information on proper management of species and critical habitat is becoming available.

Important species in the sagebrush-grassland include the prairie falcon *(F. mexicanus)*, golden eagle *(Aquila chrysaetos)*, Swainson's hawk *(Buteo swainsoni)*, rough-legged hawk *(B. lagopus)* marsh hawk *(Circus hudsonius)*, American kestrel *(F. sparverius)* great-horned owl *(Bubo virginianus)*, and long-eared owl *(Asio otus)*. The eagles and large hawks and owls feed on rabbits, rodents, and snakes. The small hawks, falcons, and owls prey on small mammals, birds, snakes, and insects. Generally, raptors may be beneficial to man's economic well-being by helping to maintain stability and diversity of natural ecosystems, but the benefits are often ignored or discredited when losses of livestock or game species occur.

REPTILES

Many species of reptiles have been recorded in sagebrush habitats. Some species may occur which are associated primarily with other types found within the broader sagebrush areas. All reptiles enter long underground hibernation periods during winter, thus avoiding the cold which is deadly to these poikilotherms. Their covering of scales allows them to endure long dry periods which are common to sagebrush communities.

Fautin (1946) listed 5 species of lizards and 3 snakes as occurring in sagebrush communities of western Utah. The lizards included collared lizards *(Crotaphytus collaris)*, leopard lizards *(C. wislizenii)*, brown-shouldered Uta's *(Uta stansburiana)*, sagebrush lizards *(Sceloporus graciosus)*, and desert horned lizards *(Phrynosoma platyrhinos)*. Most of these are insect-eaters, but many will feed on other lizards as well. The sagebrush lizard was found only in greasewood and sagebrush and was often seen in the tops of these shrubs. This species lives on shrub-dwelling rather than ground-dwelling insects.

Snakes listed by Fautin (1946) included striped racers *(Masticophis lateralis)*, Great Basin gopher snakes *(Pituophis melanoleucus)*, and western rattlesnakes *(Crotalus viridis)*. The racers fed on lizards and beetles, whereas rodents were the mainstay of gopher snakes and rattlers.

In a sagebrush-grass habitat of the Kaibab Plateau, Rasmussen (1941) reported the presence of all lizards mentioned above except leopard lizards and horned lizards. He also listed desert spiny lizards *(Sceloporus magister)*, which were found only in the sagebrush-grass habitat. The only snake he recorded was the western rattlesnake. In a central Nevada study, Linsdale (1938) recorded 13 reptiles in the Toiyabe Mountain area, many of which occurred in sagebrush habitats.

Knowlton and Janes (1933) listed several lizards which occurred in areas supporting sagebrush in Utah. These included brown-shouldered Uta's, sagebrush lizards, short-horned lizards *(P. douglassi)*, desert horned lizards, leopard lizards, and tree lizards *(Urosaurus ornatus)*. In general, smaller lizards and immatures fed mostly on smaller insects, while larger lizards fed more upon larger insects. Brown-shouldered Uta's were the most abundant and important predator of beet leafhoppers *(Eutettix tenellus)*, an insect pest.

AMPHIBIANS

Amphibians have been able to adapt to arid climates through behavioral or physiological traits that conserve moisture (Evans and Probasco 1977). For example, many species are able to escape dry conditions by burrowing. In Nevada, Linsdale (1938) reported that many hundreds of western spadefoot toads *(Scaphiopus hammondi)* left their burrows when moisture conditions were suitable. This species was the only amphibian listed by Rasmussen (1941) as occurring in sagebrush-grass habitat of the Kaibab Plateau. Other amphibians known to occur in sagebrush areas include tiger salamanders *(Ambystoma tigrinum)*, Great Basin spadefoots *(Scaphiopus intermontanus)*, and Rocky Mountain toads *(Buffo woodhousei)*. According to Stebbins (1966), these animals "will eat almost any creature that moves and can be swallowed."

INVERTEBRATES

Fautin (1946) found 9 orders of invertebrates in sagebrush communities in western Utah, including spiders (Araneida), mites (Acarina), and insects (orders Orthoptera, Hemiptera, Homoptera, Coleoptera, Lepidoptera, Diptera, and Hymenoptera). Many species, such as spittle bugs *(Clastoptera brunnea)*, and snout beetles *(Apion sordidum)* were limited in distribution to the sagebrush communities. Other species were more common in sagebrush than anywhere else. Harvester ants were the most conspicuous ground-dwelling species. Four to 8 mounds of this insect occurred per acre, and an average of 300.7 ft^2 was denuded of vegetation around each mound.

Jorgenson and Tingey (1968) collected approximately 300 species of insects from areas in Utah with big sagebrush, rubber rabbitbrush *(Chrysothamnus nauseosus)*, bitterbrush, and crested wheatgrass *(Agropyron cristatum)*. They identified several types of insects which may damage various plant species in sagebrush communities, including spittle bugs (Cercopidae), cicadas (Cicadidae), gall insects, defoliators (Lepidoptera and Chrysomelidae), borers, mirids, ants, sucking insects, and seed parasites. Gates (1964) reported that 10 to 15 thousand acres of sagebrush (including big sagebrush, low sage, black sage, and silver sage) were killed by *Aroga* (a defoliator) in Malheur County, Oregon in 1962. In another Utah study, some species of thrips (Thysanoptera) were considered potential pests to plants found in sagebrush communities (Tingey et al. 1972).

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MINERAL-CYCLING ASPECTS WITHIN THE SAGEBRUSH ECOSYSTEM

By

H. F. Mayland and R. B. Murray[1/]

INTRODUCTION

All life forms absorb minerals, which are generally used in cellular metabolism. These minerals may be secreted during normal metabolism or mineralized after cellular death. The cycle can then be repeated.

Our studies of mineral cycling within the sagebrush *(Artemisia)* ecosystem attempt to explain why the productivity of one site is different from that of another. We may also want to know if enough minerals are available to support a shrub-to-grass conversion project or if the site provides adequate nutrition to herbivores. The mineral content of *Artemisia*, for example, has been used as a means of detecting precious metals in the subsoil. This procedure, known as biogeochemical prospecting, is commonly used in north-central Asia. The mineral enrichment studies comparing *Artemisia* in areas downwind and upwind from factories provide a base line for monitoring mineral fallout (Conner et al. 1976, Gough and Severson 1976, Severson and Gough 1976). Mineral cycling information also helps us to interpret the effects of fire, grazing, or erosion on the mineral status of a given site.

Literature

The English language literature on mineral cycling in the woody *Artemisia* includes G. E. Fogg's translation of the text by Rodin and Bazilevich (1965), two dissertations from Washington State University, and a series of International Biome Program-Desert Biome studies, some of which are in press. Other pertinent studies published in English will be mentioned below.

Much of the Russian work, except for Fogg's translation, is available only through the American Chemical Society's Chemical Abstracts, and even that is of limited value, because the data are presented on the basis of ash rather than dry matter. These data would be more useful if they were also given on the basis of herbage dry matter. Lavrenko and Borisova (1976) have edited a 3-volume Russian language series entitled 'Biocomplex Investigations in Kazakhstan'. Sections of this work by Miroschnichenko on ash composition of *Artemisia pauciflora* and *Atriplex* associations and by Gagarin and Miroschnichenko on mineral composition of vegetation growing on the steppes, semidesert and deserts of central Kasakhstan should be of interest. An English translation is not available yet.

The objectives of this paper are to briefly describe the cycling process and to give some data on the dry matter biomass, litter fall and decomposition, mineral concentration and mass, and mineral turnover for *Artemisia tridentata*. These data are supplemented by data on *Artemisia sieberi*.

Artemisia pauciflora is woody and 10 to 25 cm in height. It provides feed for sheep, horses, goats and camels. *Artemisia sieberi* is also woody and 20 to 35 cm tall (Polyakov 1961).

Readers interested in the methodology of measuring production and developing nutrient budgets in an ecosystem should refer to Chapman (1976). Those interested in a broader discussion of mineral cycling in rangeland ecosystems of the world should read the papers by Charley (1977) or West (In Press).

Process

The fate of minerals on a given site includes the cycling from soil to plant to litter and again to soil where the process is repeated. The time needed for the minerals to cycle through this closed system is call turnover time. It can be most accurately determined using mineral isotopes, a costly and time-consuming process. Turnover time may, however, be estimated as the mineral content in the biomass divided by that in the annual litter. This estimate assumes a steady state growth and decomposition, and it is often calculated for above-ground plant parts only.

Minerals can be lost from this system as volatile gases like N_2, NO, NH_3, and SO_2 or in volatile organic compounds. Fire results in gaseous losses of some N

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and S and perhaps other minerals that escape in the smoke and particulate matter. Some mineral mass leaves the system through wind or water erosion. Minerals in forage may contribute to the growth of herbivores, or they may be carried off site before they are excreted.

Minerals can be added to this system by dust, rain, animal excrement, fallout from factories, or even fertilizer. Biological fixation of N_2 or foliar absorption of NH_3, SO_2, F and some of the heavy metals can occur.

Readily mobile elements like K can be translocated from leaves back to the rest of the plant before senescence. Water soluble elements can be leached from the plant, thus entering the soil mineral pool.

Biomass

Data in Table 1 illustrate nearly an order of magnitude range in the above-ground biomass for *Artemisia tridentata* at five sites in southern Idaho and a sixth in south-central Washington. Sites 1 to 4 represent a dry to wet gradient. Soil moisture at site 5 is less than at site 1, whereas moisture at site 6 is intermediate to that at sites 1 and 2. Perennial plant parts and dead parts increase in mass as the age of the shrub stand increases. *Artemisia* roots at sites 5 and 6 make up 20 to 50% of the total biomass, respectively. Roots made up 27 to 57% of the *Artemisia sieberi* communities shown in Table 2. The community information in Table 2 represents shrubs plus grasses, whereas the information in Table 1 is for the *Artemisia tridentata* component only.

Litter Fall

The leaves of *Artemisia tridentata* consist of large (>30 mm) leaves produced in early spring and small (<30 mm) leaves produced in late summer. The large leaves begin senescing and falling in late spring (Figure 1). The small leaflets do not drop at any particular time. The inflorescence parts do not drop until late winter; the drop is enhanced by cold temperatures, snow and wind.

The annual parts of *Artemisia tridentata* constitute 150 to 1100 kg/ha (Table 1). Stem loss is generally a small part of litter fall and apparently

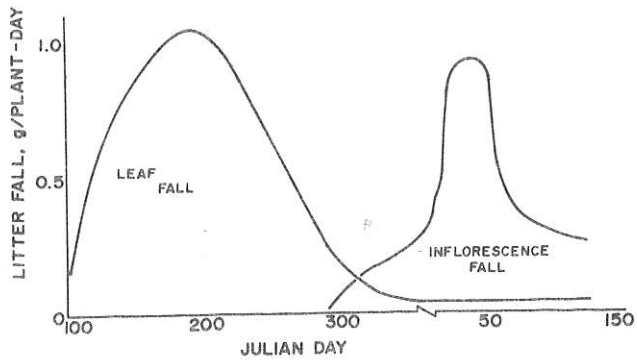

Figure 1. *Artemisia tridentata* leaf and inflorescence fall. Accumulative leaf fall was 135g/plant and accumulative inflorescence fall was 53g/plant. (Adapted from Mack 1971).

is not related to seasonal changes. We, therefore, assumed that the production of annual parts is nearly equivalent to litter fall. Mack (1971) collected 34 kg/ha of leaves and 28 kg/ha of inflorescences of *Artemisia tridentata* annually in litter traps. In another year he estimated 108 kg/ha-year leaf fall and 10 kg/ha-year inflorescence fall (Mack 1977). These amounts and proportions vary considerably from plant to plant and year to year. Root sluffing and decay also occur but are difficult to estimate.

Litter fall in the plant community may be much larger than these values shown for just the *Artemisia* component. Litter fall values of 500 to 2400 kg/ha are given in Table 2. Root residues contribute 26 to 46% of the litter fall.

Decomposition

The decomposition rate is generally measured as the loss of dry matter from material enclosed in fine mesh (<1-mm openings) bags. In reality this measures the rate of mastication or fragmentation to smaller particle sizes allowing escape from the bag. Murray (1975) found that 32 to 49% of the leaf litter remained at the Idaho study sites after 1 year (Table 3). Mack (1977) noted that 50% of the leaf litter remained after 1 year on the Washington study area and Comanor and Staffeldt (1978) reported that 47 to 57% of the leaf litter remained after 1 year near Reno. Mack (1971) found that less than 50% of the inflorescence litter remained at 1 year.

Comanor (1976) reported that 50% of the leaf and

twig mass remained at 19 months when *Artemisia tridentata* samples were buried at either 5 or 10 cm. About 63% of the small stem mass and 70% of both small and large root mass litter remained at 19 months. Over 90% of the stem mass placed on the soil surface remained after 19 months which substantiates the long residence time observed in the field. Conditions leading to litter burial obviously increase the decomposition rate.

Comanor (1976) also reported 6-hour respiration (CO_2 evolution) rates of litter exposed to various environmental conditions. The respiration process accounted for a large portion of the decomposition loss. The losses were generally greater for wet (-0.1 bar) than dry (-70 bar) samples, decreased with a decrease in temperature (range of 5 to 35 C), were greater for stems than roots, and greater for old leaves than for young leaves. The laboratory respiration measurements supported the decomposition data obtained from the buried litter studies.

Mineral Concentration and Mass

The ash elements (e.g. Si, K, Ca, Mg, P) of the Syrian desert *Artemisia* communities (Table 2) ranged from 79 to 461 kg/ha-year, of which 42 to 53% was returned by above-and below-ground litter fall. About 20 to 42% of this came from the roots, and less than 11% came from the standing green parts.

The distribution of N and the ash elements in the *Artemisia sieberi/Poa sinaica* community is given in Table 4. In this community N, Si and Ca make up 73% of the mineral element mass. Mineral concentration data showed that N, Si, Ca and K make up about 82% of the mineral mass of the shrub, and, if Mg is included, 85%.

Mineral concentration data are also given for several *Artemisia* species grown in the western United States (Table 5). The data reflect differences in mineral concentration caused by soil fertility and differences in physiological maturity of the plant parts sampled.

Mineral mass in various *Artemisia tridentata* plant parts is given in Table 6. The N mass is given in Table 1. The leaves contain 2 to 4% of the mineral elements and 15% of the N measured in the above ground parts. The roots contained 15, 37, 21 and 44% of the K, Mg, P and Ca respectively in the shrub. The K, Mg, P and Ca in the biomass are only 0.7, 0.1, 2.0 and 0,03% respectively of that available from soil (Table 6). The biomass (including litter) N represents 6% of the total N in the soil, which occurs predominately in organic forms.

When we compare mass and distribution of the elements in *Artemisia tridentata*, we note that a relatively larger portion of the total ecosystem N is found in the biomass and second that a relatively larger portion of the total N is cycled in litter (leaf and root) fall. Thus N may be the first most limiting element in the system. Phosphorus may be the second most limiting macroelement that restricts plant growth.

Mineral Turnover

Rodin and Bazilevich (1965) reported 40 to 50% of the mineral mass in the community biomass was returned annually in the litter fall (Table 2). About 6 to 26 kg N/ha were also in the litter fall. These values are lower than those anticipated for *Artemisia tridentata* (Table 1), if we assume that more than 8% of the root mass sluffs off annually. Mack (1971 and 1977) also gives data (Table 6) on the mass of *Artemisia tridentata* plant parts and the amounts of K, Mg, P and Ca contributed by leaf and inflorescence fall. The leaf litter and sluffed roots are undoubtedly the major source of minerals returned to the soil as organic matter decomposes. The amount of mineral remaining after incubating *Artemisia tridentata* leaves on the ground for 1 year is given in Table 3. Mineral losses were generally described best by the equations $Y=AX^B$ or $Y=1/(A+BX)$. The averaged correlation coefficient for the four sites and 10 elements was $r^2=0.82$.

The mobile K is easily leached from the leaf samples. However, more than 50% of the N, Mn and Cu remained in the sample at 1 year. The leaf N is not readily lost from the sample because the microorganisms recycle the N during C respiration. This process reduces the C/N values from about 36 (Mayland, Unpublished) in leaves and 65 in roots to values approaching 6 in the soil.

We estimate that the C loss resulting from the decompostion of leaf and root litter ranges from 150 to 950 g C/m^2-year. This assumes that 50% of the root matter sluffs annually.

Mineral turnover for four *Artemisia tridentata* sites in southern Idaho is given in Table 3. These values are calculated as the mineral mass in the above ground biomass divided by the mineral mass in

the leaves plus inflorescences. Phosphorus, S, Ca, Mg and K cycle in the shrub system more rapidly than do N, Na, Zn, Mn and Cu. Mineral turnover for the entire community is about twice as rapid as for the shrub component alone. This accelerated turnover of the community mineral mass occurs because grasses and forbs contribute a large portion of their biomass to the annual litter fall.

Discussion

The minerals contained in the shrub and community biomass turn over in 9 to 43 years and 5 to 16 years, respectively. During this period the additional minerals required by the plants must be obtained from mineralized soil organic matter or from exchangeable sources in the soil. The large soil reservoir of minerals (Table 6) provides more than adequate amounts of these minerals, except for N and occasionally P and Zn.

Plant-induced soil chemical patterns are significant in desert shrub communities (Charley and West 1975). These horizontal and vertical patterns develop as the shrub roots absorb minerals from the soil and concentrate them, via the litter fall, in the upper part of the soil profile under the shrub canopy. This process is particularly important for organic N and C. Vertical gradients are also noted for available P and C/N where higher values occurred near the soil surface. Charley and West (1977) reported larger amounts of mineralized N under shrub canopies than in the interspace areas. However, the amount of N mineralized versus the amount present was not different for the two areas. Charley and West (1975) found that the process of converting *Artemisia* communities to grass obliterated the horizontal N and C patterns. Incorporating shrub litter into the soil increases the decomposition rate and release of minerals.

Burning shrub communities quickly releases mineral elements for subsequent vegetative growth. The increased productivity that frequently occurs after fire is evidence that even N must be more available than before the fire. Some N, perhaps as much as 50% (Murray 1975) in the above-ground biomass might be lost by high temperature volatilization. This would normally be a very small part of the total N in the system.

West and Skujins (1977) have developed a N balance for *Atriplex confertifolia*-dominated system and have made some reference to *Artemisia*. The amount of N lost by denitrification and volatization or gained by dust fallout, blue-green algal fixation (Rychert and Skujins 1974), and symbiotic fixation in *Artemisia ludoviciana* (Clawson 1973) have no large effect on the size of the N pool. Klubek (In Press) summarized N_2-fixation and denitrification in arid soil cryptogamic-crust microenvironment. In general these processes do not dignificantly change the size of the main N pool.

Sulfur is subject to many of the same processes as N. Other mineral elements, although not generally subject to volatilization, may cycle from organic to inorganic forms in soil. These forms may be freely available, sparsely available or unavailable to plants.

Soil moisture has the major effect on plant growth. Only when moisture is abundant, especially for several years in succession, will shrubs respond to supplemental N and perhaps other mineral elements (James and Jurinak 1978).

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Table 1. Biomass statistics for *Artemisia tridentata* at Saylor Creek (site 1 near Glenns Ferry, Idaho), Piemeisel (site 2 near Twin Falls, Idaho), Mayfield (site 3 between Boise and Mountain Home, Idaho, Sand Creek (site 4 near St. Anthony, Idaho), Hanford (site 5 in Columbia Basin of south central Washington), and Big Southern Butte (site 6 near Arco, Idaho). Nitrogen data are included for site 6. Data for site 1 through 4 are from Murray, 1975. Data for site 5 are from Mack, 1971 and for site 6 are from West, Mayland, and Welch, unpublished.

Component	Biomass						N
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 6
	kg DM/ha						kg N/ha
Artemisia tridentata							
Annual parts	200	1100	300	400	150	1000	13
Perennial parts	2600	9500	3500	4600	7700	10,400	46
Dead parts	1500	3900	400	200	3400	5100	29
Roots	Not determined				3000	16,800	150
Litter	Not shown					150	9
Mixed soil & litter	Not determined					500	27
Other forbs, grasses & shrubs	800	100	200	500[†]	—	600	5
Litter	Not determined					200	1
Cryptogams & fungi	Not determined					500	12
Soil N in upper 60 cm	4000	6400	3400	7800	—	—	4500

[†]Plus nearly 5000 kg/ha *Purshia tridentata* above ground biomass.

Table 2. Biomass statistics in an (1) *Artemisia sieberi/Poa sinaica*, (2) *Artemesia sieberi/Poa sinaica/Carex pachystilis/Aspicilia esculenta*, and (3) *Artemisia sieberi/Poa sinaica/Aspicilia esculenta* communities of the Syrian desert. (Adapted from Table 44 of Bodin and Bazilevich, 1965).

Component	Community 1	2	3
Biomass, kg/ha	6100	940	1600
Green parts, %	3	14	12
Perennial parts, %	40	59	44
Roots, %	57	27	44
Litter fall, kg/ha	2400	500	700
Green parts, %	8	26	28
Perennial parts, %	46	48	35
Root residues, %	46	26	37
Mineral elements in biomass, kg/ha	461	79	106
In green parts, %	3	10	11
In perennial parts, %	55	70	59
In roots, %	42	20	30
Returned with litter fall, %	42	53	46
N returned with litter fall, kg/ha	26	6	8
In green parts, %	12	37	40
In perennial parts, %	42	41	32
In root residues, %	46	22	28

Table 3. Leaf decomposition and mineral turnover time in *Artemisia tridentata* and mineral turnover time for the entire community at Saylor Creek (Site 1), Piemeisel (Site 2), Mayfield (Site 3), and Sand Creek (Site 4). Data are from Murray 1975.

Site	Weight	N	P	S	Ca	Mg	K	Na	Zn	Mn	Cu
	Leaf decomposition, percent remaining at 1 year, %										
1	45	74	43	38	58	38	11	34	-	56	68
2	49	79	50	34	47	32	9	35	-	83	123
3	46	81	39	35	22	24	3	29	-	69	84
4	32	79	41	31	16	21	2	23	-	46	85
	Mineral turnover in *Artemisia tridentata*, years										
1	-	25	19	11	11	13	14	20	42	19	46
2	-	14	14	19	16	12	11	30	42	29	35
3	-	12	7	5	3	2	3	24	49	15	33
4	-	16	9	6	6	8	6	21	40	8	24
	Mineral turnover for entire community, years										
1	-	3	2	2	4	4	3	5	6	5	8
2	-	11	10	16	13	11	9	28	27	26	31
3	-	5	3	4	3	2	2	15	17	10	18
4	-	5	3	3	4	3	2	7	8	4	7

Table 4. Mineral element concentration in *Artemisia sieberi* shrub parts and mineral content in annual litter fall from the *Artemisia sieberi/Poa sinaica* community in the Syrian desert (from Table 45 and Figure 52 respectively of Rodin and Bazilevich, 1965).

Component	Mineral Concentration			Mineral Content		
	Leaves	Perennial above ground parts	Roots	Green parts	Perennial above ground parts	Roots
	%			kg/ha		
N	2.5	1.9	0.8	2	12	12
Si	.35	.37	.15	2	40	12
Ca	1.2	1.7	1.5	1	41	20
K	2.8	.7	.5	3	1	3
Mg	.43	.26	.12	1	1	2
P	.22	.09	.05	<1	7	3
Al	.12	.13	.05	<1	8	4
Fe	.12	.12	.06	<1	7	2
Mn	-	-	-	1	2	2
S	.37	.16	.21	1	1	1
Na	.23	.04	.13	2	<1	1
Cl	.44	.11	.05	1	<1	1
				Dry Matter Production		
				kg/ha		
Biomass				200	1100	1100

Table 5. Mineral concentration data for *Artemisia* species of the Great Basin and eastern California regions and the Syrian *Artemisia sieberi*.

Species, Plant Part	Mineral Concentration					
	Si	Ca	K	Mg	P	N
	%					
arbuscula[1,2/]	0.06	0.57	0.8	0.15	0.08	-
arbuscula[1,3/]	-	0.54	1.5	-	0.12	0.67
nova						
tridentata[4/]						
leaves	-	0.67	1.8	0.25	-	-
stems	-	0.62	1.1	-	-	-
tridentata[5/]						
leaves	-	1.02	1.0	0.40	0.19	1.2
sieberi[6/]						
leaves	0.35	1.22	2.8	0.43	0.22	2.5
branches	0.37	1.69	0.7	0.26	0.09	1.9
roots	0.15	1.53	0.5	0.12	0.05	0.8

1/ Presumed to be standing shrub biomass.
2/ Marchand 1973.
3/ Harner and Harper 1973.
4/ Wallace et al. 1973
5/ Charley 1977.
6/ Rodin et al. 1972.

Table 6. Biomass and mineral mass of *Artemisia tridentata* plant parts and available soil mineral mass in the 0 to 100 cm depth. From Mack 1971 and 1977.

Component Part	Mineral Mass				
	Biomass	K	Mg	P	Ca
	- - - - - - - kg/ha - - - - - - - -				
Leaves [1/]	150	1.3	0.3	0.1	1.1
Inflorescence [1/]	10	0.06	0.02	0.02	0.05
Stems	7700	20.0	4.6	3.9	22.0
Deadwood	3400	8.8	2.0	1.7	10.0
Roots	3000	5.3	4.1	1.5	26.0
Soil Minerals	-	3600	4500	130	22000

[1/] These data are equivalent to annual litter fall.

PHYSIOLOGY OF SAGEBRUSH

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Introduction

As described in the foregoing papers, Artemisia tridentata is an eminently successful species as evidenced both by its extensive distribution and persistence even in disturbed areas. This success naturally invites speculation on the physiological and morphological attributes of this species which might confer this notable adaptive capacity. Unfortunately, this species has received less physiological study than its predominance in the western landscape would warrant. Furthermore, those physiological studies which have been conducted usually had rather specific objectives and were restricted to a limited number of sites and ecotypes; thus, the degree of generality is quite limited.

In order to meaningfully examine physiological characteristics of Artemisia tridentata from the standpoint of ecological adaptability, it is necessary when possible to compare such characteristics or attributes with those of species which commonly grow in association with sagebrush. Thus, the basic emphasis in this review will be to address the question of how physiological characteristics of Artemisia tridentata differ from species which potentially compete for the same resources.

Though any widely distributed species such as sagebrush is undoubtedly composed of a myriad of genetically differentiated forms or ecotypes, three subspecies are commonly recognized: tridentata, wyomingensis, and vaseyana (Beetle 1960). As will be discussed, these three subspecies have seldom been subject to a comparison from the standpoint of physiological traits or even growth characteristics under comparable environmental conditions. Therefore, the degree to which one might extrapolate results of studies of one subspecies to the other subspecies must be limited. When available, the subspecific name will be provided when discussing physiological traits of Artemisia tridentata in this review.

Intraspecific Variation

Most species adapt to environmental differences by a combination of phenotypic plasticity, i.e., developmental and physiological changes resulting from environmental conditioning, and genetic differentiation. The phenotypic plasticity of many higher plant species is indeed remarkable and yet it is usually insufficient to accommodate the full extent of habitat diversity that exists within the range of any widely distributed species. Thus, intraspecific genetic variation in the form of local populations, ecotypes, and other subspecific groupings is expected. Such is the case with Artemisia tridentata.

Though intraspecific genetic variation within Artemisia tridentata is established on morphological characteristics, the extent to which this species exhibits intraspecific variation in physiological traits is at the present time not clear. The three basic subspecies have generally been distinguished by growth form, morphology of leaves, and the inflorescence of plants collected in the field. Biochemical differences, principally in phenolics, have also been used as distinguishing characters (Hanks and Jorgensen 1973, Stevens and McArthur 1974). Still, McDonough, Harniss and Campbell (1975) caution that none of the commonly employed leaf morphological features could clearly separate the subspecies when all were grown in a common greenhouse. When the subspecies are grown under common garden conditions the biochemical markers do appear to have greater fidelity and are less influenced by the environment (McArthur, personal communication).

The subspecies differ little in seed germination requirements or seedling growth (McDonough and Harniss 1974 a, b). Achenes of Artemisia tridentata in general do not exhibit specific germination requirements and are usually considered as nondormant. They germinate over a wide range of temperatures without particular pretreatments other than illumination. Subspecies vaseyana is an exception in that it is markedly stimulated in germination if a stratification treatment is employed. The stratification requirement of the vaseyana subspecies is apparently largely associated with the pericarp. Harniss and McDonough (1975) reported that contrary to expectations, seedling growth of the three subspecies was not significantly different for either shoot or root growth parameters under a variety of controlled temperature regimes. Undoubtedly other physiological and growth attributes of these subspecies do differ, but, at the present time this can only be left to speculation as specific comparisons are not to be found. Though one needs to respect the potential genetic variation in this remarkably widespread species, at the same time one may still be able to cautiously extend physiological findings from one ecotype to another.

Water Uptake and Carbon Fixation

Competitive success in a water-limited environment must surely involve a capacity for water uptake in the face of competition from other species coupled with the capacity for absorption of water in reasonably dry soils. This, combined with an efficient photosynthetic system to fix carbon dioxide from the atmosphere as water is expended in transpiration would seem to be the key to the recognized competitive success of this species. Thus, these topics will be addressed first.

As is the case with most higher plant species, water uptake of sagebrush is most active when water is most available--providing low temperature does not limit the process (Campbell and Harris 1977, DePuit and Caldwell 1973). Root growth activity of Artemisia tridentata (subsp. wyomingensis) in northern Utah has been witnessed to occur in the early spring when soils are still quite cold (Fernandez and Caldwell 1975). In fact, this root growth activity was observed to precede active vegetative growth by more than a month. Daubenmire (1975) suggests that in Washington State root growth of Artemisia tridentata (subsp. tridentata) is much slower than that of associated annual and perennial species in the spring period. Even though root growth of sagebrush may be somewhat slower, the early initiation of root activity in the spring period may be of significance in water uptake from the profile when water is usually most plentiful.

Though sagebrush is most active in root growth, water uptake, transpiration and photosynthesis during that period of the year when water is most abundant (Campbell and Harris 1977, DePuit and Caldwell 1973, 1975), this species apparently does have the capacity to extract water from dry soils when soil water potentials are as low as -60 to -70 bars (Campbell and Harris 1977). As soil moisture declines and atmospheric moisture stress usually increases concomitantly, sagebrush tissues exhibit a decrease in osmotic potential as one might expect in the classical process known as osmotic adjustment (Campbell and Harris 1977). Artemisia tridentata is not generally considered a halophyte and accordingly tissue salt concentrations do not increase strikingly as is the case with associated halophytic species such as Atriplex confertifolia or Ceratoides lanata during the process of osmotic adjustment (Wallace and Kleinkopf 1974, Moore, Breckle and Caldwell 1972). Osmotically active organic constituents may then account for the observed osmotic adjustment. Dina and Klikoff (1973) reported increases in leaf sugar concentrations on the order of 250% as total plant water potential decreased from -10 to -40 bars. Though insufficient data were reported to calculate whether the sugar changes could account totally for the apparent osmotic adjustment in these studies, such results do correspond with expectations. Leaf osmotic potentials as low as -50 bars were reported by Campbell and Harris (1977), although no constituents of the leaf osmoticum were reported. Though the evidence is fragmentary, one might at this point surmise that Artemisia tridentata possesses a very respectable ability to undergo osmotic adjustment and extract water under dry conditions and that salt accumulation in the leaves probably plays a rather minor role in this osmotic adjustment.

Photosynthetic activity of sagebrush naturally reflects environmental conditions as well as the physiological status of leaves. Most of the photosynthetic activity of sagebrush in northern Utah takes place during the spring and early summer period (April to June) when temperatures are favorable and moisture is most plentiful (DePuit and Caldwell 1973). The course of precipitation and plant water potential for a site near Logan, Utah in 1971 is represented in Figure 1. Photosynthetic activity of Artemisia

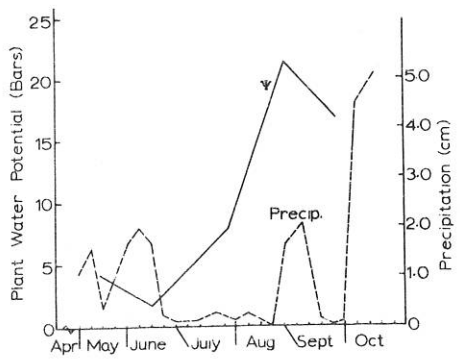

Figure 1. Seasonal pattern of precipitation and plant water potential (represented as absolute values) for Artemisia tridentata subsp. tridentata during the growing season at a site in northern Utah. From DePuit and Caldwell 1973.

tridentata subsp. tridentata on selected days during the spring and summer season is represented in Figure 2 for the same year. Since each of the days

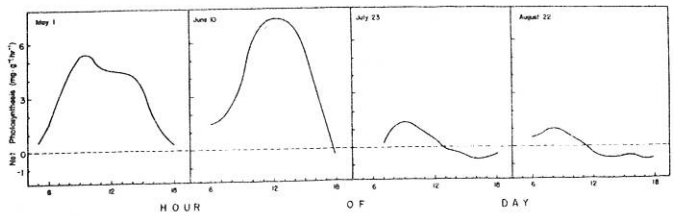

Figure 2. The daily course of net photosynthesis of Artemisia tridentata subsp. tridentata in northern Utah on four cloudless days during the growing season. Adapted from DePuit and Caldwell 1973.

represented were cloudless, photosynthetic activity was, for the most part, not light limited and thus curtailment of photosynthesis reflected other environmental or physiological factors. In this site, plant water potentials were never extremely low. During this particular year, plant water potentials only reached -22 bars whereas much more negative water potentials have been reported at other sites during other years. For example, Dina and Klikoff (1973) reported plant water potentials as low as -70 bars

at another site in northern Utah. Even though leaf water potentials were not very low, net photosynthetic activity was greatly curtailed--in fact during afternoon periods in July and August, it was often negative (see Figure 2). This, however, may not be solely a response to moisture stress since leaf temperatures were much higher at this time of the year and the average leaf age was more advanced.

To elucidate the role played by some of these factors, photosynthetic capacity under different environmental conditions was analyzed (DePuit and Caldwell 1973, 1975). The rate of plant photosynthesis as a function of leaf temperatures at constant light intensity is illustrated in Figure 3 for different phenological stages. These

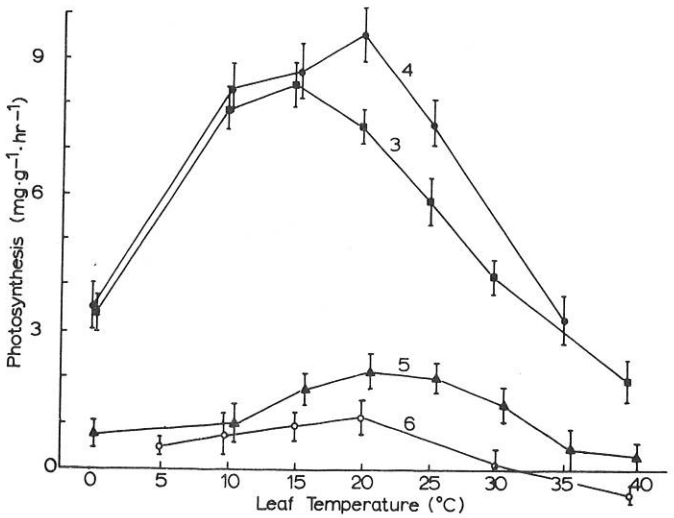

Figure 3. Net photosynthesis of Artemisia tridentata subsp. tridentata at four different phenological stages during the growing season. The measurements were made under conditions of constant irradiance (1150 microeinsteins m^{-2} s^{-1}) at several leaf temperatures. Values are means of measurements of four to six plants shown with one standard deviation. Phenological stages are given in Table 1. Adapted from DePuit and Caldwell 1973.

phenological stages are given in Table 1.

Table 1. Phenological code used for Artemisia tridentata subsp. tridentata in studies of DePuit and Caldwell (1973). Dates apply to a site in northern Utah for 1971.

0 - Winter dormancy
1 - Post dormant quiescence
2 - Swelling leaf buds (mid-April to early May)
3 - Emergent large new leaves on vegetative branches (mid-May)
4 - Rapid new vegetative stem and leaf growth. Reproductive shoots initiated. (Late May to mid-June)
5 - Reduced vegetative growth; reproductive shoot and bud growth; ephemeral leaves growing on reproductive shoots; (early July to mid-August) "spring" leaves shed
6 - Reproductive shoots full size; flower buds developing; little vegetative growth (late August to mid-September)
7 - Flower buds fully developed, some beginning to burst; ephemeral leaves on reproductive shoots dying and being shed (late September to early October)
8 - Flowering (mid-October)
9 - Fruit developing (late-October to early November)
10 - Shedding of fruit; predormancy quiescence (mid-November on)

These data were collected from plants growing in the field and, thus, water stress as well as advancing average leaf age were responsible for the general decline in photosynthetic activity with later phenological stages.

Another approach to evaluating the limiting factors for photosynthesis during the late season was to allow plants to photosynthesize at a constant leaf temperature of 20°C, which is close to the optimum temperature for photosynthesis, during cloudless days throughout the season (Figure 4). Even at the optimum temperature for photosynthesis

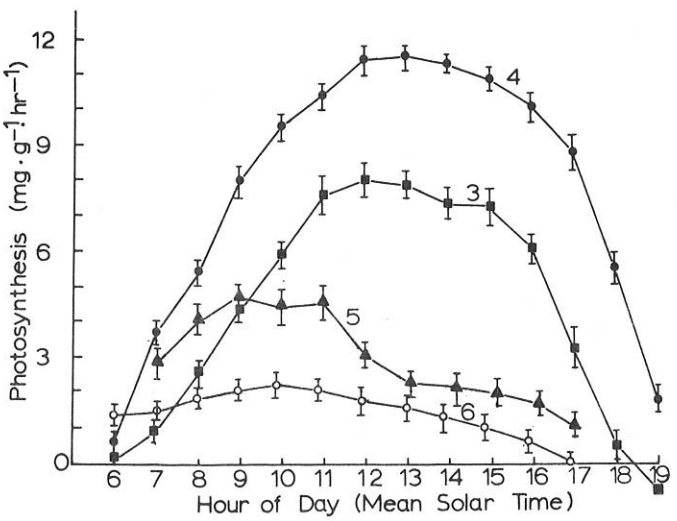

Figure 4. Net photosynthesis of Artemisia tridentata subsp. tridentata at four phenological stages during the course of the growing season. The measurements were made under conditions of constant leaf temperature (20°C) while solar irradiation varied during the course of the cloudless days selected for this figure. Photosynthesis values are means of measurements of four to six plants shown with one standard deviation. Phenological stages are given in Table 1. From DePuit and Caldwell 1973.

under conditions where light was not limiting, photosynthetic activity was depressed--particularly

during the afternoon hours. However, as apparent in Figure 4, net photosynthetic activity did not become negative--that is, respiration did not exceed gross photosynthetic CO_2 uptake. As illustrated in Figure 3 at the advanced phenological stage (stage No. 6), negative net photosynthesis only occurred at temperatures above 30°C. However, when plants were held at a constant 20°C even at the advanced phenological stage and under equally severe soil moisture potentials, photosynthesis never became negative. Thus, supraoptimal leaf temperatures, advancing leaf age and soil moisture stress all contributed to the decline of photosynthetic activity later in the season. Yet, the negative photosynthetic activity appeared to be largely the result of supraoptimal leaf temperatures.

As plants are subjected to increasing moisture stress, stomates tend to close. This is not only effective in curtailing transpiratory water loss but also naturally limits photosynthetic activity as well. The diffusional resistance to water vapor loss from a leaf is a quantitative measure of the resistance to water vapor loss from a leaf. Though there are several components to this resistance it largely reflects stomatal aperture. Naturally, there is a corresponding resistance to CO_2 uptake from the air to the leaf internal spaces. In Figure 5, the leaf diffusion resistances corresponding to photosynthetic values displayed in Figure 4 suggest that partial closure of stomates was an important factor in curtailing photosynthesis

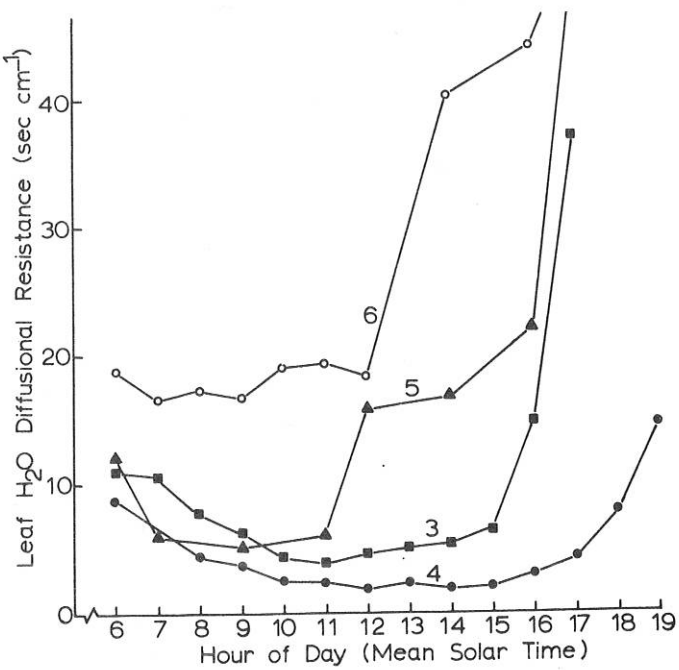

Figure 5. Leaf water vapor diffusional resistance of Artemisia tridentata subsp. tridentata at four phenological stages during the course of the growing season. These values correspond to the photosynthetic depictions in Figure 4. Phenological stages are given in Table 1. Adapted from DePuit and Caldwell 1973.

with advancing phenological stages, which also corresponded to periods of lower soil moisture potential. It is also apparent that stomates did tend to close later in the season, particularly during the afternoon hours when the lag of water absorption would be most acute. These studies suggest that sagebrush exhibits very sensitive stomatal control of water loss from leaves--much more than some associated species such as Gutierrezia sarothrae (DePuit and Caldwell 1975). Further work, however, established that the decreased photosynthetic rates associated with advanced phenological status and decreased soil moisture potentials could not be solely attributed to partial stomatal closure but also involved other limitations in the photosynthetic process (DePuit and Caldwell 1975).

In a subsequent study, an effort was made to separate the influence of soil moisture stress and phenological status of leaves on the photosynthetic capacity of sagebrush and associated species (DePuit and Caldwell 1975). Photosynthetic rates of Gutierrezia sarothrae were always substantially higher than those of Artemisia tridentata. This was evident both during the spring when photosynthetic capacity for both species was maximum and also later in the season when advanced leaf age and water stress combined to curtail photosynthesis. Artemisia tridentata underwent a greater depression of photosynthetic activity during the late season than did Gutierrezia; further, water stress appeared to play a sizable role in this depression of photosynthetic capacity. Photosynthesis as a function of leaf temperature at an advanced phenological stage (stage No. 6) is illustrated for the two species in Figure 6. In this experiment, some plants were irrigated and others were allowed to experience the normal late season decline of soil moisture potential. This decline, however, was not particularly severe. Clearly, irrigation of Artemisia stimulated photosynthesis considerably at all leaf temperatures and prevented negative photosynthetic rates at supraoptimal leaf temperatures. By comparison, the associated species Gutierrezia sarothrae exhibited only a small response to irrigation in the late season. Dina and Klikoff (1973) discovered that net photosynthesis of Artemisia tridentata in the scrub oak vegetation zone in northern Utah became negative at approximately -30 bars plant moisture potential and did not exhibit a greater tolerance of water stress than associated species Quercus gambelii and Purshia tridentata. Artemisia tridentata is able to conduct photosynthesis at tissue moisture potentials which are more severe than many common mesophytic species. However, when compared to other aridland species such as Gutierrezia sarothrae, Atriplex confertifolia, Ceratoides lanata (Moore, White and Caldwell 1972) or Larrea divaricata and Encelia farinosa (Odening, Strain and Oechel 1974), its capacity to transpire or conduct photosynthesis at low plant moisture potentials is not so impressive.

To summarize at this point, Artemisia tridentata subsp. tridentata, when growing in a northern Utah site, exhibited its greatest photosynthetic capacity during the spring period when leaf temperatures were not excessive, leaves were still

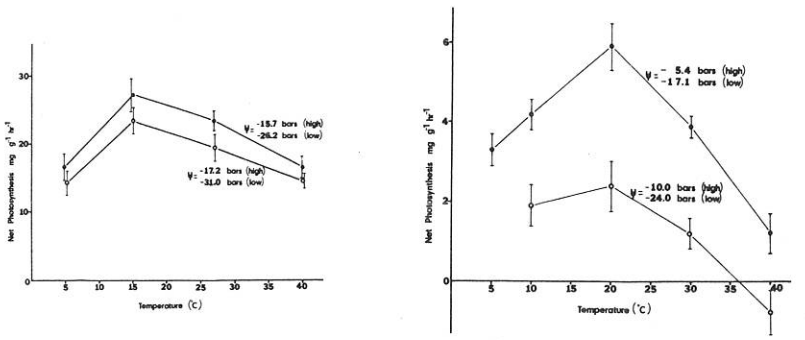

Figure 6. Net photosynthesis at different leaf temperatures late in the growing season (phenological stage 6) comparing rates of irrigated plants (●) and those subject to the normal depletion of soil moisture (○). The maximum and minimum daily plant water potentials are given adjacent to each curve. Irradiance was held constant at 1100 microeinsteins m^{-2} s^{-1}. Values are means of three to six replicates and are shown with one standard deviation. Gutierrezia sarothrae (left) and Artemisia tridentata subsp. tridentata (right). From DePuit and Caldwell 1975.

young and water stress was minimal. As the summer progressed, average leaf age increased, leaf temperatures became excessive--over 30°C--and soil moisture potential declined. Photosynthetic activity was markedly depressed and was often negative during afternoon periods. This species was quite sensitive to even mild water stress and exhibited sensitive stomatal control to reduce water loss. Although stomatal closure necessarily reduced photosynthesis, it could not account for the total decline of photosynthetic activity during the latter part of the season. Compared to several xerophytic shrubs, photosynthesis of Artemisia tridentata is comparatively sensitive to water stress.

Acclimation

As Daubenmire (1975) points out, even the subspecies Artemisia tridentata tridentata is very widely distributed and certainly must have undergone genetic differentiation to compete successfully in environments which differ strikingly in annual temperature and precipitation regimes. Thus, extrapolation of the foregoing information for northern Utah should be done with considerable caution and certainly with particular reservation to the other subspecies of Artemisia tridentata. Though such caveats should be always clearly kept in mind, it may still be useful to pose the generalization that Artemisia tridentata may be a species that though able to extract water from very dry soils is largely restricted in its major photosynthetic activity to those times when moisture is plentiful and temperatures are not excessive. Further, these few measurements of photosynthetic activity suggest that this species has the capacity to shift its photosynthetic response to temperature depending on the environment to which it has been exposed. This physiological alteration of photosynthetic activity at different temperatures can be interpreted as being adaptative for the plant.

Returning to Figure 3, one can note that not only was photosynthetic capacity changing during the course of the season, but the relative response at different temperatures was also shifting. For example, in the early season there was appreciable photosynthetic activity at 0°C leaf temperature and the optimum temperature for photosynthesis was about 15°C. Later in the season the photosynthetic temperature optimum shifted to 20° and the capacity for photosynthesis at low temperatures declined while the relative capacity at higher temperatures increased to a certain degree until water stress and advanced leaf age contributed to a decline in photosynthetic capacity at higher temperatures.

Mooney and West (1964) compared the photosynthetic acclimation capacity of five species in the White Mountains of California. They kept potted plants for at least three weeks in desert, piñon woodland and subalpine environments and then measured the relative photosynthetic activity at different temperatures. As in the study of DePuit and Caldwell (1973) Artemisia tridentata exhibited a similar capacity to maximize photosynthetic rates at lower temperature when acclimated in a cold environment and, conversely, exhibited a higher temperature optimum and also a greater capacity for photosynthesis at higher temperatures when acclimated in the desert or piñon woodland environments. Artemisia tridentata in this mountain range has a total elevational range of 1370 m and correspondingly greater photosynthetic acclimation potential than species more restricted in altitudinal distribution.

In a subsequent study, West and Mooney (1972) compared photosynthetic acclimation potential of Artemisia tridentata with that of A. arbuscula, a species restricted to higher elevations (3000-3900 m) and A. nova restricted to the piñon-juniper woodland zone (2100-2900 m). As can be seen in Figure 7, A. tridentata exhibited a greater photosynthetic acclimation potential than did A. arbuscula or A. nova. Artemisia nova was particularly limited in its acclimation capacity which corresponds with its very limited altitudinal distribution in the White Mountains. It is also

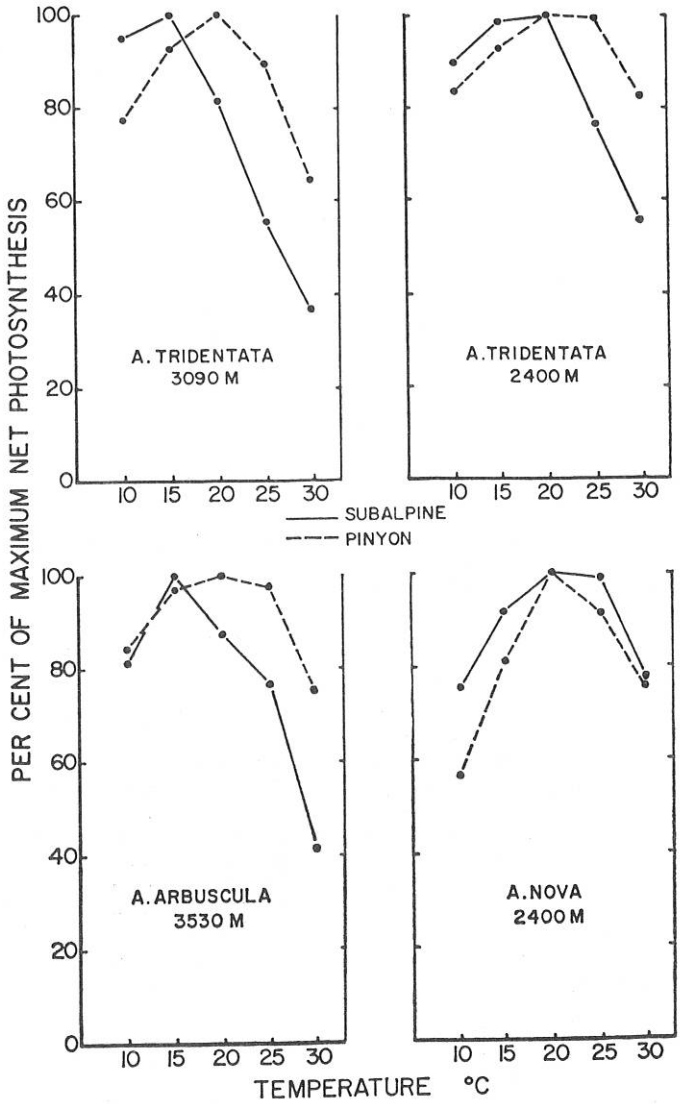

Figure 7. Relative photosynthetic activity at different leaf temperatures for Artemisia species acclimated in the piñon woodland zone (2400 m elevation) and the subalpine zone (3090 m elevation). The elevations where the plant stock was collected are given in each graph. From West and Mooney 1972.

apparent that genetic differences in populations of Artemisia tridentata existed. The population collected from higher elevations possessed somewhat greater capacity to acclimate to low temperatures than did the population collected at 2400 m. Therefore, although Artemisia tridentata exhibited a notable acclimation potential, its successful widespread distribution must in part be attributed to genetic differentiation within the species.

Artemisia tridentata possesses the normal photosynthetic mechanism commonly termed "C_3" photosynthesis (DePuit and Caldwell 1973). Unlike some species of warm environments that possess a specialized photosynthetic pathway known as "C_4" photosynthesis, which is particularly efficient at high temperatures, sagebrush photosynthetic capacity at temperatures above 30°C is limited--even when conditioned at higher temperatures. This is a common characteristic of C_3 species though some notable exceptions such as Larrea divaricata, a desert C_3 species with unusually efficacious high temperature acclimation, have been reported. (Mooney, Björkman and Collatz 1978).

Changes in dark respiration rates as a function of phenological status or conditioning temperatures have also been noted (Mooney and West 1964, DePuit and Caldwell 1973).

Although sagebrush is limited in its capacity for photosynthesis at warmer temperatures, its capacity for low temperature photosynthesis may be of decided advantage for this species. Not only is soil moisture usually most plentiful when environmental temperatures are cool in the early spring, but atmospheric moisture stress at this time is also minimal. Thus, sagebrush can enjoy an environment less conducive to transpiratory water loss and maintain minimal stomatal diffusion resistance for the uptake of carbon dioxide in photosynthesis.

Artemisia tridentata possesses two distinct leaf types during the course of the year (Goodwin 1956, Daubenmire 1975, DePuit and Caldwell 1973). The primary new leaves formed in the spring develop along the main stems and are typically sharply trilobed. As growth continues several new short lateral branchlets grow from the existing stems and support large quantities of smaller, less distinctly trilobed leaves which persist through the next winter long after the large initial or primary leaves have been shed. (The large primary leaves may be shed in May or June before periods of water stress have developed.) The smaller over-wintering leaves persist until the next spring when leaf growth for the new season commences. Thus, although the average age of individual leaves of this species is less than a year, sagebrush maintains leaves on the plant throughout the year. Exposing leaves to $^{14}CO_2$ during the coldest period of winter in the desert of northern Utah demonstrated that even following extremely low temperatures, these over-wintering leaves had the capacity to photosynthetically fix $^{14}CO_2$ (Caldwell et al. 1975). Since rates of CO_2 uptake were very low, it is doubtful that a significant net photosynthetic activity takes place during the cold winter months, particularly when soils are frozen. However, possession of a full complement of leaves during the early spring period may be extremely important in order to take advantage of favorable conditions at this time of year. Otherwise, photosynthetic activity would not commence until new leaves would be produced.

Individual leaf photosynthetic rates of Artemisia tridentata are generally not impressive. In a scrub oak community of northern Utah, Dina and Klikoff (1973) found the photosynthetic rates of sagebrush were no higher than associated species such as Quersus gambelii and Purshia tridentata. Similarly, photosynthetic rates of Artemisia tridentata in the White Mountains of California were not markedly higher than other species (Mooney and

West 1964). In a sagebrush steppe community of northern Utah, DePuit and Caldwell (1975) reported that photosynthetic rates of Artemisia tridentata subsp. tridentata were much lower than those of Agropyron spicatum var. inerme or Gutierrzia sarothrae. Though these few studies hardly constitute an extensive survey, the evidence thus far indicates photosynthetic rates of Artemisia tridentata to be certainly no greater and often much lower than associated species in several environments. It would then appear that the success of this species must depend on the display of a considerable number of leaves during the cool season of the year when moisture stress has not yet developed. Sensitive stomatal control of water loss in the over-wintering leaves may then be one mechanism allowing these leaves to persist until the spring period when they are most likely of benefit to the plant.

Deployment of Carbon

Though comparatively little is known concerning photosynthesis of sagebrush, much less is known about the disposition of photosynthetically fixed carbon within the plant. The proportion of the carbon resource that is allocated to new leaves or roots as opposed to a labile carbon pool in the form of a compounds such as carbohydrates can at this point only be surmised in a very general manner.

Total available carbohydrates, TAC, is an expression of labile carbon in the plant, i.e., carbon reserves which can be translocated and utilized at a subsequent time for either maintenance or regrowth of plant organs. This parameter has been used extensively in the field of range management to gauge the impact of defoliation on plants (e.g., Trlica and Cook 1971). Total available carbohydrates consist largely of starch, dextrins, fructosans, sucrose, and reducing sugars but not forms of carbon which are considered as purely structural such as cellulose, hemicellulose, lignin, pentosans, etc. The TAC is commonly expressed on a concentration basis for various plant parts. Classically, the seasonal changes in TAC have been taken as an indication of when plants are most adversely affected by defoliation. Further, the minimum concentrations of available carbohydrates which are exhibited by plants that have received severe defoliation and yet survive have been assumed as minimum critical levels for the plants in question. Though one cannot deny the importance of labile carbon reserves when plants are subject to perturbations such as grazing, the assumptions classically employed in the use of TAC as an indicator of plant resiliency to grazing need to be questioned. It is really the total pool of available carbohydrates in the plant that is important rather than simply the concentration of carbohydrates in various plant organs. The inability to always correlate concentration changes with defoliation effects (e.g., Trlica and Cook 1971) is of no surprise since the total labile carbon pools are unknown. Nevertheless, the concept of TAC has been widely employed and can provide some useful information if one bears in mind that changes in concentrations do not necessarily reflect the total carbon pool available as a reserve for the plant.

Coyne and Cook (1970) followed the seasonal carbohydrate concentrations in eight Great Basin Desert species in northern Utah, including Artemisia tridentata and A. arbuscula var. nova. The subspecies of Artemisia tridentata was most likely wyomingensis. Most species followed the generally expected trend of decreasing TAC levels when leaves were being produced and twigs were elongating in the spring. Artemisia tridentata was an exception and exhibited increasing rather than decreasing TAC levels in both twigs and roots during this period when normally a depletion of reserves would be expected (Figure 8). They speculated that this may be due to the fact that since sagebrush maintains a large cohort of over-wintering leaves, a drain of reserves is not necessary when new leaves and twigs are

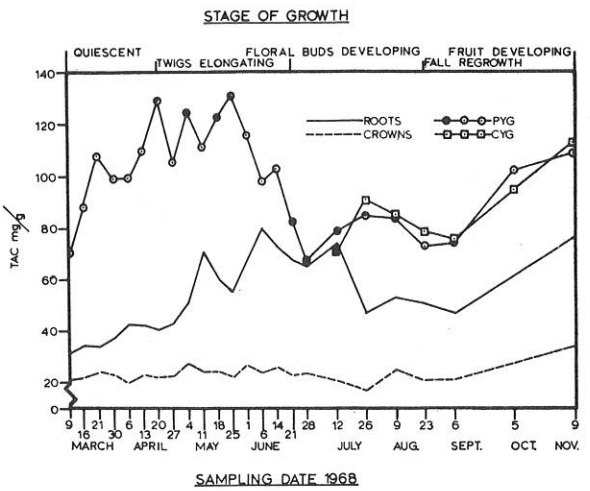

Figure 8. Concentrations of total available carbohydrates (TAC) (mg of glucose equivalent/g tissue weight) in roots, crowns, previous years' twig growth (PYG), and current years' twig growth (CYG) of Artemisia tridentata subsp. wyomingensis as related to phenological stage and date during 1968 for a site in northern Utah. From Coyne and Cook 1970.

produced because photosynthate could be supplied by the older persistent leaves. This is in agreement with some of the discussions presented in this review. They also suggested that since twigs of sagebrush exhibited a marked seasonal change in TAC and higher TAC levels than roots or crowns, that twigs were a more important storage organ for labile carbon. Although concentrations of available carbohydrates were much higher in twigs, one cannot necessarily conclude that the twigs were a more important storage organ of TAC since the total quantity of reserve carbon may be much greater in the roots and crowns. Proximity of the twig labile carbon pool to the site of carbon utilization in twig and foliage regrowth may, however, enhance the importance of twig TAC. Without more information, however, it is fruitless to pursue further speculation.

In a subsequent study, Trlica and Cook (1971) examined the response to defoliation of the eight Great Basin Desert species studied by Coyne and Cook (1970). Plants were subject to 90% removal of the current year's photosynthetic tissue and the change in TAC was observed when the plants had reached a stage of 20% estimated regrowth. This was conducted

at four different seasons of the year. They reported that Artemisia tridentata and A. arbuscula var. nova exhibited less regrowth following defoliation than any of the other species. They noted that these two Artemisia species consistently had the lowest TAC reserves of the species they were investigating. Nevertheless, one must remember that low concentrations do not necessarily mean a smaller total carbon pool if these reserves are stored in plant organs which constitute a considerable proportion of the total plant biomass. The depression of TAC following defoliation was most noticeable if the plants were subject to this defoliation after most of the twig elongation had ceased and the plants were in the flower bud stage (approximately July 1, under these circumstances). They suggested this was due to the lack of appreciable foliage regrowth and thus the absence of photosynthetic tissue to produce reserves by autumn when they were again measured. In an earlier study Wright (1970) also found that Artemisia tridentata was most susceptable to clipping when flower buds were first evident and twig elongation was about to terminate.

Trlica and Cook (1971) also noted that the response to defoliation as well as average TAC levels varied from year to year which they surmised was a reflection of the available moisture. Dina and Klikloff (1973) specifically investigated the effect of plant moisture stress on carbohydrate and nitrogen concentrations of Artemisia tridentata. They found starch concentrations to be unchanged though sugars, particularly in leaves, increased with more severe plant moisture stress. As suggested earlier in this review, this may be associated with osmotic adjustment. Although nitrogen concentrations in the entire plant did not change appreciably with increasing moisture stress, there was a noticeable movement of nitrogen from leaves to stems and roots--perhaps to be interpreted as a nitrogen conservation mechanism preceding loss of leaves. Furthermore, since Artemisia tridentata apparently has only limited capacity for photosynthesis under moisture stress as discussed earlier (Dina and Klikloff 1973, DePuit and Caldwell 1975), maintenance of high leaf nitrogen concentrations may be of little value for the plant.

Though one should be cautious in drawing conclusions from the foregoing studies, the reviewer is under obligation to provide some interpretation. If one can assume that available carbohydrate concentrations indeed reflect the effective labile carbon pool in the plant it would appear that Artemisia tridentata maintains less reserve carbon in roots and crowns than associated Great Basin Desert species. Sagebrush appears less resilient to severe defoliation. Yet, one might speculate that because this species is not usually subjected to severe defoliation, at least during those periods most critical to the plant, and also because it maintains leaves throughout the year, reserve carbon may be less important for this plant than some associated species. Apart from osmotic adjustment, water stress likely influences carbon reserves largely in an indirect manner by curtailing photosynthesis rather than to have a more immediate effect on starch concentrations.

When the entire carbon budget of a species such as sagebrush is considered, labile carbon reserves may constitute a rather small fraction of the total carbon fixed during the year. I would suggest that probably a much greater quantity of carbon is being deployed to structural tissues, namely foliage and root growth. A particularly large commitment of carbon may be devoted annually to reconstructing a portion of the fine diffuse root system. Unfortunately quantitative data do not exist to substantially support or refute this suggestion. Some preliminary studies (Caldwell et al. 1975) do, however, suggest that four times as much carbon is deployed to root system growth as to the growth of shoots. This has been much more adequately studied for some associated Great Basin Desert species, Atriplex confertifolia and Ceratoides lanata (Caldwell et al. 1977).

For these species, belowground production is in excess of three times the production of shoot tissues. Thus, the preliminary data for sagebrush coincides with those of other Great Basin Desert shrubs and represents an impressive commitment of carbon to heterotrophic organs. In view of this substantial deployment of carbon to belowground structure, some consideration of Artemisia tridentata root system characteristics will follow.

Root System

When a sagebrush plant is excavated from the soil one is immediately struck with the prominent tap root which in many soils may appear as the dominant component of the root system. Undoubtedly, the proportion of the root biomass in the tap root and diffuse root system of sagebrush varies substantially depending on soils, subspecies, etc. Thus, generalization should be restrained. Yet, one can usually expect that the diffuse root system of all three subspecies will be substantially greater than the tap root (Daubenmire 1975, Fernandez and Caldwell 1975, Tabler 1964, Sturges 1977). Studies in our laboratory have indicated that most of the belowground biomass of Artemisia tridentata subsp. wyomingensis from northern Utah consisted of extremely fine roots often of a diameter less than 500 microns and extractable from the soil only with great care (Caldwell and Fernandez 1975). Not surprisingly, Sturges (1977) reported that root density was greatest closest to the plant axis though roots could spread horizontally for a considerable distance. Furthermore, root densities were greatest in those zones of the profile where soil moisture recharge was most significant. This appeared to apply at several sites for the two subspecies which he studied, vaseyana and wyomingensis.

The competitive effectiveness of sagebrush has always been highly regarded particularly when one is attempting to establish grasses or other potential competitors within the immediate vicinity of sagebrush plants (Robertson 1943, Frischknecht 1963). Certainly, much of this competitive effectiveness can likely be explained as aggressive competition for a limited moisture resource. The pattern of soil moisture use by sagebrush is usually surmised from soil moisture depletion patterns. For example, Sturges (1977) employed this technique and generalized that "moisture use zones shifted from

the surface soil near the plant early in the season, outward and downward as the season advanced." This appeared to apply for both subspecies wyomingensis and vaseyana at several sites. This is similar to patterns of root growth activity which were measured in northern Utah, for the wyomingensis subspecies (Fernandez and Caldwell 1975). As shown in Figure 9, root growth activity commenced early in the season near the soil surface and preceded vegetative activity by several weeks. As the season progressed, the root growth activity was evident at increasing depths in the profile while roots near the surface ceased to grow. This pattern of root growth was also observed for associated Great Basin Desert shrubs, Atriplex confertifolia and Ceratoides lanata. Although the general patterns of soil moisture depletion and root growth are similar, one still must be careful in stating that new root growth is necessary in the water absorption process.

Individual components of the sagebrush root system apparently supply moisture and nutrients only to branches of the shoot system with which they are in immediate anatomical contact. This has been surmised from radioactive iodine labelling studies in which the radioisotope absorbed by one portion of the root system only appeared in one discrete portion of the shoot system (Daubenmire 1975). This also corroborates the earlier findings of Cook and Stoddart (1959) who reported that if sagebrush twigs were clipped on only one half of the plant, there was corresponding death of roots on that side of the plant.

It has been commonly observed that Artemisia tridentata is generally restricted to well-drained soils. Lunt, Letey and Clark (1973) postulated that this habitat preference may be related to the oxygen demands for root respiration of this species. They compared oxygen requirements for root respiration and root growth for three desert species, Artemisia tridentata, Franseria dumosa and Larrea divaricata. They found that Franseria had the lowest oxygen demand and was comparable to many agricultural species in this respect. Artemisia tridentata possessed nearly twice the oxygen requirement for root respiration. This could well explain the poor performance of Artemisia in waterlogged or heavy-textured soil. An example of their findings for root growth is represented in Figure 10 where depth of root growth in a soil atmosphere of 2% O_2 is depicted. Sagebrush was clearly inferior in low oxygen soils.

Though sagebrush is recognized for its competitive root system, the specific root characteristics that confer this competitive capability are not clear. Artemisia tridentata can extract water from dry soils, as was discussed earlier in this review. While this may be of competitive advantage in some circumstances, it is in some respects paradoxical that the root system would have this capacity when it is apparent that the plant (at least subspecies tridentata) has a rather limited capacity for photosynthesis at moderately low water potentials when compared to other desert species (Moore, White and Caldwell 1972, Odening, Strain and Oechel 1974). Though the sagebrush root system appears to be quite competitive, this competitive advantage apparently comes at a rather high cost.

Biological Significance of Secondary Compounds

Though there is considerable circumstantial evidence that the competitiveness of sagebrush may largely be a matter of competition for the moisture

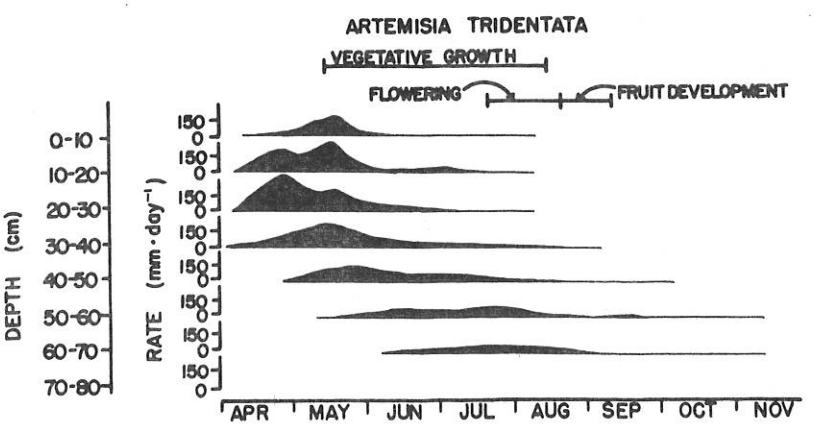

Figure 9. The daily rate of root elongation for Artemisia tridentata subsp. wyomingensis at 10-cm depth intervals in the soil. Growth rates are expressed as $mm \cdot day^{-1}$ for the visible root system in an observation window in the field (50 cm width). These measurements were taken in Curlew Valley of northern Utah in 1973. The period of active shoot elongation, denoted as vegetative growth, and the principal periods of flowering and fruit development were also indicated. Adapted from Fernandez and Caldwell 1975.

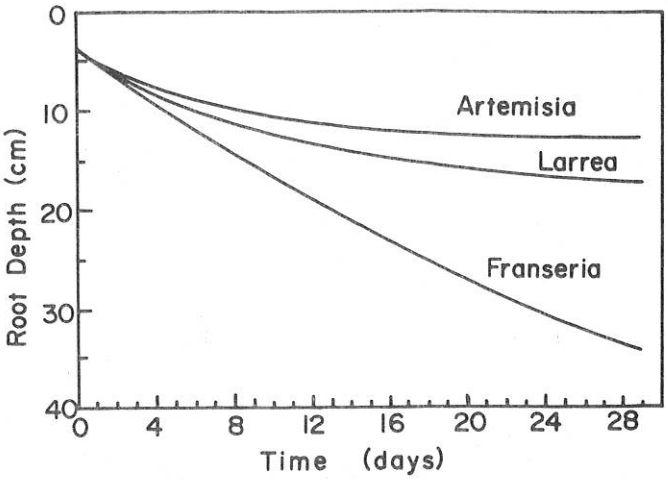

Figure 10. Depth of seedling root growth through time in a soil atmosphere of 2% oxygen for Artemisia tridentata, Franseria dumosa and Larrea tridentata under laboratory conditions. Adapted from Lunt, Letey and Clark 1973.

resource, the speculation has long been prevalent that secondary compounds produced by this species--particularly terpenoids--may confer the competitive edge for sagebrush. The role these compounds may play in reducing palatability, and thus predation by herbivores, has also been the subject of much speculation.

To demonstrate allelopathic efficacy, it is necessary to show that chemicals excreted by the plant into the environment are effective at natural concentrations in supressing growth or reproduction of its potential competitors in the field. Many plants will yield extracts which can significantly depress germination or growth of other plants; yet, this does not demonstrate effective allelopathy in nature. Certainly, Artemisia tridentata does produce such chemical compounds. For example, aqueous extracts of Artemisia tridentata litter and also the volatile compounds escaping from leaves of Artemisia tridentata can inhibit germination and seedling growth of several species (Schlatterer and Tisdale 1969, Klarich and Weaver 1973, Hoffman and Hazlett 1977). Although such experiments suggest allelopathic effectiveness, it yet remains to be demonstrated under field conditions--a difficult task. Whether water soluble compounds released from the foliage or litter of the plant will both be in sufficient concentration and also not rendered inactive by binding to soil particles must be clearly shown.

Weaver and Klarich (1977) recently demonstrated that wheat plants were sensitive to chronic low levels of volatile substances from Artemisia tridentata (subsp. vaseyana) under laboratory conditions. Furthermore, they showed that respiration rates of mature wheat leaves were much higher when placed in the field near Artemisia tridentata plants as opposed to similar field sites not in the proximity of sagebrush. If one were to interpret the stimulated leaf respiration rates of the wheat plants as an adverse effect on their metabolism, this could be taken as one indication that the volatile compounds--likely terpenes--may be effective in nature. At this point, one must certainly respect the potential phytotoxic nature of Artemisia tridentata volatile compounds as affording some competitive advantage to sagebrush. An unequivocal demonstration of this phenomenon in the field will be welcomed.

It has long been noted that subspecies and even individual plants of Artemisia tridentata vary considerably in their palatability (Scholl, Kelsey and Shafizadeh 1977). Whether the major volatile compound in Artemisia tridentata foliage influence palatability by large herbivores is, however, still in question. To address this question, Scholl et al. (1977) determined the levels of eight major volatile compounds in several Artemisia tridentata taxa from a garden near Price, Utah where mule deer were free to selectively browse these plants during the winter. Using a multiple regression approach, they attempted to establsih relationships between volatile constituents and degree of browse use by the mule deer. The regression equations could only account for a maximum of 20% of the variability in utilization. Oxygenated compounds seemed to be somewhat more highly correlated with utilization than hydrocarbons. In any case, no single constituent or even group of compounds of those examined was clearly related to browsing use of these various sagebrush taxa by the mule deer. Other compounds such as the phenolics, which have been useful in Artemisia tridentata taxonomy (Hanks et al. 1973) have also been linked with palatability differences in strains of Artemisia tridentata (Hanks et al. 1971). Whether these would be better related quantitatively with degree of browse use is, however, an open question.

The quantities of secondary compounds apparently may vary substantially with growing conditions as well as with genetic differences within Artemisia tridentata. For example, Powell (1970) found strong correlations between volatile oils in Artemisia tridentata and various site factors. Generally, he suggested that larger plants growing in the more favorable sites had decidedly higher oil contents. One might speculate that production of such secondary compounds is somewhat of a luxury and would be intensified when this plant is in favorable growing conditions.

Finally, one must always bear in mind that what are termed secondary compounds in plant metabolism because they have no apparent immediate metabolic function may yet be involved as plant metabolism regulators or as carbon and mineral storage pools (Seigler 1977). It has been shown, for example, that many terpenes are not static end products, but instead may be in dynamic equilibrium with plant metabolism and function as storage pools (Seigler 1977). Therefore, one should be cautious in immediately assigning only secondary roles to compounds that may yet have a direct metabolic involvement.

Conclusions

Certainly, no single impressive physiological trait of Artemisia tridentata can explain its success in its western landscape. In many respects it is far from physiologically superior: leaf photosynthetic rates are often comparatively low, photosynthesis is apparently usually inhibited by moderate plant water stress and high leaf temperatures, root systems have a particularly high oxygen requirement, reserve carbon levels are apparently not particularly high, it does not exhibit much resiliency to severe defoliation, and the root system is apparently very costly to maintain. The success of the species may be linked with its capacity for photosynthesis at low temperatures, physiological capacity to undergo temperature acclimation for photosynthesis, maintenance of rather large leaf area throughout the year and thus the immediate capacity for photosynthesis when conditions are favorable in the spring, sensitive stomatal control of water loss so that leaves must not be shed in great quantities when water is in short supply, capacity of the root systems to remove water from dry soils, and possibly secondary compounds which may act to deter predation and plant competitors.

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HYDROLOGIC RELATIONS OF SAGEBRUSH LANDS

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A comprehensive review of the hydrologic relations of individual sagebrush plants and of sagebrush lands is presented. The climatological regime, hydrologic relations of individual sagebrush plants, and evapotranspiration, snow accumulation, snowmelt, and infiltration characteristics of sagebrush stands are discussed. Water yield and sedimentation characteristics, grazing, and watershed values are also discussed.

Introduction

Historically, that part of the sagebrush zone not converted to crop production has remained a grazing resource. Little effort has been directed at clarifying hydrologic relations in this habitat type, compared to ecological and range management oriented investigations. Because of the extent of the sagebrush ecosystem, it seems almost axiomatic that components of the hydrologic cycle do not have equal importance everywhere.

Big sagebrush (Artemisia tridentata) occupies more than half of the total sagebrush acreage in the 11 western states. The subdivision of the big sagebrush complex into three subspecies, basin (A. t. tridentata), Wyoming (A. t. wyomingensis), and mountain (A. t. vaseyana) by Beetle (1960) and Beetle and Young (1967) has merit, aside from taxonomical considerations, because subspecies indicate important environmental and hydrologic characteristics about a site. Careful identification of sagebrush to a species, or subspecies level when appropriate, is important. Such identifications would have reduced inconsistencies now present in sagebrush hydrology literature.

Sagebrush Hydrology Study Sites

Hydrologic investigations involving entire drainage basins have been conducted at an extremely limited number of locations (Figure 1). Since these sites are located in the wetter portions of the type, study results are not necessarily representative of the entire zone.

Figure 1. Hydrologic research sites in the sagebrush zone which utilized entire drainage basins equipped with streamflow gages.

[1]Central headquarters is maintained at Fort Collins in cooperation with Colorado State University; research reported here was conducted at the Station's Research Work Unit at Laramie, in cooperation with the University of Wyoming. Portions of the research were supported by the Bureau of Land Management, US Department of the Interior.

Colorado

Boco Mountain Watersheds

This site, located near Wolcott in west-central Colorado at an elevation of 2,200 m receives about 350 mm of precipitation annually. The effects of converting mountain big sagebrush to beardless bluebunch wheatgrass (Agropyron inerme) on soil moisture level, runoff, and sediment yield were studied utilizing four 2- to 4-ha watersheds. The US Geological Survey and Bureau of Land Management cooperated on this study which began in 1964, but is no longer active (Shown et al. 1972).

Idaho

Reynolds Creek Watershed

This site, located 88 km southwest of Boise, Idaho, is operated by the USDA Science and Education Administration. Reynolds Creek is a 23,400-ha watershed representative of sagebrush rangelands in Idaho and surrounding states. Average annual precipitation varies from 250 to 1,150 mm depending on watershed elevation which ranges from 1,200 to 2,200 m. The study which began in 1960, is directed at all phases of the hydrologic cycle (Robins et al. 1965, Stephenson 1977). Numerous drainage basins, ranging in size from 2-ha headwater catchments to downstream locations in excess of 3,000 ha, are equipped with streamflow gages.

Wyoming

Wayne's Creek Watersheds

The Rocky Mountain Forest and Range Experiment Station investigated the effect of herbicide control of mountain big sagebrush upon vegetation production, ground cover, elk use, snow accumulation, and water yield. The study was conducted between 1959 and 1971 on two contiguous 27- and 43-ha watersheds located 19 km from Dubois in northwest Wyoming. The 2,900-m elevation watersheds receive an average of 520 mm of precipitation annually.

Stratton Sagebrush Hydrology Study

This study, conducted by the Rocky Mountain Forest and Range Experiment Station in cooperation with the Bureau of Land Management, began in 1968. The site is in south-central Wyoming, at an elevation of 2,400 m, with an average annual precipitation of 490 mm. Hydrologic relations on undisturbed watersheds vegetated by mountain and Wyoming big sagebrush were studied before imposing selected sagebrush management practices. Studies were conducted on five watersheds ranging from 140 to 665 ha.

Selected Physical Features of the Sagebrush Ecosystem

Precipitation

Annual precipitation within the sagebrush ecosystem ranges from about 200 mm to more than 1,000 mm. Most falls during the fall, winter, and spring, when temperatures are too low for appreciable plant growth. About two-thirds of yearly precipitation falls as snow in the mountain big sagebrush zone, but snowfall comprises a smaller proportion of annual precipitation as elevation decreases. Cold air temperatures prevent appreciable winter snowmelt on higher elevation, mountain, or basin big sagebrush lands.

Most summer rains are small. Less than 3 mm of rain was received on about two-thirds of days with precipitation at the Stratton site, and rainfall exceeded 10 mm on about 6 percent of days with precipitation (Figure 2).

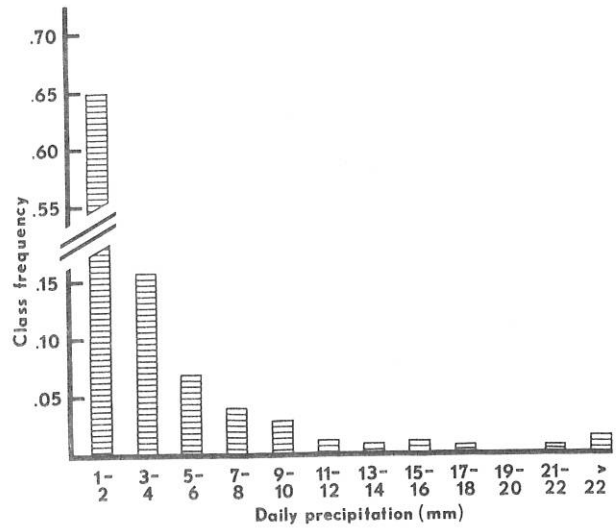

Figure 2. The majority of summer precipitation falls in small amounts in the sagebrush zone. Data collected at the Stratton site June 1, 1968 - September 30, 1977.

Cooper (1967) studied summer rainfall intensity relationships in the Reynolds Creek basin. Practically all high intensity rainfall was associated with convectional storms from April through October; rain fell between 1600 and 2200 local time. About 2 percent of summer rainfall fell at an intensity between 51 and 76 mm per hour, and another 2 percent fell at intensities greater than 76 mm per hour. There was no relationship between elevation and peak rainfall intensity, or between elevation and total rainfall falling at a given intensity. Thus, about the same proportion of seasonal rainfall exceeded a given intensity at high and low elevations. This suggests that rainfall data from an accessible station can be used to estimate the relative occurrence of high intensity rainfall over appreciable elevational ranges. A similar conclusion was also reached by Caine (1976) from studies in the alpine zone of the San Juan Mountains of southern Colorado.

According to Cooper (1967), the proportion of summer precipitation exceeding a given intensity in

Reynolds Creek basin can be estimated from the relationship

$$R = 0.13e^{-0.67I} \quad (1)$$

where R = The proportion of April-October precipitation exceeding a given intensity

I = Specified rainfall intensity, in inches per hour

e = Base of natural logs (2.718....).

Cooper believed that coefficients of equation 1 were characteristic of the regional climate and might be valid for as large an area as southern Idaho. However, this assumption should be checked for sites outside the immediate Reynolds Creek vicinity. The validity of coefficients at different locations can be checked with a limited amount of storm intensity data, or if required, the value of new constants can be determined.

Temperature Regime

No single location can typify the entire sagebrush zone, but average monthly temperatures for the Stratton study site (Wyoming), Malad, Idaho, and Winnemucca, Nevada are indicative of the cyclical nature of temperature regime (Figure 3). Temperatures warm sufficiently in the spring for plant growth, reach daily maximums of 30 to 40°C in July or August, and by October or November, become sufficiently low to prevent appreciable plant growth. In higher portions of the sagebrush zone, overwinter precipitation accumulates in the form of snow that does not melt until spring. At lower elevations, winter temperatures may warm enough to cause snowmelt, or warm enough that some midwinter precipitation is received as rain. Sagebrush then, exists where temperature and moisture relationships are favorable for rapid vegetation growth only for a short period of time in the spring and early summer.

Wind and Drifting Snow

Because of its ability to relocate snow, wind is an important hydrologic agent on sagebrush lands with substantial snowfall. The prevailing winter westerly winds reach yearly maximums in December and January (Figure 4), accentuating the blowing snow phenomenon. Newly fallen snow can drift in winds as low as 6 m/sec; greater speeds are required to transport aged or crusted snow. Where windspeeds are high, vegetation height or topography controls the depth of snow accumulation.

The magnitude of sublimation loss during drifting is just beginning to be appreciated. A theoretical description of the sublimation process was developed by Schmidt (1972). The temperature and humidity of air surrounding a snow particle, radiant energy impinging on the particle, and particle diameter, are the primary factors controlling sublimation. The rate of sublimation for a given sized particle nearly doubles as air temperature increases by 10°C over the range -20°C to 0°C. Tabler (1975) demonstrated that large quantities of water do indeed return to the atmosphere, and provided a means to

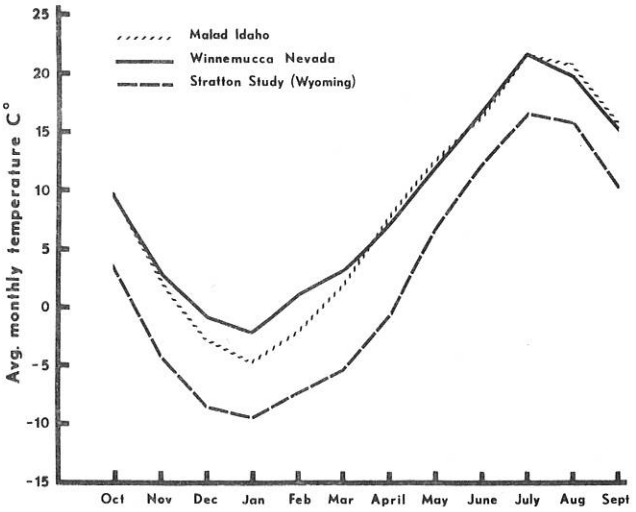

Figure 3. Average monthly temperatures at Malad, Idaho, Winnemucca, Nevada, and the Stratton area (Wyoming) are representative of annual temperature regime within the sagebrush type.

quantify sublimation loss. The percentage loss in mass of an average sized snow particle during drifting was calculated by:

$$L = 100\left(1 - 0.14^{(R/R_{\mu})}\right) \quad (2)$$

where L = The percentage loss in mass of an average sized snow particle

R = Distance traveled by the snow particle

R_{μ} = Distance an average sized snow particle travels before completely sublimating.

The mean overwinter value of R_{μ} was 3,050 m for sites in southeastern Wyoming located between 2,240 and 2,920 m in elevation. Assuming 3,050 m for R_{μ} in equation 2, an average sized snow particle would lose 39, 63, 86, and 98 percent of its mass for R/R_{μ} values of 0.25, 0.50, 1.00, and 2.00 respectively; these R/R_{μ} fractions correspond to drifting distances of 762, 1,525, 3,050, and 6,100 m, respectively. Thus, the distance that an individual snow particle can drift is finite, which accounts for the absence of "mountains of snow" downwind from regions of severe drifting.

Tabler (1975) provides a method to determine the actual quantity of relocated snow arriving at a given site which accounts for upwind vegetation and terrain storage and for the incremental distances that individual snow particles must travel.

Hydrologic Features of the Sagebrush Plant

Interception

Sagebrush plants exert a major influence on the overall hydrologic performance of sagebrush lands.

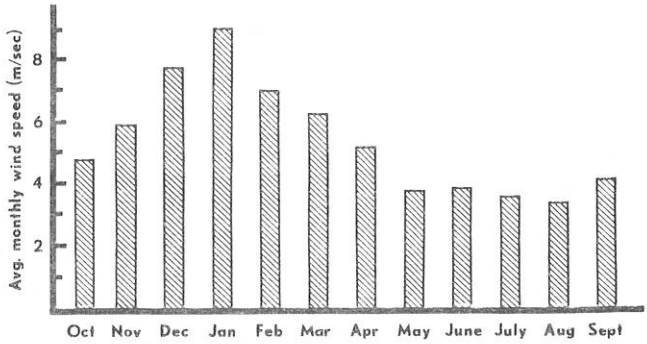

Figure 4. Maximum monthly windspeed occurs during the winter when the majority of yearly precipitation is received, thus contributing to the severity of blowing snow conditions. Data from the Stratton area.

Interception and subsequent sublimation of snow, or evaporation of rain, reduce precipitation input. West and Gifford (1976) found the water holding capacity of individual sagebrush plants 18 to 44 cm tall from Curlew Valley, Utah was 1.5 mm. In Idaho, plants with an average height and crown diameter of 114 and 76 cm respectively, held about 1.2 mm of water (Hull and Klomp 1974).

Hull and Klomp (1974) reported that about 30 percent of summer rainfall was intercepted by sagebrush stands at two study sites in Idaho. Basin big sagebrush grew at one location where plants averaged 107 cm high and had a crown coverage of 33 percent. Wyoming big sagebrush grew at their other study site, averaging 46 cm high with a crown coverage area of 11 percent. West and Gifford (1976) estimated that seasonal interception losses at Curlew Valley would be 5.9 mm, or about 4 percent of precipitation from storms larger than 1.5 mm. This estimate was based on the water-holding capacity of individual sagebrush plants and stand density. The actual amount of precipitation reaching the soil surface would be less than values determined in the Utah and Idaho studies because of additional interception by herbaceous vegetation.

Sagebrush snow-interception relationships are complex. Reports of shallower snow depths in sagebrush stands compared to adjacent sprayed or reseeded vegetation are common, indicating that differences arose because of sublimation of snow retained within the sagebrush canopy (Robertson 1947, Sonder and Alley 1961, Hull and Klomp 1974). In contrast, Connaughton (1935) found that snow accumulation in a sagebrush stand was similar to that for an area devoid of vegetation. Both Hutchison (1965) and Sturges (1977a) indicated that where drifting was common, the rate of snow accumulation was less for herbaceous vegetation than for sagebrush vegetation because of the efficiency of sagebrush crowns in trapping drifting snow. Once sagebrush crowns were covered, however, the accumulation rate was similar for both vegetation types.

These conflicting reports probably stem principally from study site differences in temperature regimes, winter snowfall depths, and magnitude of snow relocation. Additionally, the energy balance over sagebrush and herbaceous vegetation is probably not the same. Sagebrush protruding through the snowpack reradiates absorbed short wave radiation as long wave radiation which promotes snowmelt around the perimeter of the plant. This process is probably an important factor contributing to the shallower depth of snow in sagebrush vegetation, but occurs after storm events, and is not an interception phenomenon. The proportion of water from snowmelt adjacent to sagebrush plants that enters the soil and returns directly to the atmosphere is unknown.

Rooting Characteristics

Sagebrush has a two-storied root system (Figure 5). A dense root network is located in the upper 60 cm of soil, particularly the surface 15 cm of soil beneath the canopy. The tap root or deeply extending laterals commonly extend 180 cm deep, while maximum lateral root spread is about 150 cm. In a Nevada study, Robertson (1943) found sagebrush roots grew between May and August, and slightly preceded or coincided with the period of active

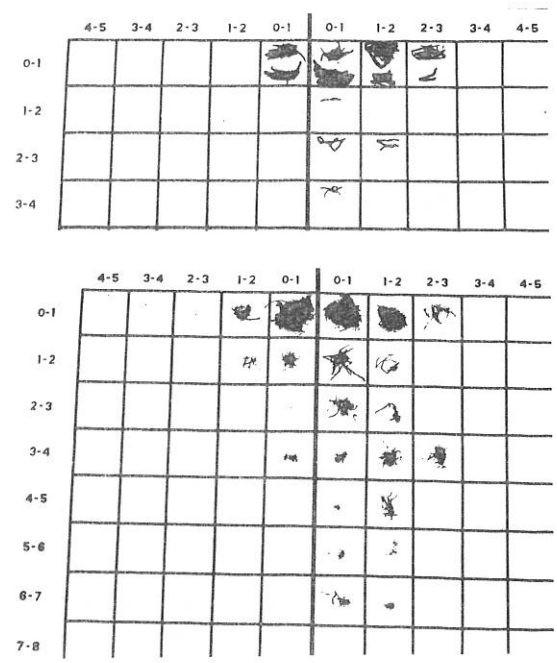

Figure 5. Sagebrush has a dense root network in surface soil in addition to deeply extending roots. The distribution of large (≥ 3 mm in diameter) and small sagebrush roots excavated from 30.5 cm^3 soil volumes on either side of the trunk is shown in the upper and lower portions of the figure. The grid is 30.5 cm (1 foot) on a side.

shoot development. Fernandez and Caldwell (1975) found essentially the same pattern of root growth in a recent Utah study. Root growth began a few days before active shoot growth in the spring and extended for several months after shoot growth and reproductive development had ended. Cook and Lewis (1963), Goodwin (1956), Hull and Klomp (1974), and Tabler (1964) provided detailed discussions of the sagebrush root system.

Special soil conditions such as shallow depth, an indurate layer, or deep alluvium, can greatly modify the morphology of sagebrush root systems. Measurements taken at bottom, midslope, and ridge positions on a slope 460 m long at the Stratton study area (Sturges 1977c) demonstrate this variation. Mountain big sagebrush grew at the two lower slope locations; Wyoming big sagebrush grew at the ridge site. Roots extended about 2 m deep at the two lower slope locations, as is characteristic for sagebrush, but no deeper than 1.5 m at the ridge location. The rocky nature of the substratum at the ridge and lack of soil water recharge below 1.5 m accounted for the shallower rooting depth. There was also a marked concentration of large, woody roots within 30 cm of the trunk of ridge plants. This concentration was absent at the lower slope locations. It is unknown if this is a characteristic difference between Wyoming and mountain big sagebrush subspecies.

Soils at each slope location belonged to a different series although parent material, macroclimate, and developmental time were the same. The amount of water available from snow for soil recharge strongly influenced soil developmental processes as well as sagebrush characteristics. Overwinter precipitation was 208 mm the year of study, but snow at the bottom, midslope, and ridge sites contained 511, 368, and 102 mm of water, respectively, because of snow relocation by wind. The average height of sagebrush plants and solum depth progressively decreased up the slope (Sturges 1977c).

Soil Moisture Use Patterns

The principal moisture reservoir of isolated sagebrush plants was identified at the bottom, midslope, and ridge study locations (Sturges 1977c). The moisture reservoir extended laterally outward 0.9 m from the trunk and 0.9 m deep. The 0.9-m depth corresponded to the zone of major soil water recharge at the ridge site. Soil was recharged to at least a 2.4-m depth at the midslope and bottom sites where roots extended 2 m deep.

Early in the growing season, plants utilized moisture primarily from surface soil adjacent to the trunk. The major withdrawal zone then shifted outward and downward as soil water adjacent to the plant was depleted. Appreciable water uptake was detectable until the first week of August. The reduction in moisture use coincided with the midsummer leaf drop that is characteristic of big sagebrush following completion of twig and leaf growth (Diettert 1938). Leaf drop is believed to be a physiological response by sagebrush to decreasing moisture availability.

Seasonal Photosynthesis Rate

DePuit and Caldwell (1973) measured the net photosynthesis pattern of basin big sagebrush under field conditions; the pattern relates closely to the seasonal moisture use regime described. Photosynthesis was influenced most by plant water potential, leaf temperature, irradiation, and stage of phenological development. The rate was highest in late May and early June, when moisture was not limiting, and then declined until August; minimum rates were detected at the time of greatest internal water stress. The photosynthetic rate mainly correlated with leaf temperature and irradiation levels when soil water levels were high. Internal plant water stress and phenological factors were also important factors controlling net photosynthesis in mid- and late summer.

Hydrologic Features of Sagebrush Stands

Evapotranspiration and Soil Moisture Withdrawal

Extracted soil water comprises a major part of precipitation input in the sagebrush ecosystem. The moisture withdrawal pattern of sagebrush stands is similar to that described for individual plants. Depletion in the upper part of the soil is rapid when soil water levels are high and herbaceous species are growing rapidly (Figure 6). As surface soil dries and sagebrush stems and leaves develop, sagebrush roots deeper than 1 m begin to extract more water and remain active for the remainder of

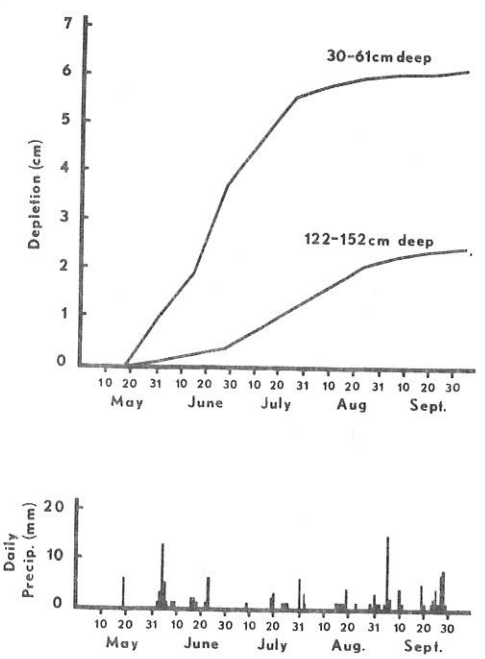

Figure 6. Sagebrush stands utilize water primarily at shallow depths early in the growing season, but moisture use zones shift downward once surface soil dries.

the growing season. Withdrawal characteristically decreases sharply at the time of midsummer leaf drop. No evidence of winter moisture use was found by Tabler (1968) at Wayne's Creek, where temperatures remain well below freezing and snow covers vegetation. In warmer climates, such as at the Hanford Reservation in southeastern Washington, Rickard (1967) found that sagebrush utilized soil water during winter.

Although deeper roots of sagebrush comprise a small proportion of total root weight, they play an important role in the water economy of a plant. For example, roots lying below 91 cm contributed about 4 percent of total root system weight for plants at the Stratton site.[2] The deeper roots become important during periods of moisture stress. Campbell and Harris (1977) evaluated soil water content and sagebrush leaf water potential through the growing season. Leaf water potential recovered to -10 bars at night early in the season and to -20 bars by the end of the season. In general, nighttime recovery of leaf water potential approximated the highest soil water potential in the root zone once soil water potential fell below about -10 bars.

Seasonal water withdrawal by two stands of mountain big sagebrush is shown in Figure 7; the soil mantle was fully recharged from snowmelt each spring at both locations. The length of the measurement interval was shorter, and summer rainfall was greater at Wayne's Creek than at Stratton, but the pattern of moisture withdrawal was similar. Heavy September precipitation (60 mm) recharged water levels in the surface 30 cm of soil at Wayne's Creek. Summer evapotranspiration can be calculated by adding summer precipitation to the seasonal change in moisture content. Evapotranspiration was 268 and 324 mm at Wayne's Creek and Stratton, respectively, or an average of 2.9 and 2.3 mm per day through the measurement period.

Seasonal evapotranspiration was also calculated at Reynolds Creek based on soil water change in the surface 91 cm of soil and interval precipitation (Rawls et al. 1973). Depletion rates of 1.0, 1.8, and 2.5 mm/day were measured at three sites progressively higher in elevation. Annual precipitation increased from 226 mm at the lower site to 639 mm at the highest site over an elevational range of 740 m. The soil profile was fully recharged at the highest site, and moisture content remained well above permanent wilting percentage through the summer. Soil at the lower site usually was not fully recharged by winter precipitation, and available moisture was completely utilized each growing season. Evapotranspiration also equaled precipitation input during a 2-year study in Washington (Campbell and Harris 1977). Precipitation was about 100 mm above and below the long-term value of 250 mm during study years. Soil moisture measurements extended between 180 and 270 cm deep.

The rooting and soil moisture withdrawal characteristics of sagebrush in combination with soil

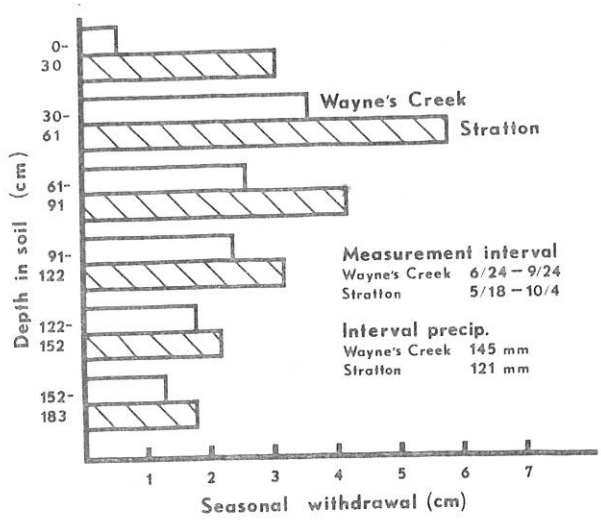

Figure 7. Seasonal water withdrawal by sagebrush stands through a 183 cm depth partitioned by 30.5-cm intervals. Sagebrush roots below 91 cm play an important role in supplying water to a plant even though they comprise a small proportion of total root weight.

depth can be used to identify sites where sagebrush control might decrease seasonal moisture use. Sagebrush removal on sites with soils less than 1 m deep will not affect total withdrawal because the herbaceous vegetation that develops after removal will utilize similar amounts of moisture as an undisturbed sagebrush stand (Tabler 1968, Sturges 1977b). However, on sites where soils are (a) more than 1 m deep and (b) where precipitation is sufficient to fully wet soil each spring, water withdrawal can decrease following sagebrush control.

Snow Accumulation and Melt

The height of vegetation controls the depth of snow accumulation on windswept lands, a concept that enabled Tabler (1975) to estimate the amount of wind-relocated snow arriving at a given site. Taller sagebrush stands retain more snow onsite against the wind than do shorter stands. Where winds are not strong enough to relocate much snow, winter precipitation controls the maximum depth of snow accumulation. In several studies the depth of snow in sagebrush vegetation was found to be less than in adjacent sagebrush-free sites. Snowmelt around sagebrush plants, attributable to long-wave radiation by plants, may be responsible for a major part of this difference.

There appears to be little difference in the snowmelt rate on sagebrush, grass, or bare areas. Snowmelt released an average of 11.4 mm of water per day over an 8-day period at a high elevation sagebrush stand in Wyoming. An adjacent grass area also had a similar melt rate (Hutchison 1965). Snowmelt on sagebrush and denuded sites was essentially complete at the same time in Idaho (Connaughton

[2]Sturges, D. L. and M. J. Trlica. Root weights and carbohydrate reserves of big sagebrush. Manuscript submitted to Ecology.

1935). Sturges (1977a) detected no differences in the snowmelt rate between sprayed and unsprayed sagebrush stands during the time vegetation was completely buried by snow nor when the snow surface was within the vegetation canopy.

Data from a snowmelt lysimeter (Sturges 1977a) indicates that daily melt can be substantially greater than average weekly rates. Daily melt commonly released 20 mm of water when snow covered vegetation, but more than 60 mm of water was released while the snow surface was within the sagebrush canopy. On 3 days when total melt was between 60 and 70 mm of water, the melt rate exceeded 6 mm per hour for 6 consecutive hours during the day. The acceleration of melt once sagebrush protruded through the snow surface was ascribed to a change in surface albedo, and reradiation of long wave radiation by sagebrush.

Infiltration and Soil Transport

Infiltration measurements conducted at many locations in the sagebrush type indicate that infiltration usually exceeds 50 mm/hour and often exceeds 75 mm/hour during the first 10 minutes of rain (Woodward 1943, Gifford and Skau 1967, Blackburn and Skau 1974, Gifford and Busby 1974). The initial infiltration rate generally decreases rapidly as dry soil is moistened, then the rate of decrease slows markedly, and infiltration may become constant. Morin and Benyamini (1977) believe that the formation of a thin, continuous crust on bare soil, not antecedent moisture conditions, is responsible for the reduction in infiltration as soil is moistened.

There is no simple theoretical model that adequately describes the complex processes which control infiltration. Investigators have relied on multiple regression analysis or similar techniques to identify soil, cover, and topographic factors that relate to infiltration and soil movement on small plots when artifical rainfall is applied. However, it has not been possible to develop specific relationships to predict either infiltration or soil transport that are applicable over widespread areas (Gifford 1976). Based on cover characteristics, Gifford (1972) found that infiltration prediction varies seasonally as well as within single storm events. There is general agreement that watershed cover, often defined to include litter and rock as well as vegetation, is an important factor influencing infiltration and subsequent soil movement caused by overland flow. Soil texture and organic matter content are other important factors influencing infiltration although the relationship changes for soils of varying texture (Meeuwig 1971). This points out the complex interrelationships between physical and biological factors that govern infiltration.

Hydrologic Features of Sagebrush Watersheds

Total Annual Runoff

Sagebrush lands and subalpine forested lands sometimes have a similar precipitation input and overlap in elevation. Sagebrush lands do yield appreciable runoff in the wetter portions of the type. The relationship between average annual precipitation and average annual runoff for sagebrush watersheds located at the Boco Mountain, Reynolds Creek, Stratton, and Wayne's Creek study areas is shown in Figure 8. For comparison purposes, precipitation-runoff values for five forested watersheds located in Colorado and Wyoming (Leaf 1975) are also shown. Sagebrush watersheds range from 3 to 644 ha, while forested watersheds range between 880 and 3,626 ha. Although precipitation-runoff figures between watersheds are not strictly comparable because of a wide variation in basin size, the data provides a general indication of how runoff varies with annual precipitation. Runoff from lands receiving less than about 370 mm of precipitation is negligible in most years. However, appreciable runoff occasionally may be produced from these lands by high intensity, summer cloudbursts, or by winter rainfall when snow overlies frozen soil.

Water Yield Timing

The maximum runoff rate and most of the annual water yield occurs during the snowmelt runoff period on both sagebrush and timbered watersheds. These relationships are evident in Figure 9 which shows hydrographs of Fool Creek, a 289-ha forested watershed located on the Frazer Experimental Forest in Colorado, Loco Creek located on the Stratton area, and Wayne's Creek. Each curve is based on 10 years of runoff information. Loco and Fool Creeks are perennial streams, while discharge on Wayne's Creek lasts only 2 to 4 months in the spring and early summer. Flows on sagebrush watersheds are sensitive to daily fluctuation in weather as shown by Wayne's Creek discharge. The earlier runoff interval and smaller water yield from sagebrush lands compared to subalpine, forested watersheds is also apparent in the figure. Winter baseflow on the forested watershed was about three times as great as on the

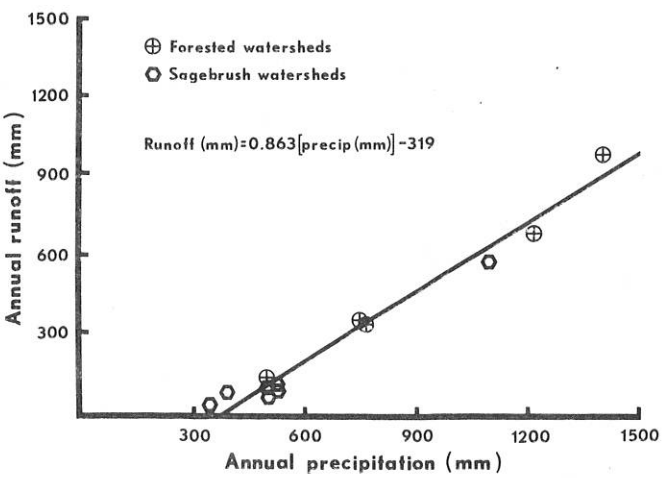

Figure 8. The relationship between annual precipitation and annual water yield indicates that little or no runoff occurs from lands receiving less than 370 mm precipitation.

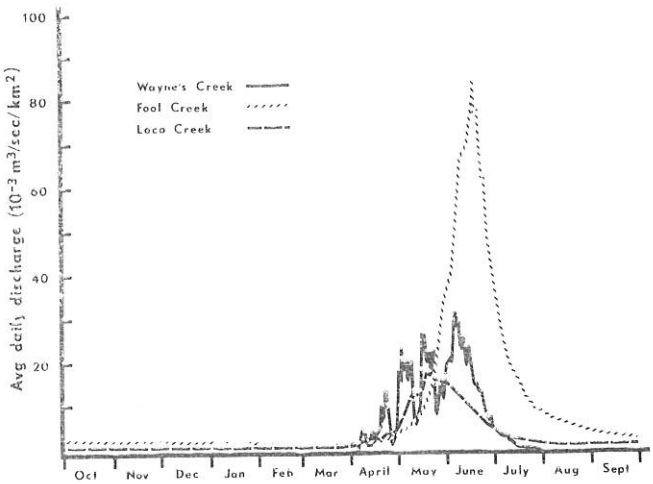

Figure 9. Total annual water yields are smaller, and snowmelt runoff occurs earlier in the year on sagebrush (Loco and Wayne's Creek) than on subalpine forested watersheds (Fool Creek).

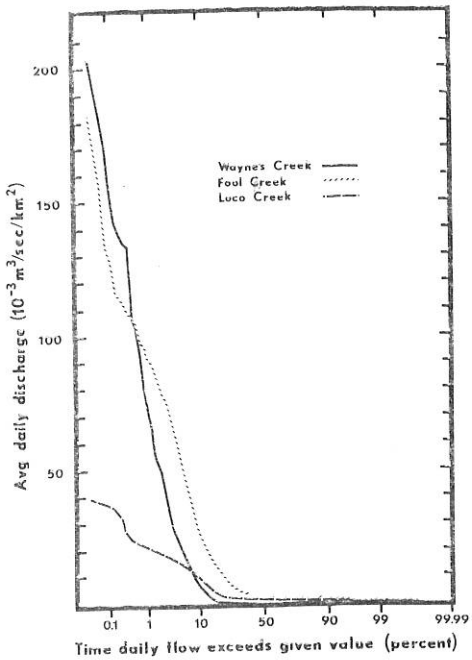

Figure 10. Flow distribution curves for intermittent (Wayne's Creek) and perennial (Loco Creek) sagebrush watersheds and a subalpine forested watershed (Fool Creek).

sagebrush watershed.

Flow duration curves, based on 10 years of record, for these same three watersheds are shown in Figure 10. Wayne's Creek and Fool Creek had maximum flow rates of about 0.02 $m^3/sec/km^2$, but duration of high flow was very short. Flow was less than 0.01 $m^3/sec/km^2$ 99 percent of the time on these watersheds and less than 0.002 $m^3/sec/km^2$ on Loco Creek. Average annual runoff on the intermittent and perennial sagebrush watersheds was similar, but water was yielded much quicker and at a higher flow rate on the intermittent drainage.

The form of the snowmelt hydrograph for sagebrush and forested watersheds is similar. For example, the time required to accumulate the first 25 percent, 50 percent, and 75 percent of total snowmelt runoff comprise similar proportions of the runoff interval (Sturges 1975a). Discharge from sagebrush watersheds is more responsive to daily fluctuations in weather during snowmelt than is discharge from timbered lands. They are usually at a lower elevation than forested watersheds, the snowpack is shallower, and snow is directly exposed to solar radiation. In addition, advected energy from upwind bare areas may be an important energy source driving snowmelt on sagebrush lands (Cox and Zuzel 1976), but probably is of lesser importance in a forest environment.

The relocation of snow into large drifts is an important hydrologic process where drifting conditions are severe. The drifts that develop in natural catchments are commonly 3 to 6 m deep and persist after the general snowpack has melted (Figure 11 - see end of paper). They probably play an important role in supplying water to springs and groundwater recharge. The amount of evaporation from snow and moistened soil around an isolated snowfield is unknown but might constitute a substantial portion of water contained in the drift. Losses of 35 percent to 50 percent of maximum drift water content have been measured for small drifts located behind snowfences (Saulmon 1973, Fletcher and Rechard 1976).

Extreme Runoff Events

Extreme runoff events at Wayne's Creek, Stratton, and Reynolds Creek have occurred in response to snowmelt, rather than summer storm runoff. The maximum instantaneous summer storm discharge on one Wayne's Creek drainage was 0.12 $m^3/sec/km^2$ over a 13-year period. Maximum instantaneous discharge from snowmelt however, was 0.53 $m^3/sec/km^2$, and snowmelt discharge exceeded 0.12 $m^3/sec/km^2$ in 77 percent of the years of study. High discharge rates from summer storm runoff occurs in arid portions of the sagebrush ecosystem but precise precipitation-runoff information does not exist for these areas.

Oversnow flow produced the highest discharge measured on the Stratton area (Sturges 1975b). This type of flow developed on Sane Creek, a south-facing watershed, in years with an extremely late melt season (Figure 12). The rate of snowmelt on upland areas exceeded infiltration capacity of soil, and water flowed into drainages which were filled with dense, windslabbed snow. Water transmission through and under the snowpack was not rapid enough to keep up with inflow. Water flowing on the snow surface

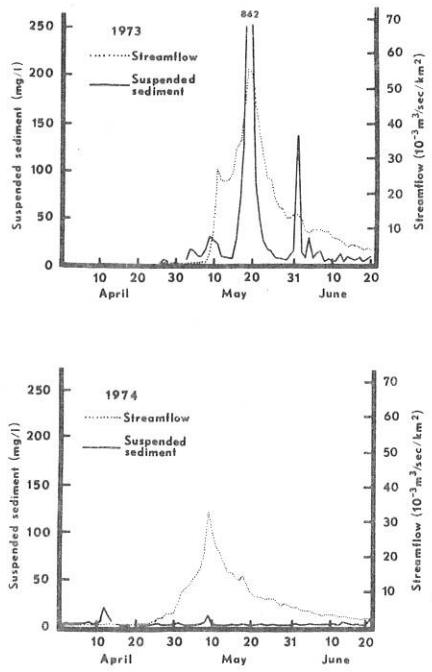

Figure 12. Maximum runoff rates and sediment transport are associated with snowmelt in the higher portions of the sagebrush type. At the Stratton area, oversnow runoff produced high flow rates and sediment yields in 1973 compared to 1974, a year without oversnow flow.

eroded a pronounced channel in the pack that acted as an efficient conveyance system. Instantaneous discharge during oversnow flow was more than three times greater than discharge in years without this phenomenon, and yield efficiency was also much higher than in years of normal runoff.

In the Pacific Northwest, the most severe flooding on lands typified by the Reynolds Creek drainage occurs between December and March and is associated with rain falling on a snowpack overlying frozen soil. The severity and location of flood-producing zones is governed by the intensity and amount of rainfall, quantity of snowmelt, and infiltration characteristics of frozen soil (Johnson and McArthur 1973). Storm runoff varied from 0 to 13 mm within Reynolds Creek basin during one storm with a watershed precipitation input of 13 to 38 mm. Runoff ranged from 0 to 20 mm during a second storm when 13 to 76 mm of precipitation was received. The zones of greatest runoff did not coincide with areas of highest precipitation in either storm.

Sediment Transport

Sediment is transported from sagebrush lands primarily during periods of major runoff. These events are associated with snowmelt in the higher precipitation zones of the sagebrush type and with summer storm runoff in the more arid portions. Similarly, snowmelt runoff was responsible for most sediment movement from subalpine grassland watersheds on Black Mesa in Colorado (Frank et al. 1975). Data on runoff-sediment relationships collected from experimental watersheds located in Idaho and Wyoming are shown in Table 1. Bedload transport between watersheds is not strictly comparable because stilling basins for retaining course sediment have different trapping efficiencies.

Summit Watershed at Reynolds Creek receives about 250 mm of precipitation annually, and essentially all runoff is produced by intense summer rainstorms. The average annual sediment yield is about three times greater than yields from Reynolds Mountain or Upper Sheep Creek, where most runoff and sediment movement occurs during snowmelt. The difference in maximum suspended solid concentration between Summit and the other two watersheds is even more pronounced (Table 1). Johnson and Smith (1977) discussed the nature of sediment particles moved by bedload transport on the Reynolds Creek watersheds.

Total sediment transport and maximum suspended solid concentrations measured at the Stratton area in Loco and Sane Creek are lower than values from the Reynolds Creek study (Table 1). About 100 suspended solid measurements were made on the two Wayne's Creek watersheds. There, maximum sediment concentrations were only 214 and 746 mg/1; bedload deposition figures were also low for these watersheds.

Conclusions arising from sediment investigations at Reynolds Creek are probably applicable through the sagebrush zone (Johnson et al. 1974). Approximately 5 percent to 10 percent of yearly runoff transports 50 percent to 90 percent of the sediment, the increase in sediment yield from dry to wet years is about 10 fold, and sediment yield and instantaneous sediment concentration usually increase with watershed size because of streambank erosion along downstream channel reaches. The sharp increase in sediment yield on the Stratton area in a year with oversnow flow, (Figure 12) supports generalizations concerning the importance of extreme runoff events and the short duration of high sediment production periods.

Johnson and Hanson (1976) were able to estimate suspended sediment discharge for individual runoff events at Reynolds Creek using a conceptual model of the form,

$$SS = a \left(\frac{P * V}{100{,}000} \right)^b \qquad (3)$$

where SS = Total suspended sediment for the event (m^3)

P = Peak discharge in m^3/sec

V = Total runoff (m^3)

a and b = model parameters.

An optimization technique indicated that the value of b was about 1 for five different measurement locations. Therefore, the value of a was determined with b having a value of 1. They believed this model could be applied to other streams after

Table 1. Selected physical characteristics and sediment discharge information for sagebrush watersheds in Idaho and Wyoming

Watershed information				Sediment information				
						Avg. yearly sediment yield		
Name	Size (ha)	Elev. (m)	Precip. (mm)	Years record	Max. suspended solid (mg/l)	Suspended (kg/ha)	Bedload (kg/ha)	Total (kg/ha)
Reynolds Creek[1]								
Reynolds Mtn.	40	2,082	1,095	9	1,380	227	113	340
Upper Sheep Creek	26	1,945	390	5	5,000	54	233	287
Summit	83	1,364	250	8	143,000	- -	- -	949
Stratton Study								
Loco Creek	664	2,410	490	3	393	11.1	0.1	11.2
Sane Creek	238	2,390	490	5	862	- -	0.1	- -
Wayne's Creek								
Watershed II	27	2,970	520	13	214	- -	5	- -
Watershed III	43	2,970	520	13	746	- -	6	- -

[1] Data from Johnson and Smith 1977

collecting sediment information from only a few events to determine the value of model parameter a.

During snowmelt runoff, suspended sediment levels exhibit characteristic diurnal and seasonal variations. These relationships on Loco Creek are evident in Figure 13, where 1976 suspended sediment and streamflow levels are shown early in the runoff period, just after maximum snowmelt discharge, and late in the runoff season. The change in sediment concentration closely paralleled daily changes in water discharge until shortly after maximum snowmelt discharge. Sediment concentration then decreased much faster than hydrograph recession, and the daily fluctuation was reduced. The daily cycle in sediment concentration was evident in water collected from Loco Creek in 1974 at 0600 and 1800 when daily discharge was near minimum and maximum values. From the onset of snowmelt until maximum discharge, suspended solid content of morning samples averaged 26 mg/l, while evening samples averaged 65 mg/l (Sturges 1975c). In 1974, suspended sediment concentrations in Loco Creek water were less than 11 mg/l on most winter days, but increased rapidly as snowmelt runoff began and reached a maximum value of 300 mg/l at the time of maximum snowmelt discharge, and then decreased rapidly to a plateau of about 20 mg/l through the summer.

Grazing and Watershed Values

The need for environmental analyses and environmental impact statements has focused attention on the lack of precise knowledge about hydrologic impacts of livestock grazing. One area where information is available relates to livestock grazing and the bacterial quality of water. Water's bacterial quality is an important aspect of its suitability for human consumption. This assessment is usually based on the presence of total coliform, fecal coliform, or fecal streptococci bacteria.

Domestic livestock with access to a waterway increase bacteria levels (Figure 14). Studies in Colorado (Morrison and Fair 1966, Kunkle and Meiman 1967), Idaho (Stephenson and Street 1978), and Utah (Darling 1973) show a sharp increase in bacteria levels as cows or sheep are turned into an area. Livestock do not have to directly contact a stream to cause pollution. Irrigation water flowing from a mountain meadow in Colorado grazed by cattle elevated stream bacteria levels. Similarly, bacteria concentrations characteristically increase during snowmelt or in periods of summer storm runoff. The bacteria may be carried directly in runoff water or can be attached to sediment particles.

The coliform group includes subtypes that are found in soil and on vegetation, as well as fecal coliforms that grow only in the intestinal tract of warm-blooded animals. Fecal streptococci, another common indicator species, is confined to the gut of warm-blooded animals, and is especially prevalent in ruminant feces.

Substantial populations of indicator bacteria species exist in water coming from lands where no human activity or domestic livestock grazing has occurred (Stuart et al. 1971, McSwain and Swank

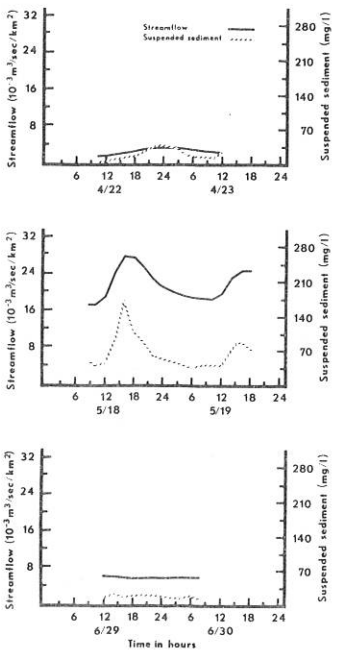

Figure 13. Daily changes in suspended sediment concentration and water discharge parallel each other until shortly after maximum snowmelt runoff (upper two figures). Daily change was not evident late in the snowmelt runoff season (lower figure).

1977). Consequently, while grazing may elevate bacteria levels, the absence of livestock does not insure that water will be of an acceptable bacteriologic quality. Indeed, it is generally conceded that there is no such thing as "safe" drinking water in a wildland situation; all natural waters must be regarded as unsafe, regardless of whether or not the source area is impacted by man's activities.

Another major concern about range livestock relates to their effect on watershed stability. Grazing animals remove forage and compact soil, activities which infiltrometer plot studies have identified as decreasing infiltration and increasing runoff and soil transport. However, the effects of grazing on watershed soil stability and on stream sediment transport have not been quantified. Furthermore, definitive criteria to determine acceptable livestock disturbance levels that have widespread applicability and that are readily applied by the land manager have not been developed.

No controlled experiments involving entire drainage basins have been conducted on sagebrush lands to determine the effects of grazing. However, a study by Rich and Reynolds (1963) on Arizona chaparral watersheds evaluated the effects of grazing on the basis of changes in basal area of grass, total annual runoff, and annual sediment deposition in retention ponds. Two grazing intensities, 40 percent and 80 percent removal of perennial grasses, were studied. Neither grazing intensity had a significant or practical effect on water yield or sediment deposition. The authors mentioned that detecting changes in sediment movement caused by grazing is difficult because of the tremendous natural variability in sediment transport. Watershed sediment movement on study drainages ranged from 0 to 1,033 kg/ha/year.

It is worth noting that grazing can be compatible with watershed stability. The low rates of sediment transport at Wayne's Creek and the Stratton study (Table 1) occurred under cattle and sheep grazing, respectively. Suspended sediment measurements at Wayne's Creek were made while watersheds were being grazed during the pretreatment calibration period; annual bedload deposition measurements continued through the treatment evaluation phase of the study when watersheds were deferred from grazing.

Hydrologic Research Needs in the Sagebrush Ecosystem

A. Hydrologic investigations involving entire drainage basins in those portions of the sagebrush ecosystem receiving less than 350 mm of precipitation are needed to supplement investigations being conducted in areas of higher precipitation. Specifically, work should address:

   1. Summer rainfall characteristics such as storm size and intensity, the amount of precipitation received as rain and snow in winter, and the importance of snow relocation by wind.

   2. Surface runoff in relation to precipitation and climatic factors that induce the runoff.

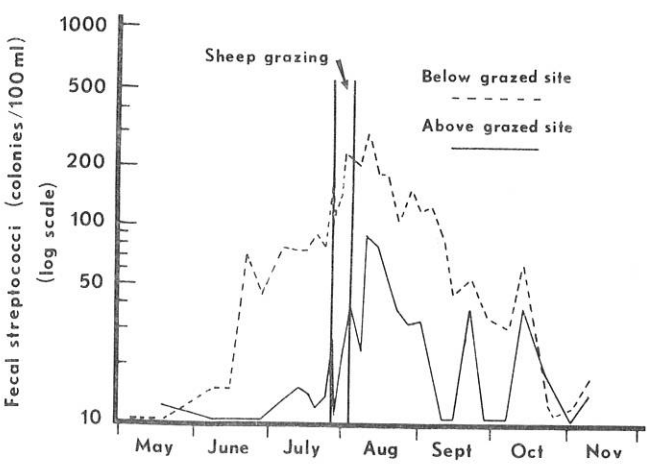

Figure 14. The presence of livestock near or adjacent to streams elevate bacteria counts. Data shows fecal streptococci levels above and below an area grazed by sheep in Utah (Darling, 1973).

3. Sediment transport during runoff periods including concentration, total sediment discharge, as well as identification of source areas.

4. The yearly soil moisture regime in relation to growth cycle and rooting characteristics of vegetation.

B. Snow hydrologic investigations on sagebrush lands are needed to address:

1. The relative importance of direct solar radiation and advected energy in driving snowmelt.

2. The disposition of solar energy impinging on sagebrush vegetation throughout the snowmelt period.

3. The magnitude of evaporation from late-lying snowfields and adjacent moistened soil in relation to total water content of the snowfield.

4. Surface and groundwater studies to determine the importance of late-lying snowdrifts in sustaining streamflow.

5. Methods to inventory snow cover and water content of snow on windswept watersheds, where depths range from a few centimeters to many meters.

6. Techniques to utilize blowing snow as a water resource for increasing onsite vegetation growth or to provide supplemental water for streamflow and surface storage facilities.

C. Development of dynamic hydrologic simulation models are needed to approximate the hydrologic cycle in both arid and mesic portions of the sagebrush ecosystem. Such models can help land managers predict hydrologic changes stemming from land management practices.

D. Quantitative information is needed about how sagebrush management practices such as burning, mechanical control, spraying, and livestock grazing effect watershed stability, chemical water quality, sediment transport, total annual water discharge, and streamflow timing.

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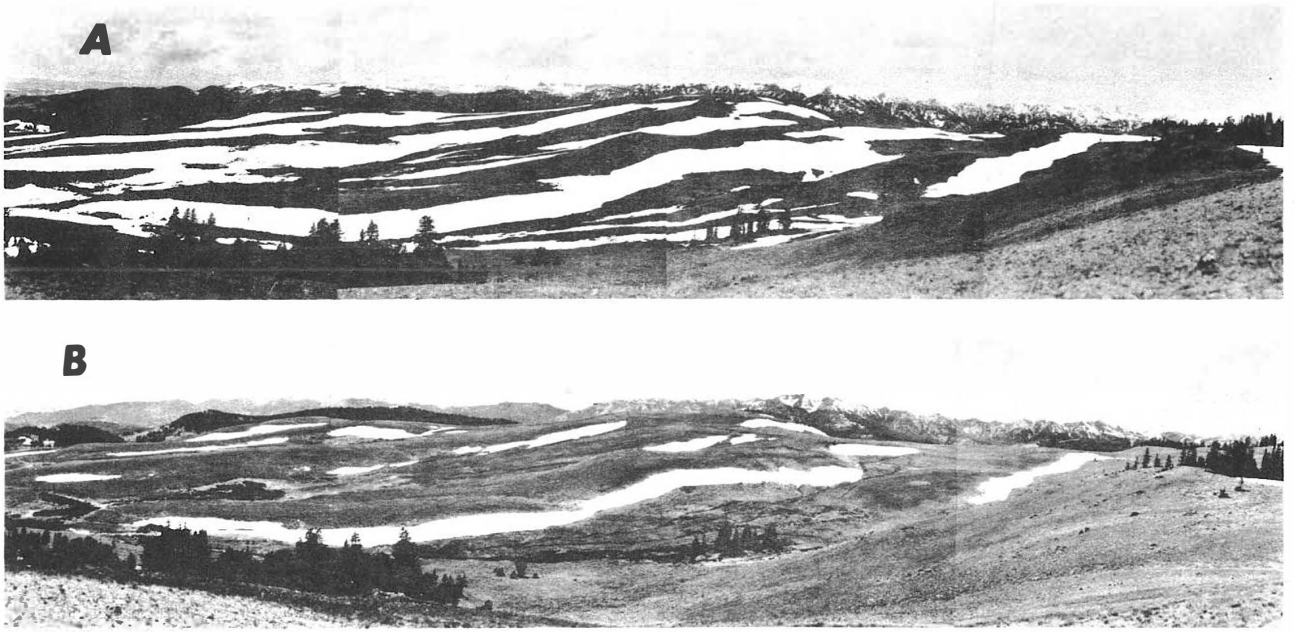

Figure 11. Relocation of snow into large drifts is an important hydrologic process on windswept sagebrush lands. Such drifts persist after the general snow cover has melted and can recharge groundwater.

A. Snow conditions on Wayne's Creek June 3, preceding peak snowmelt runoff.

B. Snow conditions June 16, about 1 week after the hydrograph peak.

USE OF FIRE AS A MANAGEMENT TOOL IN SAGEBRUSH ECOSYSTEMS

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Abstract

Prescribed burning is a viable and effective natural tool for vegetation manipulations in many sagebrush-bunchgrass communities. Unlike other manipulation techniques, prescribed burning can accomplish many objectives simultaneously. The best results will be possible only when a burn is carefully planned with special attention given impacts on existing vegetation and soils. Fire effects and implementation procedures are discussed.

Interest in prescribed fire as a vegetation manipulation tool has increased sharply in the past 10 years. This interest has been stimulated by many factors. One is the increasing difficulty of using herbicides on public range. Another factor is the high cost of mechanical manipulation techniques. Probably the most important factor is the current view that fire is a natural component of range ecosystems, and its use results in the smallest disruption of the ecosystem.

Burning is not a new tool for manipulation of sagebrush-bunchgrass range. Fire was a commonly used technique 50 years ago. The only long term ecological study of burning was from 2 burns conducted on the upper Snake River Plains of Idaho in 1936 and 1937. This work and evaluations that followed in Idaho illustrated the usefulness of prescribed burning.

The use of prescribed burning in sagebrush ecosystems is primarily for the reduction of sagebrush cover (Figure 1). This reduction in cover results in increased herbaceous production and habitat diversity. These changes benefit not only domestic livestock operations but also the vast majority of the native fauna. To maximize the benefits accruing from the use of prescribed fire to break the sagebrush monoculture, management decisions must be made prior to and after treatment. The purpose of this article is to summarize available information to facilitate the decision making process.

Figure 1. Burning to reduce sagebrush cover in eastern Oregon.

Effect of Fire on Vegetation

The most obvious effect of fire on sagebrush-bunchgrass vegetation is the reduction in brush cover. Big sagebrush *(Artemisia tridentata)* is easily fire killed (Table 1) as it does not resprout (Blaisdell 1953, Pechanec et al. 1954). There are

Table 1. Relative response of cold desert shrubs to fall burning (Wright et al. 1978)

Severely damaged	Slightly damaged	Undamaged
Antelope bitterbrush *(Purshia tridentata)*	Curlleaf mahogany *(Cercocarpus ledifolius)*	Ceanothus (sprouting) *(Ceanothus* sp.*)*
Big sagebrush *(Artemisia tridentata)*	Desert bitterbrush *(Purshia glandulosa)*	Common snowberry *(Symphoricarpos albus)*
Black sagebrush *(Artemesia nova)*	Mountain mahogany *(Cercocarpus montanus)*	Gamble's Oak *(Quercus gambelii)*
Broom snakeweed *(Gutierrezia sarothrae)*	Mountain snowberry *(Symphoricarpos oreophilus)*	Horsebrush *(Tetradymia canescens)*
Ceanothus (non-sprouting) *(Ceanothus* sp.*)*	Serviceberry *(Amelanchier alnifolia)*	Rabbitbrush *(Chrysothamnus* sp.*)*
Cliffrose *(Cowania mexicana)*	Silver sagebrush *(Artemisia cana)*	
Low sagebrush *(Artemisia arbuscula)*		
Three-tip sagebrush *(Artemisia tripartita)*		

no published reports indicating that any big sagebrush subspecies resprout after fire. The subspecies may be important with respect to the length of time a burned area remains free of sagebrush. Mountain big sagebrush *(A. tridentata* subsp. *vaseyana)* may reoccupy an area faster because it is found on more mesic sites (Winward and Tisdale 1977). Slower reestablishment may occur with basin big sagebrush *(A. tridentata* subsp. *tridentata)* and Wyoming big sagebrush *(A. tridentata* subsp. *wyomingensis)* as they occupy dryer sites. If a good moisture year occurs shortly after burning, sagebrush reestablishment can be greatly accelerated (Sneva 1978).

Other sagebrush species occur throughout the sagebrush-bunchgrass ecosystem. Fires rarely occur in low sagebrush *(A. arbuscula)* or black sagebrush *(A. nova)* communities. Fires can spread in three-tip sagebrush *(A. tripartita)* and silver sagebrush *(A. cana)* communities. The latter two species can resprout with silver sagebrush being the most vigorous sprouter (Beetle 1960).

Rabbitbrush *(Chrysothamnus* sp.*)* occurs to some extent in most sagebrush-bunchgrass communities. This plant presents problems on areas to be burned as the various species resprout vigorously after burning (Blaisdell 1953, Countryman and Cornelius 1957, Chadwick and Dalke 1965). Exceptions have been observed but conditions necessary to inflict high mortalities could not be isolated (Robertson and Cords 1957). Horsebrush *(Tetradymia canescens)* responds similarly to rabbitbrush. Horsebrush can increase 5 fold, 12 years after burning (Blaisdell 1953).

The response of bitterbrush *(Purshia* sp.*)* is of particular interest because of its importance as a browse plant. Antelope bitterbrush *(Purshia tridentata)* is a weak sprouter and the majority of evidence indicates it is severely damaged by fire (Blaisdell 1953, Countryman and Cornelius 1957, Nord 1965). For bitterbrush to resprout after burning, the soil must be wet at the time of burning or shortly thereafter (Blaisdell and Mueggler 1956). In Nevada, Klebenow et al. (1976) observed that when antelope bitterbrush resprouts mortality is generally high the following year. Desert bitterbrush *(Purshia glandulosa)* generally resprouts after burning even under dry conditions (Nord 1965).

A summary of fire effects on bitterbrush is given by Wright et al. (1978). High intensity wild fires during midsummer do the most damage to bitterbrush. Fall prescribed burns result in higher mortality than cool spring burns. If fall prescribed burns are conducted with favorable soil moisture conditions, resprouting and layering occur in the decumbant ecotype. Reproduction from seed is highest from fall burns. Fire harms the columnar ecotypes more than the decumbant ecotypes. Fire harms bitterbrush more on fine textured and calcareous soils than on coarse textured and well drained soils.

Broom snakeweed *(Gutierrezia sarothrae)* is a weak sprouting perennial that is severely damaged by fire (Pechanec et al. 1954). New plants tend to invade open areas rapidly, and highest frequencies were found on 22-year old burns (Barney and Frischknecht 1974).

Less widely distributed species which are damaged by fire include serviceberry *(Amelanchier alnifolia)*, granite gilia *(Gilia pungens)*, and mountain snowberry *(Symphoricarpos oreophilus)* (Blaisdell 1953, Pechanec et al. 1954).

Herbaceous vegetation generally does not suffer long lasting effects from burning (Figure 2). Bluegrasses *(Poa* sp.*)* are slightly damaged by burning (Table 2). Wright and Klemmedson (1965) observed no change in basal area of Sandberg bluegrass

(Poa sandbergii) when burned at any season. Some decreases have been observed as a result of wildfire (Countryman and Cornelius 1957, Uresk et al. 1976).

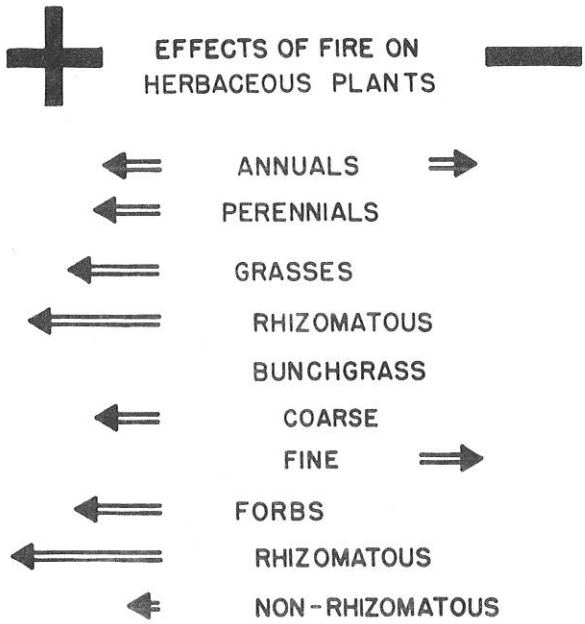

Figure 2. Generalized directional response of herbaceous vegetation to burning (Mueggler 1976).

Cheatgrass *(Bromus tectorum)* is not appreciably affected by burning although production may be reduced the first year. Burning was found to reduce stands of cheatgrass in eastern Washington, presumably because of seed destruction (Robocker et al. 1965). June and July burns reduced cheatgrass plant numbers to 14 and 11 per 900 cm^2 compared to 41, 45, and 124 plants per 900 cm^2 on August, October, and November burns (Pechanec and Hull 1945). These reductions are only temporary as annuals produce abundant seed the year after burning.

The majority of evidence indicates that Idaho fescue *(Festuca idahoensis)* is severely damaged regardless of when or where it is burned (Pechanec and Stewart 1944, Blaisdell 1953, Countryman and Cornelius 1957, Conrad and Poulton 1966, Harniss and Murray 1973). However, in eastern Oregon fall burning caused no mortality and only a 34 percent reduction in basal area (Britton et al. 1978).

Indian ricegrass *(Oryzopsis hymenoides)* is important in sagebrush-bunchgrass communities only in localized situations. As such, it has not been the subject of intensive research. Pechanec and Stewart (1944) mention it as being slightly damaged but slow to increase after burning.

In eastern Oregon, junegrass *(Koeleria cristata)* has been found to be one of the most fire resistant bunchgrasses (Britton et al. 1978). Burning in mid-May reduced basal area by 32 percent with 20 percent mortality. During mid-June just after seed set, basal area was reduced 18 percent with no

Table 2. Relative response of cold desert grass and grasslike species to fire (Wright et al. 1978)

Severely damaged	Slightly damaged	Undamaged
Idaho fescue *(Festuca idahoensis)*	Bluebunch wheatgrass *(Agropyron spicatum)*	Cheatgrass *(Bromus tectorum)*
Needle-and-thread *(Stipa comata)*	Big bluegrass *(Poa ampula)*	Crested wheatgrass *(Agropyron desertorum)*
Threadleaf sedge *(Carex filifolia)*	Columbia needlegrass *(Stipa columbiana)*	Douglas sedge *(Carex douglasii)*
Thurber needlegrass *(Stipa thurberiana)*	Cusick bluegrass *(Poa cusickii)*	Intermediate wheatgrass *(Agropyron intermedium)*
	Indian ricegrass *(Oryzopsis hymeniodes)*	Plains reedgrass *(Calamagrostis montanensis)*
	Nevada bluegrass *(Poa nevadensis)*	Prairie junegrass *(Koeleria cristata)*
	Squirreltail *(Sitanion hystrix)*	Pubescent wheatgrass *(Agropyron trichophorum)*
	Western needlegrass *(Stipa occidentalis)*	Riparian wheatgrass *(Agropyron riparium)*
		Sandberg bluegrass *(Poa sandbergii)*
		Tall wheatgrass *(Agropyron elongatum)*
		Thickspike wheatgrass *(Agropyron dasystachyum)*
		Western wheatgrass *(Agropyron smithii)*

mortality while burning in mid-October produced only slightly more basal area reduction. This lack of appreciable damage is probably due to the relative small size of the typical junegrass clone.

Most needlegrasses *(Stipa* sp.*)* are severely damaged by burning, especially during the first year (Countryman and Cornelius 1957, Wright and Klemmedson 1965, Wright 1971, Harniss and Murray 1973, Uresk et al. 1976, Britton et al. 1978). This universal damage to needlegrass appears related to their intolerance to herbage removal and the large amounts of dead material per unit basal area (Wright 1971).

Squirreltail *(Sitanion hystrix)* is quite fire resistant although some damage is apparent. In southern Idaho, Wright and Klemmedson (1965) observed no plant mortality but some reduction (15 percent) in basal area for plants burned in July. Wright (1971) reported that burning generally harmed squirreltail most during May and somewhat less thereafter with respect to herbage production. Burning squirreltail plants in a drought year

Table 3. Relative response of cold desert forbs to fall burning (Wright et al. 1978)

Severely damaged	Slightly damaged	Undamaged
Hairy fleabane *(Erigeron concinnus)*	Astragalus *(Astragalus* sp.*)*	Arrowleaf balsamroot *(Balsamorhiza sagittata)*
Hoary phlox *(Phlox canescens)*	Matroot penstemon *(Penstemon radicosus)*	Common comandra *(Comandra umbellata)*
Littleleaf pussytoes *(Antennaria microphylla)*	Munro globemallow *(Sphaeralcea munroana)*	Commonflower *(Helianthus annus)*
Low pussytoes *(Antennaria dimorpha)*	Northwestern paintbrush *(Castilleja angustifolia)*	Coyote tobacco *(Nicotiana attenuata)*
Mat eriogonum *(Eriogonum caespitosum)*	Pinnate tansymustard *(Descurainia pinnata)*	Douglas knotweed *(Polygonum douglasii)*
Uinta sandwort *(Arenaria uintahensis)*	Plumeweed *(Cordylanthus ramosus)*	Flaxleaf plainsmustard *(Sisymbrium linifolium)*
Wyeth eriogonum *(Eriogonum heracleoides)*	Red globemallow *(Sphaeralcea coccinea)*	Flixweed tansymustard *(Descurainia sophia)*
	Sticky geranium *(Geranium viscosissimum)*	Foothill deathcamas *(Zigadenus paniculatus)*
	Tailcup lupine *(Lupinus caudatus)*	Gayophytum *(Gayophytum diffusum)*
	Tapertip hawksbeard *(Crepis acuminata)*	Goldenrod *(Solidago* sp.*)*
	Tongueleaf violet *(Viola nuttallii)*	Goosefoot *(Chenopodium* sp.*)*
	Tumblemustard *(Sisymbrium altissimum)*	Lambstongue groundsel *(Senecio integerrimus)*
	Wavyleaf thistle *(Cirsium undulatum)*	Longleaf phlox *(Phlox longifolia)*
	Whitlow-wart *(Draba verna)*	Orange arnica *(Arnica fulgens)*
	Wild lettuce *(Lactuca* sp.*)*	Pale alyssum *(Alyssum alyssoides)*
		Purpledaisy fleabane *(Erigeron corymbosus)*
		Russian thistle *(Salsola pestifer)*
		Velvet lupine *(Lupinus leucophyllus)*
		Western yarrow *(Achillea lanulosa)*
		Wild onion *(Allium* sp.*)*

resulted in 30 percent mortality in mid-May but no mortality for mid-June or October burns (Britton et al. 1978).

The wheatgrasses *(Agropyron* sp.*)* are generally fire resistant. Fall burning of crested wheatgrass *(A. desertorum)* results in only small changes in the stand (Kay 1960, Lodge 1960). Bluebunch wheatgrass *(A. spicatum)* is slightly affected by burning and will usually return to preburn production in 1 to 3 years (Blaisdell 1953, Conrad and Poulton 1966, Harniss and Murray 1973, Uresk et al. 1976, Britton et al. 1978). Other wheatgrasses respond somewhere between crested wheatgrass and bluebunch wheatgrass with the exception of the rhizomatous wheatgrasses such as thickspike wheatgrass *(A. dasystachyum)* which increases after burning (Blaisdell 1953).

Forbs generally respond better to burning than do grasses. Where plant communities have large proportions of forbs in the herbaceous component, burning may provide the best manipulation technique. Fall burning does not harm most forbs because they are often dry and disintegrated by this time. Probably the best research treatment of forbs is from the prescribed burns conducted in Clark and Fremont counties on the upper Snake River plains of Idaho. This work is presented in a series of 3 articles by Blaisdell (1953), Pechanec et al. (1954), and Harniss and Murray (1973). Table 3 gives an expanded treatment of the information from this series of articles.

Effects of Fire on Soil

Fire affects soils in many ways. The oxidation of plant biomass adds a considerable quantity of nutrients to the soil surface. Assuming that the vegetation has an ash content of between 5 and 10 percent (Britton et al. 1976), it is possible to add 500 to 1000 kg/ha of minerals to the soil surface in a typical sagebrush-bunchgrass community.

Primary nutrients added to the soil surface will include phosphorus, potassium, calcium, magnesium, and varying amounts of micronutrients (Figure 3). Nitrogen and sulfur in the plant material are essentially volatilized in the combustion process (Daubenmire 1968). Increased total and available soil nitrogen have been observed after burning. Sharrow and Wright (1977) summarized possible mechanisms for this increase. Possible explanations for the increases are: 1) stimulation of legumes (Mayland 1967), 2) washing of charred surface material into the soil by rain (Metz et al. 1961), and 3) stimulation by nutrient-rich ash of nitrifying (Fowells and Stephenson 1934, Burns 1952) and nitrogen-fixing (Isaac and Hopkins 1937) microorganisms. This increase in available soil nitrogen and the increased soil temperature often results in increased herbage production (Sharrow and Wright 1977).

If nutrients are not leached into the soil they are susceptible to movement by erosive forces. Buckhouse and Gifford (1976) evaluated this movement by water in a pinyon-juniper community. They found that runoff waters from simulated rainfall showed a significant increase of about 0.2 ppm phosphorus following burning of debris piles. Following the burn, the release of nutrients evident in the ash was apparently sufficient to cause a detectable increase of the element at the soil surface where it could be picked up by runoff waters. A similar pattern was observed for potassium. Sodium, nitrate-nitrogen, and calcium did not appear to be appreciably affected by burning with respect to runoff waters. In Texas, Wright et al. (1976) found that loam soils on slopes less than 20 percent could be burned and allowed to heal naturally without appreciable soil or water quality losses. However, on slopes greater than 45 percent soil losses could be sustained with a subsequent lowering of water quality.

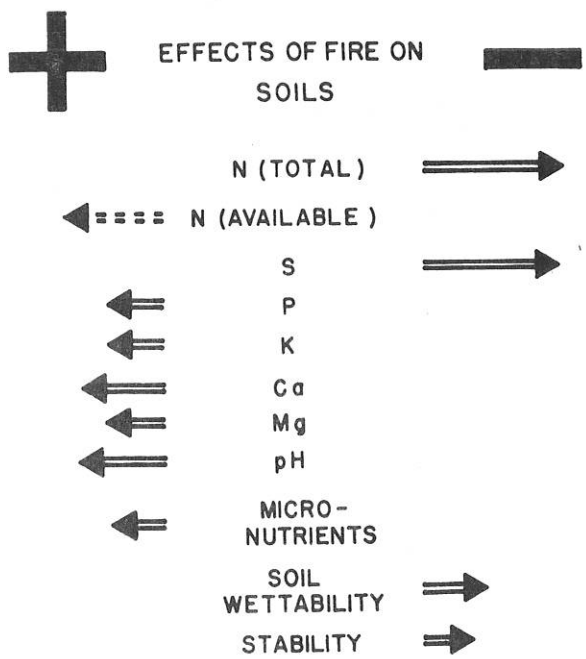

Figure 3. Generalized directional response of soils to burning (Mueggler 1976).

Other factors that affect sediment production include intensity of storms, size and frequency of bare areas, and wettability of the soil. Orr (1970) found that summer storm runoff and sediment production were closely related to precipitation rates in excess of 0.9 cm/hr. Size of bare areas substantially affects the influence of a given ground cover (Packer 1951). As the size of the bare openings increases, the influence of ground cover decreases. Burning sagebrush range can influence the wettability of the soil. Repellency can be produced by burning the sagebrush leaf mulch under the shrub rather than the shrub (Salih et al. 1973). This effect can be reduced when the mulch is cool and damp.

Wind, another viable agent of soil movement, can cause problems on burned areas. Sandy soils are most adversely affected by wind movement. This wind erosion has been noted in Idaho by Blaisdell (1953). In Utah, Ralphs and Busby (1978) encountered problems due to wind erosion. On one burn due to a drought year, wind erosion was a concern. However, the problems lasted only one season as the crested wheatgrass seeding stabilized the area.

The damage to soil historically attributed to rangeland burning is now questionable (Vallentine 1971). Although wildfire is more apt to damage soil, prescribed burning can minimize impacts through careful selection of sites to be burned (Blaisdell 1953).

Burning and Management

The decision to use prescribed fire in a management scheme should be based on the above mentioned impacts on vegetation and soils as they relate to desired objectives. Vallentine (1971) lists three broad objectives related to use of prescribed fire. These include: 1) kill or suppress undesirable brush plants, 2) prevent invasion of inferior species in the understory, and 3) increase forage production. This list can be increased to include many desired changes such as increased palatability of forages, rejuvenate woody plants for browse production, seedbed preparation, reduce water consumption by brush, and many others. Where prescribed fire is an applicable tool, many objectives can be achieved simultaneously. For example in west Texas, Wright (1974) stated that fire can be used to 1) remove litter, 2) increase forage yield, 3) increase forage palatability, 4) reduce brush canopy, and 5) kill undesirable forb and cactus species.

In sagebrush-bunchgrass communities two primary objectives are apparent. These are to break the dominance and monoculture status of sagebrush and increase herbaceous production and habitat diversity. Of course, many other objectives can be addressed through careful planning and execution of the prescribed burn.

With a set of objectives in hand, the question of how to execute the prescribed burn becomes paramount. The following prescription guidelines are taken from a state-of-the-art review by Wright et al. (1978).

Big Sagebrush-Bunchgrass

Sagebrush range is difficult to burn unless there is at least 650 to 750 kg/ha of herbaceous fuel (Beardall and Sylvester 1976). Moreover, burning should not be considered as a management tool unless the canopy cover of big sagebrush is at least a third of the plant cover (Pechanec et al. 1954). It is doubtful if successful burns can be consistently conducted where the sagebrush cover is less than 20 percent (Figure 4). After the decision to burn has been made, try to avoid burning immediately after heavy seed crops, as the sagebrush can reoccupy the burned area rapidly during years with good moisture (Pechanec et al. 1954, Johnson and Payne 1968). Early spring or late summer (August) burns may be the most preferable (Blackburn and Bruner 1975, Beardall and Sylvester 1976). Good soil moisture down to 30 to 45 cm should be present before burning.

Various procedures have been used to conduct prescribed fire in sagebrush-bunchgrass communities. Pechanec et al. (1954) plowed a single 2 m fireline around an area in southeastern Idaho. Then immediately adjacent to the fireline on the downwind side, they plowed another line with the berm pushed to the center of the plowed area. This berm acted as a buffer for firebrands rolling along the ground. Then a final line was plowed 30 to 60 m inside and parallel to outside line. This uncleared strip was burned with backfires or strip headfires in the forenoon when the wind was 8 to 12 km/hr and the relative humidity was about 40 percent during late August. After the uncleared strip had been burned, the remaining area was burned with a headfire, starting about 2:30 p.m. This headfire should be set with air temperature above 24 C, relative humidity at 15 to 20 percent, and wind at 12 to 24 km/hr (Ralphs et al. 1976).

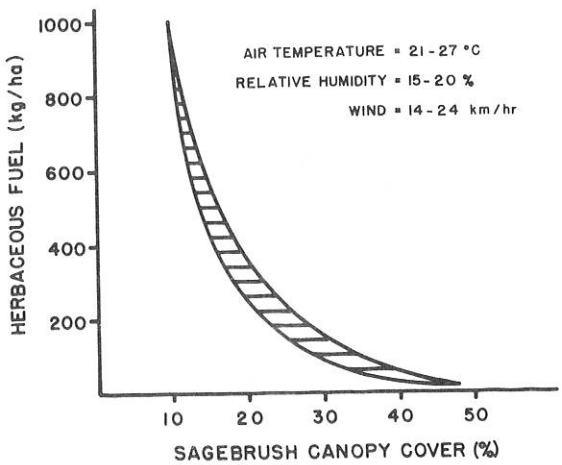

Figure 4. Hypothetical relationship of sagebrush canopy cover and herbaceous fuel loading for successful fall burning.

A similar technique of burning was used at the Benmore Experimental Range in central Utah (Blackburn and Bruner 1975). Their firelines varied from 7 to 50 m, with the narrow lines located on the upwind side. Davis (1976) states that, based on theoretical values and experience, flashfuels can be expected to ignite 15 to 27 m ahead of an advancing fire front in sagebrush-bunchgrass. This implies that a 30 m fireline on the downwind side of a fire should be adequate.

Recommendation: Based on the above data and research by Ralphs et al. (1976), it is recommended that a dozed line 3 to 4 m wide, be put around the area to be burned (preferably at least 200 ha in size according to Davis 1976). Then strip headfire a 50 m strip on the leeward sides during morning hours when wind is 8 to 12 km/hr and humidity is about 40 percent. As the fire backs up in heavy fuel beyond the 50 m strip, use a pumper to extinguish the leading edge. About 2:00 p.m. headfire the remaining area when air temperature is above 24 C, relative humidity is 15 to 20 percent, and wind is 12 to 24 km/hr (Ralphs et al. 1976).

Big sagebrush and low sagebrush

Where dense stands of big sagebrush are surrounded by low sagebrush, no firelines are usually

necessary even during hot days with winds up to 40 km/hr (Beardall and Sylvester 1976). Thus, the burns can be conducted on warm days with gusty wind whenever it is convenient.

Recommendation: Beardall and Sylvester (1976) suggest burning in early spring when relative humidity is below 60 percent, wind speed above 12 km/hr, and only if there is more than 650 to 750 kg/ha of herbaceous fuel. This same procedure can be used with snow banks as natural barriers instead of low sagebrush.

After the fire is out, how should the area be managed? Without a doubt, the most important thing to remember is do not graze the area for one year following the burn. This should be adhered to if nothing else is. This time period will allow for an uninterrupted growth cycle by the herbaceous vegetation.

When the burned area initially has less than 20 percent of the plant cover occupied by desirable, fire-resistant, herbaceous species, it is generally practical to reseed (Pechanec 1954). Although many species are available for reseeding, one of the crested wheatgrasses will generally give the most consistent and desirable results. As a rule of thumb, about 6 kg/ha of crested wheatgrass seed should be drilled (Sneva 1978).

Expected Results

A series of demonstration burns were conducted throughout Utah in 1974 and 1976 (Ralphs and Busby 1978). Approximately 2000 ha were treated in the 6 prescribed burns. Sagebrush canopy cover was reduced from 22-30 percent to 0-2 percent. Grass cover increased on all but two of the burns in spite of the severe drought conditions of 1976 and 1977. Forage production on a poor condition range increased from 112 kg/ha prior to treatment, to over 700 kg/ha after burning and seeding to crested wheatgrass (Figures 5 and 6). On a fair condition mountain loam site, forage production the first year after burning was slightly greater (30 kg/ha) compared to preburn production (258 kg/ha). This production should increase to over 1000 kg/ha with normal precipitation. Similar results were reported by Pechanec et al. (1954) in southeastern Idaho. Although the burned areas were not seeded, there was a doubling of herbaceous production.

Figure 5. A pasture on the Park Valley Hereford Corporation ranch, Utah, prior to burning in 1974.

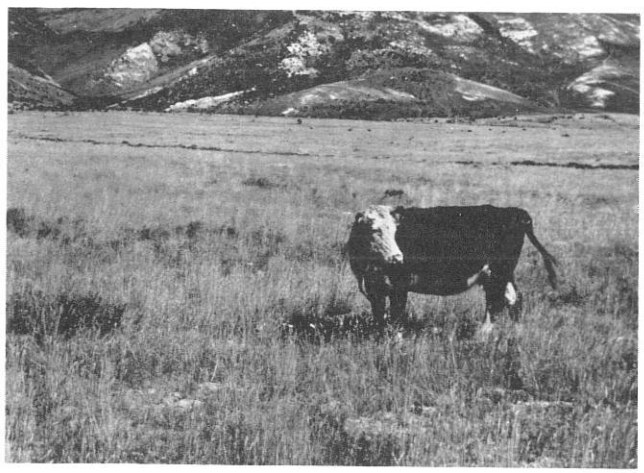

Figure 6. The same pasture as above after burning and seeding to crested wheatgrass as it appeared in in 1976.

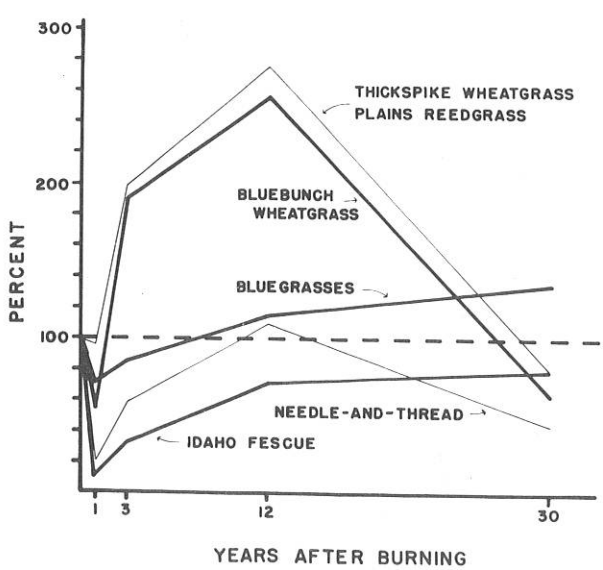

Figure 7. Relative change in grasses over 30 years on the upper Snake River plains (Harniss and Murray 1973).

How long will the effects of prescribed burning last? Very little data is available to answer this question. Harniss and Murray (1973) evaluated the Idaho burns reported by Pechanec et al. (1954). It appeared that the beneficial effects should last longer than 12 years and be negligible by 30 years (Figures 7 and 8) (Harniss and Murray 1973). The longevity of a particular burn effect will be dependent on the site, management scheme, and moisture patterns.

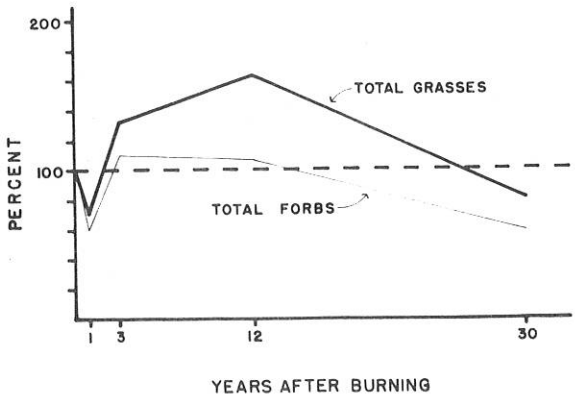

Figure 8. Relative change in grasses and forbs over 30 years on the upper Snake River plains (Harniss and Murray 1973).

Costs of prescribed burning are variable. It is dependent on location, availability of equipment and personnel, topography of the area, size of burn, and other factors. The largest cash cost associated with burning is for fire break construction. The average cash cost per kilometer on the six Utah burns was about $100.00 or $2.70/ha. The total cost of burning, including labor and equipment, was $11.32/ha. Seeding costs averaged $18.04/ha.

Proper management following the burn is essential in maintaining the benefits obtained. Resting the pasture for at least one growing season will allow the native grasses to recover. Resting for two growing seasons will provide for the establishment of the seeded species. Periodic rest thereafter will extend the useful lifetime of the treatment.

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USE OF HERBICIDES AS A MANAGEMENT TOOL

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Abstract

Use of herbicides provides effective and efficient control of brush and herbaceous weeds in the management of the sagebrush-grass ecosystem. Rabbitbrush and other root or crown-sprouting shrubs are harder to control than sagebrush and require careful timing of spraying or a wider spectrum of herbicides. Techniques have been developed for control of downy brome and other herbaceous weeds when seeding of perennial grasses is involved in improvement of degraded sagebrush rangelands. Weed control-seeding systems, involving control of brush and herbaceous weeds plus seeding of forage and browse species, have been successful in conversion of degraded communities to stable, high-producing rangelands.

The basic response of the sagebrush/grasslands of western North America to the introduction of concentrations of domestic herbivores has been an increase in density of shrubs at the expense of herbaceous species (see Young et al. this volume).

Once big sagebrush (*Artemisia tridentata*) becomes established as the dominant species of degraded sagebrush/grassland plant communities, it is persistent enough to stabilize succession in these communities for long periods. We do not know for sure how long this tenure of dominance would last, but the life expectancy of big sagebrush may exceed 150 years (Ferguson 1964). We do know that degraded big sagebrush communities can remain static for decades, even with livestock grazing excluded.

Range managers had relatively few tools with which to counter this increase in brush during the first half of the twentieth century. Implements and power sources for mechanically destroying the brush fields were not available until the late 1930's. Fire is an obvious choice for manipulating large areas of rangeland, but fire in the sagebrush/grasslands is a mixed blessing (Pechanec and Stewart 1944, Blaisdell 1953). Degraded stands of sagebrush are difficult to burn except under unusually hazardous burning conditions. If no herbaceous perennial species are present, not only does the stand burn with difficulty, but also the burned site is open to increases by root-sprouting or seed-establishment shrubs (Young and Evans 1974b). The ultimate danger in burning without enough perennial grasses is that the site is open to invasion by alien annuals, especially downy brome (*Bromus tectorum*). Some perennial grasses are susceptible to damage or are killed by burning at certain times in the growing season (Wright and Klemmedson 1965).

During the late 1930's and early 1940's the mechanical treatments of railing or plowing, first with wheatland plows and later with rangeland plows were widely used to prepare degraded sites for seeding with exotic wheatgrasses (*Agropyron* spp.).

The discovery of 2,4-D [(2,4-dichlorophenoxy) acetic acid] as a plant growth regulator in 1942 began the development of synthetic hormones for weed control (Bovey 1971).

BIG SAGEBRUSH

After World War II, several scientists independently recognized the potential of 2,4-D in controlling sagebrush for the release of perennial grasses. This herbicide is currently registered by the Environmental Protection Agency (EPA) for use on sagebrush rangelands.

Among the first to demonstrate the effectiveness of 2,4-D for controlling big sagebrush were Elwell and Cox (1950), Cornelius and Graham (1951), and Hull and Vaughn (1951). Working independently, Hyder (1953) demonstrated its usefulness in eastern Oregon and Bohmont (1954) and Hull et al. (1952) demonstrated its usefulness in Wyoming.

Gradually, guidelines were developed to help ensure the success of spray application. As the brush control program with 2,4-D became widespread, there were a few failures, almost all of which can be traced to violations of the initial guidelines.

Where to spray

The choice of the proper site for a spray application is the most important factor in ensuring the success of the herbicide treatment as a range improvement practice. It does no good to kill the brush if no perennial grasses are available to take advantage of the released environmental potential (Alley 1956). Hyder and Sneva (1956) developed the rule of thumb that only if one could step from plant to plant of perennial grass species were there enough perennials to permit forage response and to prevent the invasion of annual grasses or other undesirable species.

The best sites to spray were old, even aged, stands with an abundance of mature plants. Errors were made in spraying sites with silver sagebrush (*Artemisia cana*) or low sagebrush (*A. arbuscula*) and expecting them to be as productive as sites with big sagebrush. Treatment of silver or low sagebrush sites with 2,4-D would kill the brush, but such sites would never produce as much grass as the big sagebrush sites. Errors were made in spraying sites with desirable species such as bitterbrush (*Purshia tridentata*), which led to confrontations between range managers and wildlife managers. These confrontations were unnecessary; careful selection of sites could have prevented them. By application of timing techniques developed by Hyder and Sneva (1962), big sagebrush can usually be removed from a site without killing the desirable bitterbrush.

Errors were also made in choosing sites with large populations of green or gray rabbitbrush (*Chrysothamnus viscidiflorus* or *C. nauseosus*) or horsebrush (*Tetradymia canescens*). These root-sprouting species are relatively difficult to control, and improper application of 2,4-D to sites with these species often released them from competition by big sagebrush (Robertson and Cords 1957).

When to spray

Big sagebrush is most susceptible to 2.4-D when it is rapidly growing in the spring. Because big sagebrush has persistent leaves, its phenology is difficult to measure. Hyder (1954) used the phenology of the native perennial grass Sandberg bluegrass (*Poa sandbergii*) to estimate the correct time for applying herbicides. He concluded that the correct time for spraying in eastern Oregon extended from the heading of Sandberg bluegrass until one-half of the green color was gone. Measurements of soil moisture were determined to be important in estimating the correct time for herbicide application, which generally was the month of May. However, on shallow soils or south slopes, the correct application time may be much shorter and in wet years it may be much longer. In Wyoming it was deemed more reliable to estimate the correct timing of herbicide application from phenology of big sagebrush itself rather than relying on that of other species (personal communication from H.P. Alley).

How to spray

Almost all applications of 2,4-D to control big sagebrush were made aerially. Original recommendations called for the butyl or isopropyl ester to be applied at 1.1 to 1.7 kg of active ingredient per hectare, with sufficient water for application at 5 liters/ha. Low- volatile esters (l.v.e.) were recommended where big sagebrush was hard to control. Some range managers preferred diesel oil to water as a carrier, but the increase in efficiency of weed control seldom justified the increase in cost. In an assessment of spraying for control of big sagebrush in the Vale project in southeastern Oregon, Heady and Bartolome (1977) concluded that no clear-cut advantage was gained by the use of oil as a carrier. However, many land managers and some scientists (personal communication from H.P. Alley) strongly believe that oil is a better carrier than water for applying 2,4-D to big sagebrush.

Errors made in spraying for big sagebrush control include improper mixing of the herbicide and carrier, flying too high or fast, and improper marking of sites to be sprayed during herbicide application (Pechanec et al. 1965). Such errors were probably less important than errors in the timing of spraying (personal communication from F.A. Sneva).

Management

From the very beginning of research on control of big sagebrush, range scientists have stressed that probably more programs failed for lack of posttreatment management than for any other reason except the choice of sites with too few perennial grasses.

Ideally, areas treated with 2,4-D for control of big sagebrush should be allowed to rest the season after spraying and should not be grazed the next season until after the seeds of the

perennial grasses are ripe. Subsequently, proper grazing management must be practiced to maintain the perennial grass stand. Such management requires fencing and water-source development. All too often the sprayed areas have been the only productive areas in grazing allotments, and the lack of post-treatment management has allowed overutilization of the perennial grasses that were released from competition when the brush was killed.

RABBITBRUSH

As we previously noted, species of rabbitbrush are more difficult to control with 2,4-D than big sagebrush. Hyder et al. (1958 , 1962) determined that application must be carefully timed for adequate control of rabbitbrush. The current annual growth of the shoots must reach 7.5 cm and soil moisture must be available if the herbicide is to be effective. The length of time that green rabbitbrush is susceptible to 2,4-D varies greatly among years and locations. The period of susceptibility may equal that of big sagebrush, or it may not occur at all.

Predicting the optimum date for 2,4-D application

Prediction of the optimum date for application of 2,4-D to green rabbitbrush is essential because herbicide-mixing facilities, aircraft, and flagging crews must be prepared in advance if they are to be ready for the application at the often remote sites by the chosen date. Prediction is complicated by the phenology pattern of growth for green rabbitbrush, in which 40% of the current year's growth can occur within 2 weeks before the optimum application date (Young and Evans 1974a). Prediction is further complicated by the interaction of age and competition on the growth rate and phenology of green rabbitbrush. Young stands grow faster than old stands that are competing with big sagebrush plants.

Color infrared photography can be used to predict the optimum spray date for green rabbitbrush (Evans et al. 1973, Young et al. 1976). This method has the advantage of enabling the collection of large, statistically precise samples from remote areas in a very short time. A single trained interpreter can predict the optimum application date from photographs and return a recommendation within 24 hours.

"Second-generation" herbicides

There are some seasons when 2,4-D cannot adequately control green abbitbrush or when the susceptible period is so short that only small areas can be treated. These problems have been lessened by the development of "second-generation" herbicides that translocate better and control green rabbitbrush more effectively than 2,4-D.

The most effective and widely tested of these herbicides has been picloram (4-amino-3,5,6-trichloropicolinic acid). A relatively low rate of picloram, 0.3 kg/ha has been shown to be extremely effective for control of green rabbitbrush (Tueller and Evans 1969, Cook et al. 1965). Picloram does not control big sagebrush at this rate, so 2,4-D must be applied with the picloram for control of both species. Picloram has not been marketed as a mixture with l.v.e. of 2,4-D. Tank mixtures of potassium salts of picloram and l.v.e. of 2,4-D have been effective in aerial applications to mixed stands of green rabbitbrush and big sagebrush (Evans and Young 1975). Picloram has not been registered by EPA for application for rabbitbrush/sagebrush control. Some states, such as Wyoming have a within-state label for use of picloram on rangelands.

Dicamba (3,6-dichloro-o-anisic acid) has been registered by EPA for use on sagebrush rangelands, but we know of no published reports of comparative trials with dicamba on rabbitbrush/sagebrush communities. Undoubtedly trials on the efficacy of dicamba were required for registration, but, to the best of our knowledge, they were not published.

OTHER SHRUBS

Big sagebrush is the landscape-characterizing species of the shrub/ grasslands and green rabbitbrush is the subdominant shrub that most often creates control problems. However, low sagebrush (*Artemisia arbuscula*) communities are widespread and important. Control measures have been developed for this and the closely allied species *A. longilobus* (Eckert and Evans 1968). Low sagebrush sites are relatively lower in potential forage production than big sagebrush sites, but the proportional increases in production of the perennial grass portion of the communities after spraying are greater with low than with big sagebrush (Eckert et al. 1972).

Most big sagebrush communities comprise some shrubs other than the dominant and rabbitbrush. Especially at higher elevations a diversity of shrubs may be present. Species of *Ribes*, *Ephedra*, *Prunus*, and horsebrush may complicate the design of vegetation-manipulation treatments (Young and Evans 1974b). Most of these other species are clonal and sprout from ligno-tubers, crowns, or roots, making control with herbicides difficult.

TENURE OF GRASS DOMINANCE AFTER RELEASE

How long do perennial grasses remain dominant after release from shrub competition? This is one of the most perplexing questions involved in economic evaluations of the use of herbicides for brush control in sagebrush/grasslands (Johnson 1969, Sneva 1972). Some grass communities are reinvaded by shrubs almost immediatley after brush control. A very few stands have remained virtually shrub free for years (Welden et al. 1958). Sneva (1972) believed that sagebrush control in the Great Basin lasts longer than sagebrush control from similar treatments in Wyoming because of the intense summer drought in the Great Basin,

which limits seedling establishment of shrubs. Other scientists believe that Johnson's (1969) estimate of the useful life of sprayed areas in Wyoming was too short, because the stands he studied did not initially have complete shrub control (personal communication from H.P. Alley).

Competition between big sagebrush and perennial grasses has been studied for many years (Robertson and Pearse 1945, Blaisdell 1949, Cook 1958). Working with crested wheatgrass (*Agropyron desertorum*) and Wyoming big sagebrush (*A. tridentata* subsp. *wyomingensis*), Rittenhouse and Sneva (1976) reported that perennial grass production declined 3.3 to 5.7% for every 1% increase in brush crown cover.

On public lands, the maintenance of mixed stand of perennial grasses, forbs, and shrubs is a goal of multiple-use management, even though maximum forage production may result only with minimum density of big sagebrush. In keeping with this goal, the guidelines of most public land management agencies specify that spraying of big sagebrush is to provide only incomplete control of shrubs. The goal is desirable, but this methodology for achieving it may be faulty. Studies by Young and Evans (1974b) have shown that partial control of shrubs can lead to dramatic increases in shrub density through increased seed production and seedling establishment. Total control of shrubs on some areas with no control on adjacent ones may be a more effective alternative. The dynamics of both partial control of shrubs in relation to perennial grass density and the posttreatment invasion of shrubs into grass-dominated communities are aspects of sagebrush/grasslands ecology that merit further study.

HERBACEOUS WEEDS

Within the sagebrush/grasslands, control of herbaceous weeds is predominantly the control of alien annuals to allow the establishment of seedlings of desirable perennials. The secondary successional role of native herbaceous species has been almost entirely preempted by downy brome and associated alien species (Piemeisel 1938).

Sites dominated by downy brome (*Bromus tectorum*) are largely closed to the establishment of perennial grass seedlings (Robertson and Pearse 1945). Attempts to introduce wheatgrasses in downy brome sites by seeding generally have failed unless the site was first fallowed by mechanical methods (Hull and Holmgren 1964).

Paraquat

The herbicide paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) was first used for downy brome control in sites to be reseeded because of its relatively unique characteristic of being deactivated when it strikes the soil. This characteristic permitted the spraying of paraquat at 1.1 kg/ha and the immediate seeding of wheatgrasses (Evans et al. 1967). Paraquat is registered by EPA for specific uses on sagebrush rangelands. If the annual community being treated with paraquat contained tumble mustard (*Sisymbrium altissimum*) 2,4-D at 0.5 kg/ha was added for control of this species. Being a contact herbicide, paraquat must be applied after the downy brome has emerged. In most of the sagebrush/grasslands this makes spring seeding necessary.

Under the environmental conditions of the sagebrush/grasslands, it is difficult to consistently control downy brome with aerially applied paraquat even though ground applications are always effective. The addition of proper surfactants enhances the effectiveness of ground applications of paraquat (Evans and Eckert 1965).

Atrazine fallow

After evaluating large numbers of soil-active herbicides, Evans et al. (1969) determined that atrazine [2-chloro-4-(ethylamino)-6-(isoplopylamino)-s-triazine] was the best candidate for creating herbicidal fallows. The characteristics evaluated were spectrum of weed control, consistency of performance among years, and amount of herbicide residue 1 year after application.

The atrazine-fallow technique was developed (Eckert and Evans 1967) and extensively tested (Eckert et al. 1974). Atrazine is registered by EPA for specific uses on sagebrush rangelands. The atrazine is applied in the fall and a fallow is created during the next growing season. The area is seeded to wheatgrasses 1 year after the herbicide is applied. The amount of herbicide residue that is present at the time of seeding is critical in the success of seedling establishment (Eckert et al. 1972, Eckert 1974). Seedling success is enhanced by seeding the wheatgrass in the bottom of furrows made with a modified rangeland drill (Asher and Eckert 1973). The furrow provides a favorable microenvironment for seedling establishment (Evans et al. 1970) and removes herbicide residues on the soil surface to the area between the furrows.

Medusahead

The alien annual grass medusahead (*Taeniatherum asperum*) has invaded portions of Oregon, California, Washington, and Idaho (Young and Evans 1970). The atrazine-fallow technique works equally well on medusahead and downy brome (Young et al. 1969 and unpublished research by Young and Evans, Science and Education Administration, Federal Research, Reno). Medusahead invasion in the sagebrush/grasslands is largely restricted to low sagebrush sites (Young and Evans 1971).

WEED-CONTROL SYSTEMS

We have described the development of techniques for controlling excessively dense stands of big sagebrush and releasing native perennial grasses. We have stressed that sites without enough perennial grasses to preempt the environmental potential released by killing the brush should not be sprayed.

If such degraded big sagebrush sites are not invaded by downy brome, the brush can be sprayed and a heavy-duty rangeland drill used to seed in the standing dead brush (Kay and Street 1961). For most sites, the use of a rangeland drill modified to make furrows enhances seedling establishment (Asher and Eckert 1973).

For big sagebrush communities in which the perennial grasses are gone and downy brome has invaded the shrub understory, it is possible to vertically integrate (combine in sequence) 2,4-D and atrazine-fallow treatments into a weed-control system (Evans and Young 1977). The system can be used by (a) applying the atrazine in the fall and the 2,4-D the next spring, (b) applying the 2,4-D in the spring and the atrazine the next fall, or (c) applying a mixture of both herbicides in the spring at the optimum date for brush control.

The herbicide karbutilate [tert-butylcarbamic acid ester with 3-(m-hydroxyphenyl)-1,1-dimethylurea] has the unique capabilities of controlling shrubs, creating a herbaceous fallow, and leaving a low enough residue to permit seeding after 1 year when applied at 1.1 kg/ha (Young and Evans 1978). This method has not been researched and tested as extensively as the atrazine plus 2,4-D weed-control systems and karbutilate is not registered by EPA for use on sagebrush rangelands. The best results have been obtained when sites fallowed with karbutilate are not seeded until spring, 1 1/2 years after the herbicide is applied.

Atrazine fallows make excellent seedbeds for transplanting seedlings of desirable browse species (Christensen et al. 1974). Shrub transplanting can also be adapted to weed-control systems in which atrazine and 2,4-D are used (Evans and Young 1977).

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SAGEBRUSH ECOSYSTEM SYMPOSIUM

Use of Mechanical Methods as a Management Tool

by

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The sagebrush ecosystems that we are treating in this symposuim encompass the interactions of animals, fire, climate, topography, and vegetation - including one or more forms of sagebrush (Artemisia). It is assumed that the rate of flow of energy to the system and the recycling of nutrients within the system are measures of the function of the ecosystem. The nutrient spinoffs are not the only economic values of a sagebrush ecosystem to society, though they are extremely important to the people living on the land and adjacent communities where business depends on the economic multiplier effect of food and fiber products form the sagebrush ecosystem. The aesthetic values to the non-production oriented user (the recreationist) is more difficult to understand and measure because different people with varying biological and recreational interests enjoy different conditions of the sagebrush type rangelands.

For example, the hunter's interest might be merely cheatgrass range in poor condition yet best adapted for chukar partridge or other kinds of planted game birds. Others like a mosaic of meadows, grasslands, and low forms of Artemisia which favor sage grouse populations. Still others would like to see fire sweep off the sagebrush in varying degrees and clear the way for extensive grasslands favorable to antelope and livestock.

The Economics of Time

Whether it is public land or private land, it is urgent on many range sites in the sagebrush ecosystem for some form of control to be instituted whether by mechanical means or by other means. Natural recovery is very slow. Secondary succession in sagebrush-grass range in most sites is too slow.

Robertson (1971) traced this process on a 20 acre tract of eroded sagebrush range in northern Nevada over a 20 year period. He stated that "30 years rest enabled the 20 acre tract of eroded sagebrush-grass range in northern Nevada to increase its vegetal cover in all life forms. The cover of perennial forbs increased most, 85 percent. Thurber needlegrass increased sevenfold. Only annual forbs and annual weeds declined. Bluebunch wheatgrass was reestablishing naturally in favored spots. Newly cleared and seeded range outside the exclosure produced three times as much grass forage as was produced after 30 years of range rest without clearing". Where food for human consumption is a consideration, mechanical control of sagebrush would seem more expeditious that range rest alone.

Suitability

Suitability criteria were offered by Cook (1966) for converting sagebrush range into seeded grasslands.

1) Annual precipitation should be at least 27.5 cm (11 inches); 32.5 to 35 cm (13 to 14 inches) for best results.
2) Soils should be 60 cm (24 inches) deep to allow roots to become properly established.

Mechanical manipulation of big sagebrush for an improved native plant cover have been carried out in the 22 to 27 cm (9 to 11 inch) rainfall belt, but only with low cost methods. Excellent guides to site suitability for mechanical conversion of sagebrush range are offered by the USDA Soil Conservation Service range site descriptions.

Hydrlolgic Impacts

On arid rangelands, water is the factor most influentially limiting production. Accordingly, the choices of mechanical methods for controlling sagebrush might well be considered on the basis of their affect on the hydrology of the site. Infiltration rates measured by Gifford (1972) on an experimental site five miles west of Holbrook, Idaho, indicated a reduction in infiltration rates compared to unplowed land, especially in the fall of the second year following plowing. This occurred despite the fact that there was an increase in plant cover over the same period. The sediment yields were the greatest the first year following plowing. This topic is treated more fully elsewhere (see Gifford).

Timing

Research on mechanical removal of sagebrush top-growth is a useful guide to timing of mechanical control operations other than earth moving practices, such as plowing. Wright (1970) determined that an 80 percent clipping treatment reduced yields of big sagebrush most when applied during July, moderately when applied during the spring, and least when applied during the late winter months.

A marked decrease in yield resulting from certain seasons of harvest during 1962-1968 amounted to 50 percent for summer harvesting and 35 percent for spring harvesting. Removal of herbage in the winter and early spring caused least depression of yields, according to Cook. (1971).

Accordingly, mechanical removal of sagebrush top-growth, whether by chaining or other means, should give a more complete kill if applied during July or August. Other factors however, may come into play in the case of farms and ranches. Equipment is less available during summer time due to competition of other farming and ranching activities.

Field trials using light anchor chains and fast moving farm tractors give a much more complete pull-up of big sagebrush during the mid-spring period, when range soils were still fluffy from winter frost heaving, than during the summer when the soils around the plants are harder and drier.

Some Other Ecologic Considerations

The effect of sagebrush community modification with the light rapid chain on jackrabbit hunting by coyotes was measured indirectly along a 400 meter

(1320 feet) border between chained and unchained sagebrush range. The transects reached 50 meters (165 feet) on each side of the division line between treated and untreated areas. On 10 transects the ratio of identifiable coyote trails (passes) in the chained area in relation to the unchained area was 5.3 to 2. Apparently hunting success for the coyotes was not as fruitful in the dense stands of sagebrush as where the prey had less adequate cover.

No distinction is drawn nor comparison made between predator activities in sagebrush communities treated mechanically and those treated with chemicals to control sagebrush.

Habitat Impacts

The impact of sagebrush control operations, whether by fire, chemicals or mechanical means severely affect upland game bird habitat. Low sagebrush forms provide feed and cover for sage grouse (Centrocircus urophasianus). The low forms seem to be preferred to the sagebrush species and growth forms taller than 30 cm (1 foot).

Chemical controls are slightly more selective than the plow or disc, the latter being means of completely killing especially the smaller plants. The Ely chain, depending on the number of passes that are made, is nearly as final as the moldboard plow for a sagebrush stand of the type preferred by sage grouse, as is the disc.

The light rapid anchor chain more nearly approaches the type of sagebrush stand modification favorable to sage grouse habitat if done right. Many of the low forms of sagebrush are passed over by light chain but the taller, more brittle, decadent plants, which are not preferred by sage grouse for cover or food, are most subject to removal by the light-rapid chaining method. It is conceivable that this implement might be used for improving sage grouse habitat. The idea would be worthy of further research.

One should not overlook the fact that the sage grouse broods initially require a certain amount of feed of types produced in grassy parks and meadows pending the development of the mature digestive system which is better adapted to sagebrush roughage. It seems logical that some form of sagebrush control would be necessary to the existence of such meadow broodgrounds. Some form of sagebrush control, whether natural or induced, could conceivably forestall the depletion of deep soil moisture by sagebrush roots penetrating down beyond the reach of herbaceous grasses and forbs of the meadow sites.

A study by Klebenow and Gray (1968) described the importance of forbs to sage grouse chicks. Only during the first week of the life of a sage grouse do insects predominate the diet. After that week, forbs became the most important food. Shrubs were taken in small amounts at first but progressively increased in importance as chicks grew older (figure 1). In sage grouse management, it is important that we recognize that forbs are a necessary part of the habitat. Big sagebrush is a strong competitor - even inhibitor to many forb species.

Equipment

There is a wide spectrum of choices of mechanical equipment and methods suitable for maximizing the above uses and also to maximize nutrient harvest from the ecosystem in terms of meat and fiber. They vary all the way from the implements of the range "farmer" who has as his goal complete elimination of sagebrush from the ecosystem and establishment of grasses and forbs suitable for livestock and possibly certain classes of wildlife, to complete protection for natural recovery or preservation of existing plant cover.

Specifically, the choices range through the moldboard plow, the heavy duty offset discs, the brushland plow, wheatland plow, the dixie harrow, beaters (mowers), heavy anchor chains of the Ely type, plain heavy anchor chains, rails, cables, and the light rapid anchor chains.

TYPES AND ADAPTATIONS

Moldboard Plow

The plow is the most violent of the mechanical instruments used in manipulating the sagebrush ecosystem. The moldboard plow is well adapted for control of most low forms of sagebrush and undesirable annuals and perenials herbaceous species, but costs are usually high and often prohibitive. Two times over the land with a moldboard plow is considered to be a most intensive type of basic seedbed preparation. Power requirement is determined by the number of plow bottoms of the implement. The range is very wide.

Disk Plows

The standard disk plow is commercially available with from 1 to 6 disks with an average cutting width of 22 cm (9 inches)per disk. It is adapted for deep plowing and is comparable to the moldboard plow in effectiveness. It works better in heavy brush or rocky ground where the moldboard plow cannot be used effectively.

The Wheatland Plow

The wheatland plow is a 1 way disk tiller with vertical disks spaced at fixed distances along a common axle. The axle and disks rotate as a unit at an angle of 35° to 50° with the line of travel. It is supported by three wheels designated as land, front-furrow, and rear furrow. The wheatland type of plow often gives 80 to 95 percent kill of sagebrush on the fairly rock-free ground when operating 2 to 3 inches deep. Breakage is a problem in rocky ground. A 40 horsepower crawler type tractor provides sufficient power for a 2.7m (9 foot) plow with 65 to 70cm (26 to 28 inch) disks on fairly level ground.

The Brushland Plow

Patterened after the Australian "stump jump plow" and pulled by a crawler tractor, the brushland plow has been one of the more popular plows on the Forest Service and the Bureau of Land Management projects. It has 7 or so disk arms, independently spring loaded. Each arm supports one 70cm (28 inch) and one 65cm (26 inch) disk, supported by a single shaft and bearing assembly. If solid objects are encountered, the obstructed pair or pairs of disks

raise over the object while others continue to work. This disk plow is especially effective on sagebrush lands. It can be used in rocky situations without excessive breakage. The principal limitation is the cost of the plow and the power to pull it.

The Offset Disk

Offset disks are available as extra heavy duty, heavy duty, medium, light duty, and horse portable disks. Offset disks consist of 2 gangs of disks mounted on a separate frame, one directly ahead of the other so that the soils is thrown in one direction by the lead gang and in the opposite direction by the rear gang. Breakage is usually less on offset disks that on the wheatland type plows but more than in the case of the brushland disk plow. The cutaway disks common to this type of plow do a better job of cutting of vegetation into mulch than do other plows. The power requirement varies with the sizes which run from 40 to 80cm (16 to 32 inches) in diameter. This implemented is broadly adaptable for preparing seed beds in the sagebrush ecosystems. Once over is usually sufficient to kill a high percentage of the sagebrush when the disks are penetrating 15 to 20cm (6 to 8 inches) deep. The power requirement is approximately twice as much as is needed for the brushland plow.

Pipe Harrows

Pipe harrows sometimes called "Dixie" harrows were designed for removal of small, brittle sagebrush on rocky lands where other implements are not adapted. Sagebrush kill with this implement varies from 20 percent to as much as 70 percent depending on conditions. It seldom does a good job of removing herbaceous plants and willowy shrubs such as young sagebrush and rabbitbrush.

Rails, Cables,and Chains

Rails, cables, and chains exist in a wide variety. Advent of the use of different varieties has occured in about that order. In a few cases, the cable and chain idea have been combined to obtain low-cost, large scale sagebrush control. A rancher in the Snowville, Utah area reports excellent results with heavy railroad rails bolted to a 90m (300 foot) oil field cable. Apparently shearing force plus the flexibility of the cable-rail combination gives an effective self-cleaning feature lacking in the fixed rail type implement. The rails fastened to the cable apparently reduced the amount of "jumping" common to the cable by itself.

Anchor chains of varying weights became readily available after World War II and have been used extensively in various forms. Links weigh 36 to 40kg (80 to 90 pounds). The 31 to 36kg (70 to 80 pound) classes have been most popular in the past but the light-rapid chains are now gaining initial popularity. The BLM innovated the "Ely" chain, an arrangement which gives much more scarification of the surface, often equal to a plow job, but much more rapid and less costly than plowing.

Each end of the cable or chain is attached to a separate tractor and they travel in parallel paths pulling a "U" of "J" shaped loop behind. The length of the chain depends on topography, vegetation, and the power available. A 60m (200 foot) chain will cover a 36m (120 foot) swath while a 303m (1000 foot) chain will cover about 182m (600 feet) as it goes. Chains and cables are useful on lands too rough and too steep for other equipment. They are most useful on large and brittle sagebrush. Kills of over 90 percent have been obtained. Only a few of the younger, flexible plants are killed so a 50 to 70 percent kill is more common on middle aged stands of shrubs. Chaining is especially useful for releasing valuable understory plants from decadent sagebrush, greasewood, and rabbitbrush competition. Where seeding is necessary an area can be chained twice or more to get the desired effects. After the second time over, the broken sagebrush plants are usually pushed into windrows or bunches convenient for burning.

The tendency for a 38m (125 foot) length of chain to windrow the broken sagebrush plants into broad windrows was noted in the light chaining operation. These windrows are approximately half the width of the chain swath. One can visualize both advantages and disadvantages to this windrow arrangement of the debris in terms of clean-up operations by burning, in terms of reduced temperatures and lowered evaporation of moisture from the surface within the piles of sagebrush (the opposite in bare areas), and in terms of biological inhibition of certain species of seedlings on one hand and stimulation of seeded species on the other hand. Hoffman and Hazlett (1977), working under laboratory conditions, found that certain species of germinating range plants were inhibited by aqueous extracts of the leaves of Artemisia tridentata and even by the volatile substances from the leaves. Conversely, the same authors stated that Bromus inermis and Chrysothamnus nauseosus germinated to a greater extenst (under the influence of aqueous leaf extracts and aromatic compounds of Artemisia tridentata and Artemisia cana) than their respective controls.

It is a widely accepted fact that germination of most species of grasses in arid lands is impaired somewhat where the soil surface has no litter protection and is exposed to the direct, descicating rays of the sun. It is suggested that controlled research is necessary in order to determine what, if any, inhibitory effect exists under chained brush pileups.

Costs:

Researchers Kearl and Cordingly (1975) compared imputs and cost of range seeding comparing moldboard plow, disk plow, and offset disc in terms of man hours of labor and financial costs per acre. Their information was based on a study of reseeding projects on 64 range sites totaling over 10,000 acres. About twice as many man hours were required for preparing seedbed using moldboard plows as using disk plow or offset disc. In terms of total costs including labor, fuel, repairs, seed, and other costs, moldboard plowing systems were about 20 percent higher and offset disc plowing was 20 percent lower than disk plowing.

The cost of the light-rapid chaining operation is from $1.50 to $4.00 per acre. It is about the

only large scale sagebrush control implement on which small farm tractors can be used.

Retreatment

Control of sagebrush in the present forms is not permanent. Reinvasion is almost certain. It can be retarded through good management but seldom stopped.

In a Western Montana study by Johnson and Payne (1968) there was no statistically significant difference between survival on numerous range sites that were sprayed and sites that were plowed and seeded to grass.

The reestablishment of sagebrush was found mostly in association with mature brush left by an incomplete kill at the time of the control operation. It was therefore concluded that unkilled sagebrush is the major cause of reinvasion.

The same workers found that the time of treatment was also a major factor in reestablishment of sagebrush plants. The exceptionally early re-establishment rates likely resulted from a scattering of the new sagebrush seed crop where plowing was carried out in the late autumn after sagebrush seeds matured. The practice of mechanically removing sagebrush in the autumn after seed maturation seems to assure severe reinfestation of the treated areas. That seems to be another important factor in re-establishment, even considering the competition from associated vegetation. The same workers investigated sagebrush reinvasion in relation to other environmental factors including soil texture, erosion severity, precipitation patters and slope. They concluded that there was no strong statistical relationship between those environmental factors and sagebrush reinvasion whether the control was through use of chemicals or by mechanical treatment.

Conclusion:

Mechanical methods of brush control are widely useful. The rancher and technician must know the site needs and choose the most suitable methods.

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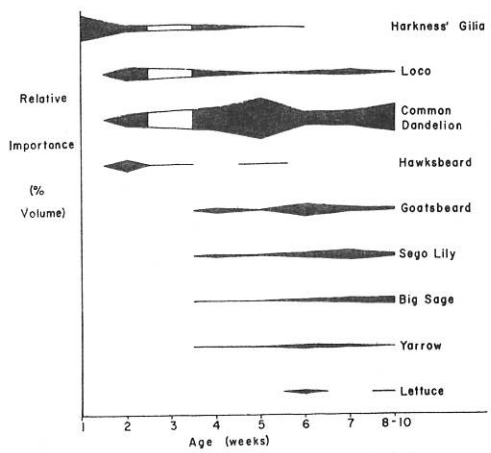

FIG. 1. The relative importance of the plant food items, over 5% volume, found in juvenile sage grouse crops, 1965.

From Klebenow and Gray (1968)

BIOLOGICAL METHODS: A TOOL FOR SAGEBRUSH MANAGEMENT

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Abstract

Grass production declines as sagebrush increases on western ranges, which creates a management problem. Biological methods can be useful alternative tools to the more costly mechanical and chemical methods for managing sagebrush. Although certain insects and small mammals are capable of killing sagebrush under optimum conditions, insufficient information is available for managing these biological agents. Computer models can be used to advantage to help provide information on the needs of wildlife for sagebrush habitat and also help predict population irruptions of agents that kill sagebrush. At present, domestic sheep offer best possibilities for controlling sagebrush and they should be considered in management programs.

Many authors have reported that big sagebrush (*Artemisia tridentata*) has spread widely throughout its natural range in the western United States since settlement (Pickford 1932, Cottam and Stewart 1940, Cottam 1947, Wright and Wright 1948, Christensen 1963, Christensen and Welsh 1963, Hironaka and Tisdale 1963, Mason 1963, Tisdale *et al.* 1965, Morris 1966). Most writers attribute the spread of sagebrush to overgrazing by domestic animals and lack of fires; few consider that biological agents were important factors limiting sagebrush before the area was settled. Then, too, other reports of sagebrush in localized areas having been killed by insects and small mammals suggest that these factors might also have been operative prior to settlement.

Whereas the kill of sagebrush by certain insects and small mammals has resulted from irruptions in their populations, little is known about events that trigger such irruptions. In some respects, these events seem to be related to climate, but such biological relationships are complex and not well understood. Although my purpose is to discuss various biological agents as management tools, I want first to say something about the need for sagebrush control.

The Invasion Problem

Pearson (1975) reported that *Artemisia tridentata* possesses two characteristics which give it a competitive advantage in desert ecosystems where it is abundant: 1) its ability to carry on photosynthesis during winter months at temperatures near and below the freezing point of water, and 2) its ability to switch from a relatively high rate of photosynthesis to a dormant stage as soil moisture stresses build, and then to switch back again as moisture again accumulates in photosynthetic tissues. These features may be as important to its survival as its lack of palatability to livestock and its flowering and fruiting characteristics.

In the last 3 or 4 decades, land management agencies and range users have sought to increase desirable range forage by reducing sagebrush and planting grass. Sagebrush has reinvaded seeded foothill ranges, regardless of eradication procedure or method of grazing. However, the extent of reinvasion is reduced by effective eradication prior to seeding and subsequent moderate grazing (Blaisdell 1949, Frischknecht and Plummer 1955, Frischknecht and Bleak 1957, Cook 1966, Frischknecht and Harris 1968). Despite efforts to restrict sagebrush invasion, climatic effects tend to dwarf the effects of range management by allowing sagebrush to increase (Frischknecht 1978). Reinvasion is a chronic situation requiring periodic control of sagebrush to maintain production of seeded grasses.

A study of 25 sagebrush (*A. tridentata tridentata*) colonies on crested wheatgrass range, each having arisen from one large parent plant, revealed that the maximum distance of progeny spread from parent plants averaged 12.6 m (42 ft), but 90 percent of the total progeny was within 9 m (30 ft) of parent plants (Frischknecht 1962). This means that plants spaced about 9 m (30 ft) apart have the potential of quickly developing into a full stand of sagebrush under optimum conditions. The amount of time required for full stand development depends upon the intensity of spring grazing and, more importantly, upon climatic conditions. *Chrysothamnus nauseosus* is a prolific invader also, but it offers far less competition to grass and it is shorter lived than *A. tridentata tridentata* (Frischknecht 1963).

Within a 4-year period, sagebrush density on one of the heavily grazed crested wheatgrass pastures on the Benmore Experimental Range in west-central Utah increased from 7 to 30 plants over 1 dm (4 in) high per 9 m^2 (100 ft^2) of area. Numbers of plants under 1 dm (4 in) high increased from 14 to 31 in the 4-year period.

A comparison of sagebrush density and cover on pristine and on depleted areas focuses further attention on the invasion problem. Christensen (1963) reported that data from 71 transects in undisturbed bunchgrass communities in 7 central Utah counties showed that sagebrush had an average foliage cover of only 15.8 percent compared to an average cover of 56.1

percent for *Agropyron spicatum* and 14.1 percent for *Poa secunda*. That author concluded that sagebrush is rarely the leading dominant where vegetation has been subjected to little disturbance.

On three protected relict areas in northeastern Utah, Christensen and Welsh (1963) found that perennial grasses comprised 91.9, 67.5, and 76.4 percent of the total vegetative cover. Combined figures for big sagebrush and snakeweed on the same sites were only 3.9, 14.3, and 12.0 percent, respectively. In contrast, perennial grasses on an unprotected area subjected to heavy grazing made up only 0.5 percent of the total cover and the two woody species, 92.8 percent.

Tisdale *et al.* (1965) found three major plant communities on an area of pristine vegetation in Idaho. Two of the communities occypied most of the area. The *Artemisia tripartita/Festuca idahoensis* association had a shrub cover averaging 14 plants per 9 m^2 (100 ft^2), with a mean foliage cover of about 10 percent, and a height of 51 cm (1.7 ft). The *Artemisia tridentata/Festuca/Agropyron* community, confined largely to south and west slopes, had a shrub cover of from 3 to 7 mature plants per 9 m^2 (100 ft^2), a mean foliage cover of 13 percent, and an average height of 105 cm (3-1/2 ft). The small *Artemisia longiloba/Festuca/Stipa* community was sharply defined edaphically. It has about 25 plants of *A. longiloba* per 9 m^2 (100 ft^2), only 1.5 percent foliage cover, and a mean height of only 25 cm (10 in).

Cooper (1953) concluded that conservative grazing and occasional resting throughout the growing season would enable climax grasses to replace big sagebrush without artificial aid within 10 years under favorable weather and grazing conditions. *Agropyron spicatum* and *A. smithii* increased from 25 to 75 percent, whereas sagebrush decreased from 55 to 10 percent between 1942 and 1949. Such a dramatic change raises the question of whether some biological agent could have been an unknown factor in the rapid reduction of sagebrush.

Biological Methods

Fire, herbicides, and mechanical methods are well known as tools for managing sagebrush. Biological methods are less well known. Biological management implies that the biological agent can be managed. It is one thing to discover agents that can control sagebrush and another thing to manage them. At present, some biological methods hold much greater promise than others, but all should be considered.

Phytosynthesis in plants converts solar energy into chemical energy such as that found in fossil fuels, in wood, and in the carbohydrates, proteins, and fats in plant parts. Fire converts chemical energy stored in sagebrush to heat that is dissipated into the atmosphere. Mechanical methods redistribute the stored chemical energy and some elements are recycled following the decomposition process. As a management tool, herbicides upset the normal photosynthesis-respiration process of sagebrush, eliminating it from competition with more desirable plants. Biological management involves use of animals that feed upon sagebrush. An advantage of biological management is that some animals can convert the chemical energy in plants into animal protein, such as meat, fiber, and hides, that can be readily used by man.

Insects as a Management Tool

Jorgensen (1955) and Jorgensen and Tingey (1968) reported finding many kinds of insects on *Artemisia tridentata*, but concluded that most of them would not cause serious damage, mainly because of low level of occurrence. These authors found that *Aroga websteri* (Clark), an insect that defoliates the apical portions of small branches and is known to kill sagebrush, was usually present but in low numbers during their study. This insect will be discussed in greater detail.

As many as 10 species of one order (*Thysanoptra*) of insects were found on big sagebrush by Tingey *et al.* (1972). These authors cited 5 additional species of thrips found by others on big sagebrush, but concluded that these sucking insects would have marginal damage potential because of their generally low level of occurrence.

A colleague, who is making a special study of insects on sagebrush, indicates that at least 50 species of aphids and 35 species of gall-producing insects are to be found on sagebrush, but seldom kill plants (Charles Tiernan, personal communication). These are but a few of the great numbers of insects that sagebrush hosts.

In the case of the sagebrush defoliator moth (*Aroga websteri* [Clark]), Gates (1964) estimated that 4,000-6,000 ha (10,000-15,000 acres) of sagebrush were killed by this insect in Malheur County, Oregon, in 1962. The infestation exploded in the spring of 1963, and over 4.8 million ha (12 million acres) of sagebrush in Oregon alone were infested to some degree with *Aroga*. Old stagnant stands of sagebrush were most heavily damaged. Thrifty sagebrush in borrow pits, swales, or areas of more favorable moisture were better able to resist infestation, whereas over the fence sagebrush had been blackened by *Aroga*. *Aroga* has been positively identified on *Artemisia tridentata, A. arbuscula, A. nova,* and *A. cana.*

According to Gates, the life cycle of *Aroga* begins when the adult moth lays eggs in the late summer or early fall in small cracks in the bark or on the leaves of sagebrush. Larvae hatch in about 2 weeks, mine into the leaves of sagebrush plants, and overwinter. In spring, larvae continue to mine leaves, which are cut from the plant and pulled into little groups by webs from the larvae. The cocoons are built within small groups of leaves and webs. Larvae go into the pupal stage in June or July and adult moths hatch in about 2 weeks.

Gates reported that entomologists at Oregon State University found that some samples of *Aroga* were heavily parasitized. One kind of parasite works on the larva and the other on the pupa. Outbreaks of *Aroga* that are heavy enough to kill sagebrush occur when the predators fail to control high population buildup. At present, range managers do not have the knowledge to manage insects and their predators for sagebrush control.

The effects of another insect capable of killing sagebrush (*Trirhabda pilosa* [Blake]) were described by Pringle (1960). He reported that in July 1954 a patch of big sagebrush, less than 0.8 ha (2 acres) in area, near Kamloops, British Columbia, had turned a rusty brown color. Myriads of small metallic blue larvae were stripping the surface layers from the leaves. In the spring of 1955, 90 percent of that sagebrush patch was dead. Shrubs used by ants as

aphid pasture were not damaged by *Trirhabda* to any degree before the ants left. When the ants were gone, these particular plants were killed the following season by hatching *Trirhabda* larvae. In this same area in 1955, larvae were abundant on sagebrush over an estimated 600 ha (1,500 acres). By June 1956, 70 to 80 percent of the sagebrush in this area was dead. By that time the beetles were prevalent over a wide area. In July, they swarmed to a 1,000- to 1,200-ha (2,500- to 3,000-acres) patch of sagebrush that had not been previously affected. By 1958, insects were active in areas as far as 8 km (5 miles) from their origin. In attempts to transplant about 1,000 beetles, one out of four transplants succeeded.

Trirhabda attenuata (Say) infested threetip sagebrush in epidemic numbers killing sagebrush over 800 ha (2,000 acres) near Thermopolis, Wyoming (Fisser and Lavigne 1961). Some idea of insect density can be gained by knowing that, near the center of the infestation, 460 adults were collected in 100 sweeps with a 37.5-cm (15-inch) insect net. On the edge of the infestation, only 16 adults were collected per hundred sweeps. All plants of the community were infested except *Artemisia ludoviciana*. Again, the insect did not infest *Artemisia tridentata* plants near ant hills.

Daubenmire (1975) reported that grasshoppers do not eat the foliage of *Artemisia*, but they congregate in the canopy of *Artemisia* to roost at night after feeding on green leaves of other plants. However, Allred (1941) reported that grasshoppers and drought killed 50 percent of the big sagebrush along the Little Powder River drainage in northeastern Wyoming and southeastern Montana in 1936. Near Gillette and Moorcraft, Wyoming, where drought was thought to be equal to that in the Little Powder River drainage, a minor grasshopper infestation killed only 15 percent of the sagebrush. Sagebrush kill was particularly heavy on heavy clay soils with southwest exposures or gently sloping valley uplands, where 70 percent or more of the total forage density was grass. Sagebrush kill was poor where there was little or no grass and sagebrush formed 70 percent of the cover. Two grasshopper species that were numerous in 1934 and 1935 and reached peak population in 1936 were *Aulocara elliotti* and *Ageneolettix deorum*. Both species are thought to eat sagebrush as a last resort. Allred further reported that one grasshopper species, *Melanoplus mexicanus*, fed over large areas of sagebrush in eastern Montana in 1939, even when moisture was abundant and grasses were available. At that time, thousands of hectares of sagebrush were partly or entirely defoliated and bark was often eaten from the smaller twigs and branches.

It can be concluded that using insects for biological management of sagebrush would involve highly complex strategies. Best control would depend upon finding an insect that had no natural parasitic enemies and that would be host specific to sagebrush. For example, a small white moth from Pakistan (*Coleophora parthenica*) is being studied as a biological control agent on Russian thistle. It also attacks halogeton. There are no known natural enemies of this moth in the United States, which should give it a better chance of reaching larger populations capable of killing plants, than it would have in areas where it is suppressed by its own predators. An unanswered question is, "Will it spread to valuable forage or agriculture plants?"

Small Mammals as Management Tools

Several species of small mammals can be found in the sagebrush ecosystem but few species are known to kill sagebrush. Jackrabbits (*Lepus californicus*) often migrate into dense stands of sagebrush when snow covers the ground in winter and use sagebrush for both food and cover. Currie and Goodwin (1966) reported that rabbits preferred the 2-year-old woody stems of sagebrush. The current growth and seed stalks were nipped off and dropped on the ground, but sagebrush plants are not usually killed by rabbits over large areas.

Voles (*Microtus* spp.) are known to girdle and kill sagebrush over sizable areas in certain years (Murray 1965, Mueggler 1967, Phillips 1970, Frischknecht and Baker 1972). Murray (1965) discussed changes in vole populations in California during the 1957-1958 outbreak and cited other references dealing with outbreaks and crashes in vole populations.

Mueggler (1967) sampled eight stands of sagebrush in Montana at elevations ranging from 2,040 to 2,280 m (6,800 to 7,600 ft) where voles had killed 10 to 84 percent of the sagebrush. The sagebrush canopy averaged 30 to 90 cm (1 to 3 ft) tall and made up 50 to 70 percent of the ground cover. Grasses and forbs made up 60 to 80 percent of the ground cover with litter adding another 10 to 30 percent. Voles stripped bark from the main stems and large branches, but seldom girdled young sagebrush stems.

Frischknecht and Baker (1972) reported that total kill of sagebrush by voles ranged from 56 to 73 percent in six different drainages between 1,950 and 2,250 m (6,500 and 7,500 ft) elevation. An additional 20 to 35 percent of the plants showed some damage by voles. Voles completely girdled sagebrush plants that also showed insect damage in the form of twig galls. Good herbaceous cover and continuous snow cover were conducive to high sagebrush kill by voles. Frischknecht and Baker suggested that if it were possible to predict irruptions of vole populations in advance, areas where sagebrush control is desired should not be grazed during the growing season to allow herbaceous cover to develop as vole habitat. Conversely, areas where sagebrush and other shrubs are desired should be grazed to remove herbaceous cover that would be conducive to high vole populations. This suggestion is substantiated by observations of Frank (1957) in Germany. High stocking rates and intensive pasturing by cattle prevented vole population outbreaks.

Knowing the requirements for good vole habitat, it is conceivable that ungrazed shrub-grassland communities might have been greatly influenced by voles in reducing the density of shrubs over the years, even prior to settlement.

Microtine rodents are the most prolific breeders of all mammals (Hamilton 1937) and populations irrupt under optimum conditions. One female *Microtus* had 9 litters in 8 months and another had 13 litters in 1 year. Number of young per litter varied from 1 to 11 with an average of slightly over 5 based on monthly data over 4 years. Hamilton reported that in some years breeding continues through the winter, although in New York the breeding season is usually from mid-March to mid-November. There is no evidence that

mass movement of microtines occurs. When a population high has been reached, there is usually no territory for the rodents to preempt. When the supportable density of the habitat has been reached, the population crashes the following winter (Frank 1957). Psychological and physical stress, disease, and the added stress of winter are responsible.

Frischknecht and Baker (1972) cited evidence that recent irruptions in vole populations in some western States were approximately 4 years apart.

Lidicker (1973) cited references to show that 2- to 4-year fluctuations in populations are presumed typical of *Microtus californicus*. Reproduction shows a seasonal pattern beginning 1 to 2 months after the start of the rainy season and ending with desiccation of vegetation in June. Green vegetation is important to reproduction (Lidicker 1973, Gill 1976). Grasses are used for both food and cover.

Hamilton (1937) discerned a 4-year cycle in peak *Microtus* populations in the northeastern United States. Population peaks occurred there in 1919-1920, 1923-1924, 1927-1928, 1931-1932, and 1935-1936. Although complete records were unavailable, reports since 1863 have indicated cyclic population peaks. On the basis of past records, Hamilton (1937) indicated that peaks of future cycles could be expected in the Northeast in 1939-1940, 1943-1944, and so on. He cited reports from the Midwest showing that peaks in *Microtus* populations occurred simultaneously with those in the East in 1923-1924, 1927-1928, and 1931-1932.

More recently, Myers and Krebs (1974) have indicated that the two outstanding remaining mysteries relative to population cycles are: Why the cycle has a period of from 3 to 4 years, and how the cycles of isolated populations are synchronized? Further study of these phenomena seems justified. Predictions of population irruptions would aid management of sagebrush ranges.

Large Herbivores as Management Tools

Several large herbivores depend heavily upon sagebrush range for winter habitat, particularly where pinyon and juniper trees provide protection. In severe winters, sagebrush has been killed by heavy concentrations of deer and elk. However, heavy winter browsing by these animals would not be a recommended practice for managing sagebrush. As management tools, sheep are best. They are easily managed and consume large amounts of sagebrush under optimum conditions. Research at the U.S. Sheep Experiment Station, Dubois, Idaho, showed that grazing by sheep in late fall (mid-November to late December) reduced sagebrush and increased grasses and forbs (Laycock 1961, 1967). Conversely, over a period of 14 years, heavy spring grazing increased sagebrush 78 percent and decreased grasses and forbs more than 50 percent.

Frischknecht and Harris (1973) concluded that late-fall grazing by sheep can control the increase of sagebrush on seeded range, if the practice is initiated before brush becomes dense. Grazing by sheep in late fall will reduce the size and reproduction of sagebrush plants. Control was effective where sagebrush density averaged about 1½ plants of all sizes per 9 m^2 (100 ft^2) of area. Where sagebrush density averaged 13 plants per 9 m^2 (100 ft^2), sheep had little effect on sagebrush. Further, the animals lost excessive weight both in early and late fall. When fall grazing was discontinued, sagebrush plants that had been greatly reduced by grazing flourished and put on considerable growth. This enlargement suggests that biological control by sheep grazing should be repeated every few years for effective control of sagebrush. Research has shown that cattle offer no hope for controlling sagebrush on seeded range, even with a protein supplement.

Kilpatrick (1965) reported that 0.1125 kg (¼ lb) of protein supplement daily will help to keep sheep thrifty and encourage greater use of sagebrush. Sheep given the supplement can be herded closer together to induce heavier use of browse. When sheep have been fed a protein supplement in the fall and early winter, they can be held on brush ranges longer without harm. Sheepmen confirm that sheep will eat more sagebrush if they are fed a protein supplement than they will if fed a high carbohydrate supplement.

Cook and Harris (1968) reported that sheep should be fed a supplement to prevent large weight losses during inclement weather from December to April. Certain (particularly middle aged) animals stay in good flesh and produce well with little supplemental feed. A diversified plant cover is more desirable than a single forage.

Johnson *et al.* (1976) reported that big sagebrush was lethal to sheep fed 0.3375 kg (3/4 lb) daily by stomach pump for 1, 2, or 3 days. However, it was not toxic to sheep fed 0.1125 kg (1/4 lb) daily and slowly increased to 0.3375 kg (3/4 lb) daily. These authors suggested caution in moving sheep rapidly onto sagebrush range.

Palatability Differences in Sagebrush

Obviously, differences in palatability of big sagebrush will influence the amount consumed by animals. Differences in palatability of big sagebrush to both livestock and wildlife have been recognized by Winward (1970), Hanks *et al.* (1971, 1973), and Brunner (1972). In Idaho, Winward and Tisdale (1977) used morphological, chemical, cytological, ecological, and distribution characteristics in recognizing five subspecies. These subspecies were *A. tridentata* ssp. *wyomingensis*, *A. tridentata* ssp. *tridentata*, *A. tridentata* ssp. *vaseyana*, *A. tridentata* ssp. *vaseyana* form *spiciformis*, and (what Winward and Tisdale called) type "X." The last subspecies occurred along the western border of Idaho and in eastern Oregon for a distance of about 64 to 80 km (40 to 50 miles). Winward and Tisdale found *A. tridentata* ssp. *wyomingensis* confined to the drier portions of the sagebrush region. Beetle and Young (1965) placed this subspecies intermediate in ecology and distribution between *A. tridentata* ssp. *vaseyana* and *A. tridentata* ssp. *tridentata*. Scholl *et al.* (1977) determined that less than one-fifth of the variation in use of different sagebrush taxa could be attributed to relative percentages of volatile constituents in the leaves. Oxygenated compounds, such as methacrolein and arthole, seemed to be more highly correlated with use than hydrocarbons, and this correlation appeared to be inverse. *Artemisia tridentata* ssp. *vaseyana* appeared to be preferred to *A. tridentata* ssp. *tridentata*. *A. tridentata* ssp. *wyomingensis* was the least preferred of all taxa examined.

Smith (1958) reported great variation in the palatability of individual big sagebrush plants to deer. He reported further that confined deer did not consume over an average 0.45 kg (1 lb) per day of sagebrush and appear to reach satiation point, unless forced to eat sagebrush because other forage is lacking.

Nagy and Tengerdy (1968) observed an antibacterial effect on rumen bacteria of wild and captive deer, when 16 ml of big sagebrush oil was added to 10 ml of rumen fluid nutrient broth. Nagy and Tengerdy considered that deer would tolerate a diet of 50 percent sagebrush, provided the sagebrush contains 1 to 5 percent volatile oil.

Defoliation of Sagebrush in Cold Weather

In addition to the combinations of factors mentioned as affecting biological control, this paper will report on defoliation of sagebrush by animals in cold weather. This factor has been discussed on occasion, but nothing about it has been published.

Over the years while making estimates of sheep use of big sagebrush in December, we occasionally observed many leaves of sagebrush lying on the ground at the base of plants. On a cold December day in 1967, leaves of big sagebrush were frozen and many dropped to the ground if they were brushed against. The minimum temperature that day was -21°C. The snow cover averaged approximately 10 cm (4 in) in depth.

When we found sagebrush leaves frozen (January 31, 1969), we decided to defoliate several plants and determine the effects on growth the following spring. An average of 5 to 10 cm (2 to 4 in) of snow covered the ground. The minimum air temperature around 6 a.m. that day had been -13°C. It had risen only slightly by 8 a.m., when the defoliation procedure began.

Plants of big sagebrush were paired according to size and appearance. The flip of a coin decided which plant of each pair would be defoliated; foliage on the other plant was left as a check. Leaves were easily knocked off plants by striking branches of the plant with a stick. The stick was swung mainly with an upward motion so as to do as little damage to twigs as possible. Defoliation was complete, except for a few small grayish leaves less than 0.62 cm (1/4 in) in length that remained closely appressed to some of the younger branchlets. Although the sky was clear and the sun shining, leaves of sagebrush remained brittle and were easily knocked off until about 9 a.m. By that time, the temperature had climbed to -8°C and the procedure was discontinued because it was becoming more difficult to defoliate the plant as leaves thawed. A total of 24 plants had been paired; 12 plants had been defoliated.

When observations were made May 8, 1969, a few clusters of new leaves were present on most defoliated plants, but leaf volume was not over 5 percent of the total of the untreated counterpart. Many new leaves were unusually large, some ranging from 2.5 to 3.12 cm (1 to 1¼ in) in length and 1.25 cm (0.5 in) in width. Additional leaves appeared as the growing season progressed. By the end of July, most plants that had been defoliated appeared to have about half the leaf volume of control plants. Also, few if any flower stalks were produced on plants that had been defoliated, but numerous flower stalks were produced on the controls. This situation persisted into the fall.

In early November, the average weight of leaves on defoliated shrubs was estimated to be 220 g per plant and 480 g per control. In addition, the estimated weight of flower stalks on untreated plants averaged 5 times the weight of their leaves. Six of the 12 defoliated plants produced no flower stalks, and the estimated weight of the few flower stalks on the other 6 plants was less than one-tenth the weight of their leaves. Seed matured about December 15, but the amount on treated plants was negligible compared to the heavy crop on control plants.

These observations provided new information about late-fall grazing. Grazing by sheep during late fall (mid-November to mid-December) may have been more effective in reducing volume of sagebrush than grazing during early fall (mid-October to mid-November) for two reasons: 1) Sheep eat more browse during cold weather, and 2) plants might have been partially defoliated by animal contact when leaves were frozen.

Importance of Sagebrush as Wildlife Habitat

One of the pressing unanswered questions in sagebrush management is, "How much sagebrush is needed for wildlife habitat?" Because sagebrush retains its leaves in winter, it provides food and cover for many kinds of wildlife as well as for domestic range sheep. Dependence on sagebrush by both large and small animals becomes most critical during the winter. Not only are small patches of dense sagebrush essential to jackrabbits during heavy snow, but to the survival of sagegrouse as well (Mussehl 1971). Sagebrush fulfills all sagegrouse requirements for food and shelter through the winter. In Idaho, sagegrouse used blacksage as long as snow was only 7.5 to 15 cm (3 to 6 in) in depth. When 25 cm (10 in) of snow covered the short brush, sagegrouse left the area and returned when blacksage was again exposed during mild weather. Flocks on winter range numbered from 10 to approximately 1,000 birds. Large roosting groups were formed from smaller flocks. Wintering concentrations were largest during cold weather.

Spring strutting grounds, which are openings in sagebrush colonies are also important. From these openings, the birds can retreat into sagebrush for cover. Telemetered birds are known to have left the strutting grounds and to have sought nesting cover 4.8 km (3 miles) away. During summer, sagegrouse use some of the lighter sagebrush areas for raising broods. Juvenile grouse prefer areas having a good density of forbs, with sagebrush cover ranging from 1 to 20 percent. Special searchs showed no sagegrouse droppings in areas where 100 percent of the sagebrush had been killed (Mussehl 1971).

In areas where sagebrush is important to sagegrouse, the following guidelines were recommended by the Western Sage Grouse Committee (Lyon 1966) for modifying existing sagebrush stands. No control program should be planned where density of sagebrush does not exceed 174 plants per ha (435 plants per acre) with 10 to 20 percent crown cover. No sagebrush should be treated within 0.4 km (1/4 mile) of any sagegrouse strutting ground or within

90 m (100 yards) on both sides of streams and around all mountain meadows. No control program should affect more than 50 percent of the sagebrush stand concerned. Further recommendations were as follows:

1. Alternative strips of treated and untreated sagebrush should be no more than 90 m (100 yards) in width.

2. Block spraying should be limited to 32 ha (80 acres) or less with such blocks being no more than 0.4 km (1/4 mile) in width. The area treated should not exceed 25 percent of the total.

3. Partial kills over large areas should leave a minimum of 174 plants per ha (435 plants per acre) with 10 to 20 percent crown cover.

4. Untreated strips or blocks should not be treated until sagebrush density in previously treated areas has reached at least 174 plants per ha (435 plants per acre) and 10 percent crown cover.

Conclusions and Recommendations

Range managers must understand sagebrush ecology to develop management strategies. They must also understand the ecology of biological agents that are potential management tools. We need to know how to manipulate sagebrush stands by using biological agents that can provide some measure of sagebrush control. At the present time, sheep are the best possibility. Although certain insects and small mammals can control sagebrush under certain conditions, information on their management is insufficient. The effect of such biological agents on sagebrush and associated plants requires additional research. Studies are also needed to provide information on the fecundity, development, and mortality of these biological agents.

Computer models are needed. By using computer models, management can predict outbreaks of damaging insect infestations, vole irruptions, and other biological events that affect sagebrush. Also, with computer models managers can predict growth and development of sagebrush stands in space and time. Of course, the usefulness of models is restricted by the adequacy of the data used in forming the model.

Environmental and biological monitoring is necessary to provide necessary input into computer models. Environmental monitoring includes past and current weather information that can aid in predicting severe frosts, winter storms, and other factors that affect biological control. Biological monitoring should include the effect of action taken and should update model predictions.

A multifactorial approach is needed in managing sagebrush ecosystems. That approach should combine biological strategies with chemical and mechanical strategies to reduce the heavy cost. The combined strategy would also lessen the harmful effects of chemicals used alone.

Information is lacking as to specific wildlife needs for sagebrush habitat. Heretofore, range managers have assummed that reductions of sagebrush in dense stands created diversity of habitat that is beneficial to animals and that adequate sagebrush would remain in untreated areas for wildlife needs. Although specific needs have been outlined for sage-grouse, the question arises as to how the birds thrived before settlement, when sagebrush was far less dense. Perhaps the heavy grass cover was also important and should be considered in management programs. Another factor is that at least some of the birds are migratory and travel distances from winter to summer ranges of 48 to 120 km (30 to 75 miles) in Idaho (Dalke *et al.* 1960). Migratory distances of 80 to 160 km (50 to 100 miles) were reported by Patterson (1952) in Wyoming. Although there are many unanswered questions on biological management of sagebrush, sufficient information is available to involve domestic animals such as sheep in management programs. Sheep can be used even on cattle range. The possibility of using other biological agents will be enhanced as we acquire knowledge and fill information gaps.

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Species and Methods for Seeding in the Sagebrush Ecosystem

Wesley Keller[1/]

Introduction

According to the US Forest Service (1936) much of the nearly 40 million ha of the former sagebrush-bunchgrass type (the sagebrush ecosystem) has lost the desirable forage species it once had, primarily through overgrazing. The result has been depletion of the type as a whole, as a forage resource, of as much as 60 to 90 percent. (The sagebrush ecosystem, an important link between winter and summer ranges for sheep and between summer ranges and the home ranch for cattle, is called the spring-fall range. This spring-fall range, adequate at the time of settlement (Forsling 1928), has lost some millions of ha of its potentially most productive land to the plow, because vigorous sagebrush is an excellent indicator of good agricultural land.) Seeding is the only known method of rapidly restoring ranges that have lost their desirable forage plants. Stewart (1951) wrote that the sagebrush zone represents the greatest need and offers the greatest opportunity for range seeding. Within the sagebrush ecosystem a few million ha have been seeded and many other millions await that treatment.

Seeding should be discussed under two major headings. First is the choice of species. After over 40 years experience, choice of species, not now particularly difficult, is still not cut-and-dried for much of the range. In the future, when new range plants having distinctive characteristics have been developed by forage plant breeders, the choice might well be more difficult. The second main heading is the actual process of seeding. Much has been learned, but because seeding success is still greatly dependent upon weather (as yet predictable only a few days ahead), seeding remains a risky undertaking. Stoddart (1946a) expressed it well: "Very dry years will invariably result in disappointment. In unusually wet years almost any planting will be successful. Average years can be determined; annual and seasonal variations put the inevitable gamble in range seeding." Choice of species and methods of getting them established constitute the major part of this review.

Evidence increases that range seeding may undergo significant changes in the years ahead. Some of these changes, as they affect range improvement, are considered in the "Discussion" part of the paper. Foremost among these is the problem created by monoculture. The black grass bug (*Labops hesperius*) may have been the first warning that range seeding activities, primarily to a single species, had upset the dynamic balance which the native vegetation had achieved with its environment. Others have followed. We are beginning to encounter problems we cannot cope with under our present concept of range improvement. The search for new and acceptable approaches to range improvement may well be the major challenge faced by scientists concerned about the range for decades or even generations ahead.

Whether this forecast is correct or not, inevitably the range, correctly called a modified ecosystem by Love (1961) will be encroached upon in the future as other needs demand space. Yet, what remains range will continue to assume increasing importance. And methods of seeding, and the choice of species to use, will require increasingly specialized and technical understanding.

Early Range Seeding

Considerable information on range improvement by seeding had been accumulated before much serious attention was paid to improving the sagebrush ecosystem. One of the early leaders was George Vasey, botanist on the Powell expeditions exploring the Western United States, later the first chief of the Division of Botany, USDA. In this latter capacity, Vasey (1889) described Congress' intent in providing the first grass experiment stations as "primarily to ascertain that plants are best adapted for cultivation for grazing purposes on the 76 million acres (31 million ha) of arid plains in Eastern Colorado, Western Kansas and Nebraska, and Southern Wyoming." In 1890 he wrote that experiments were about to begin to improve the range. Considering the first step to be a knowledge of the grasses, he published part I (Vasey 1890) and part II (Vasey 1891) of illustrated grasses of the southwest.

At about the same time Cassidy and O'Brine (1890) in Colorado, Toumey (1891) in Arizona, and McLarin (1891) in Wyoming conducted studies to find superior forage plants for their arid lands. The Colorado work even included chemical analyses in a search for better quality forage.

Kennedy and Doten (1901) after a survey of a depleted summer sheep range in Nevada, asked the following questions:

1) How and how much do the sheep permanently injure the forage plants, both by eating them and by tramping them down?

2) How can this kind of injury be prevented or made less harmful.

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3) Can sheep owners profitably improve the injured ranges by sowing on them seed from the best native and introduced forage plants?

4) If so, what kind of seed will be best for this purpose?

5) Finally, how can enough seed from the best plants and grasses be produced cheaply enough to make reseeding practical?

These few references sufficiently indicate that by 1900 many people were knowledgable about the range, concerned for its improvement, and asking questions we still seek answers for today. Probably none of the early investigators comprehended the magnitude of the problem they were attacking, a problem that is substantially greater today than it was then.

Nelson (1902) described resting, rotative grazing, reseeding, harrowing, and disking as means of range improvement in Wyoming. Nelson and Nelson (1903) published a description of the wheatgrasses of Wyoming, naming them as among the best forage plants of the area studied. They record that as early as 1894 wheatgrasses and other native species had been grown on the experimental farm. Nelson (1904) reported that if less than 2.5 cm rain fell each month, April through June, the grasses did not become established. Tests in 1901-1903 had involved 66 grasses and 15 other forage plants. In 1903 they seeded 16 species of saltbushes (*Atriplex*).

Griffiths (1907) named western wheatgrass (*A. occidentales* - now *A. smithii*) and bunchgrass (*A. spicatum*) as successful species. He adds, "much thought and attention (have been given) to the feature of range improvement by reseeding in all its phases", and that the work had been in progress for 10 yrs, "with profitable results". As to why seedings of native species might fail, he thought good years were followed by bad, so that if seeds were collected in good years, when seeds were plentiful, and planted the following year, it being a bad year, the seeding would fail. (Stoddart (1946a) thought good and bad years came in groups, though not with enough dependability to be a guide in seeding.)

For 15 to 20 years following Griffiths, range research was dominated by Arthur W. Sampson. His work, mostly on summer range in the National Forests, will not be reviewed here. However, Sampson brought the best scientific training of his time to range research, and made many contributions that have application to all rangelands. His work advanced range science greatly. He believed most depleted ranges could be rehabilitated by deferred rotation grazing; he tied deferred rotation grazing to the growth requirements of the forage plants involved; he showed that range condition and trend could be determined by the vegetation on the ground and by which species were decreasing and which were increasing; he thought it was always beneficial to cover the seed, in seeding operations - broadcast seed could be covered by sheep, but if the soil was loose the seed might be covered too deeply; he pointed out that the principle causes of failure were lack of soil treatment (control of competing vegetation), drought, and use of the wrong species for the site. After moving to the University of California at Berkeley, Sampson produced a widely accepted textbook on Range Management. Some sketches of his life and a full listing of his writings appear in the Journal of Range Management, Volume 20, Number 6, November 1967.

The status of range seeding in 1919 is well stated by Jardine and Anderson (1919), "The results presented in bulletin 4 (Sampson 1913) as well as the results of investigations since it was issued, indicate that the expense of seeding rangelands to cultivated species is warranted only on mountain meadows and other areas of minor extent 500 ft or more below true timber line and having favorable soil and moisture conditions". Five years later Jardine (1924) wrote the following revealing statement for a national symposium on The Forage Problem, "Outlook for range improvement by artificial seeding not encouraging. Range improvement by seeding with seed of cultivated plants and with seed of a limited number of native plants, has been tried in perhaps 1000 seeding tests, representing fairly well the many combinations of soil and climate. The results indicate that improvement in this way is limited to small areas where the soil and moisture conditions are far above the average. Such lands do not exceed, perhaps, one-half of one percent of the grazing areas within the National Forests, are negligible on the open range areas, and constitute but a small part of private holdings".

The status of range seeding in the Intermountain Region around 1930 is well expressed by Forsling and Dayton (1931). They specify 43 cm as the lower limit of precipitation for range seeding, except in special cases, as for watershed protection, where extra soil preparation can be justified. They required at least 15 cm to come during the main growing season. They indicate that for the lower mountain slopes and higher foothills of inland mountain rangelands seeds were available of common brome (*Smooth brome - Bromus inermis*), crested wheatgrass (*A. cristatum and desertorum*), slender wheatgrass (*A. trachycaulum*), yellow sweet clover (*Melilotus officinalis*), white sweet clover (*M. alba*), and alfalfa (*Medicago sativa*). Seed was not available of bluebunch (*A. spicatum*), beardless (*inerme*), bluestem (western), thickspike (*dasystachyum*), streambank (*riparium*), and violet (*violaceum*) wheatgrasses, or mountain brome (*B. marginatus*). Regarding crested wheatgrass, they write as follows, "In recent range seeding trials thin stands only were obtained at 7,400 ft (2256 m) elevation in the oak zone in Central Utah and at 7600 ft (2316 m) elevation in Southwestern Colorado, and not more than a fair stand was obtained in the foothills of the Rocky Mountains in Northern Colorado. This species did not do so well as common bromegrass in these locations". It is clear that they were working well above the altitude at which crested wheatgrass is best adapted. Note that the only native grass of which seed was available was slender wheatgrass, no doubt imported from Canada.

Chapline et al. (1944) presented a history of western range research. They record that the transfer of the Office of Grazing Studies (in the FS) from Administration to create a new office in the Branch of Research did much to improve the research opportunity in all areas of range. They write that as a result of the accumulated experience, "there is a much better and more widespread understanding of the four basic principles of range management".

1) Proper kind and class of livestock.

2) Proper season of grazing.
3) Proper distribution of Grazing.
4) Proper number of animals.

Range seeding is not mentioned because each of the 4 principles listed applies to 100 percent of the range, while seeding, for the present at least, is restricted to sites too badly depleted to be restored by natural revegetation.

Crested Wheatgrass: Introduction and Early Studies

Crested wheatgrass was first introduced into the US in 1898 by N. E. Hansen, then on a plant exploration expedition to Russia, Siberia, Turkestan, and China for the US Government (Ryerson 1976). Hansen sent 5 lots of seed from Russia, labeled *Agropyron cristatum*. There is no record of these seeds being planted (Dillman 1946). In 1906 the Moscow Botanical Garden sent over 6 lots of seeds, one labeled *A. cristatum* and 5 *A. desertorum*. Westover et al. (1932) made no distinction between *cristatum* and *desertorum*, calling both crested wheatgrass because they were so similar. Years later crested became the common name for *A. desertorum*, and fairway for *A. cristatum*. This distinction will be made throughout this review, although prior to 1954 unless specified, crested wheatgrass could be either one, or a combination of the two. (For interesting accounts of the early experiences with crested wheatgrass in the US and Canada read Westover et al. (1932), Dillman (1946), and Rogler (1960).)

Dillman (1910) wrote as follows about a 1908 seeding of crested wheatgrass at the Belle Fourche Station at Newell, South Dakota, "This grass . . . . gives evidence of being a very hardy grass. It was observed that this species starts growth very early in the spring, and is not injured by severe frosts." Pieters (1923) wrote that, "slender wheatgrass and crested wheatgrass (*A. cristatum*) have shown promise, especially the latter". Woodward (1923) thought crested the best adapted grass for the soils and arid climate of Montana, producing good yields of forage and seed; that it was both cold and drought resistant, and early, and gave promise on dryland. Kirk (1928) wote that crested wheatgrass (*A. cristatum*), newly under test, has great possibilities for both hay and pasture in Southwestern Canada. Kirk found this grass to have good seeding habits; it was drought resistant, palatable, produced high yields, and had a high protein content. According to Dillman (1946) Kirk had already selected the Fairway strain of *A. cristatum*, and in 1927 had grown 579 kg of seed from a one-ha seed increase plot. Yet as late as 1932 Westover et al. (1932), in a major paper on crested wheatgrass, comment that smooth brome, introduced in 1884, had for years been the outstanding grass on the Northern Great Plains, and added that ". . . it is not to be assumed that bromegrass will be replaced by crested wheatgrass." Kirk et al. (1934) and Kirk (1935) wrote further in promotion of crested wheatgrass in Canada. Clarke (1935) claimed it to be by far the best grass for the dry prairie areas; that it does not kill out once established; that it stands close grazing and severe trampling exceptionally well; that during a cycle of dry years since 1928 it had yielded 1.68 to 2.24 metric tons of hay per ha while slender wheatgrass killed out badly and smooth brome was partly killed and yielded little. Reitz et al. (1936) recommended drilling crested in 4-row strips across the prevailing wind with an ordinary grain drill, each 30 meters. This required only one-third kg seed per ha and one man could seed 80 ha per day. The planting was not to be grazed for 2 or 3 years to help the young plants become established, make seed, and spread. Stewart (1938) recommended drilling weedy land in strips across the prevailing wind, to cover one-fifth to one-third of the total area, to hold cost down. Stewart et al. (1939) thought plowing too expensive in seedbed preparation except on sites capable of yielding a crop adequate to mow for hay.

Stevenson and White (1939) compared Fairway wheatgrass with the Standard Type (*desertorum*-now called crested). Fairway (*A. cristatum*) yielded a little more forage, and, after 6 years, about 25 percent more root fiber. They recommended *cristatum* for forage production throughout the dryland areas of Western Canada.

Excitement over crested wheatgrass began in the Northern Plains in the 1920's and spread rather rapidly into Montana and Southern Canada. Not until the latter part of the 1930's was the discovery made that its range of adaptation included also the Intermountain Region and the higher valleys farther south. The Grazing Service (1941) discussed range seeding and include a variety of methods on arid land. One illustration shows Civilian Conservation Corps boys pushing hand garden planters through the native vegetation. Yet they claimed promising results.

It is now a matter of history that crested wheatgrass gave range seeding in the sagebrush ecosystem a tremendous shot in the arm. Hull and Klomp (1966) wrote that crested was the first successful species seeded in the sagebrush-grass type in Southern Idaho, and that it had continued to be the best adapted species.

Other Introductions

Other introduced grasses that have played an important part in seeding in the sagebrush ecosystem include tall wheatgrass (*Agropyron elongatum*) intermediate wheatgrass (*A. intermedium*), pubescent wheatgrass (*A. trichophorum*), Siberian wheatgrass (*A. sibiricum*), and Russian wildrye (*Elymus junceus*). However, all of them combined are of less importance to arid range than crested wheatgrass. Tall wheatgrass, much used in seeding trials during the 1930's and 1940's, has very large seeds and excellent seedling vigor. However, it has not established itself as an important species for arid range. It has excellent salt tolerance.

Kochia prostrata was first introduced in 1959 from the USSR, but was apparently lost after having been planted at the Western Regional Plant Introduction station at Pullman, Washington. A second introduction was made in 1965 and grown at Logan, Utah, from where it has been distributed to several interested agencies. Preliminary tests are quite favorable, but much more needs to be learned about it before its value for the sagebrush ecosystem can be ascertained. Reports during the 1930's from the USSR indicate that it is important there.

Requirements for Successful Seeding

Robertson and Pearse (1946) listed 5 requirements for successful seeding; Stewart (1947) specified 8

requirements, covering approximately the same ground. These requirements remain as valid today as 40 years ago, and with slight modification will be discussed next in this review.

Choice of Sites

Within the sagebrush ecosystem the choice of sites is relatively easy. An almost infallible rule is; the bigger the sage, the better the site. Kearney et al. (1914) verified that vigor of sage is a good index of land suitability for crop production. Also, abandoned dryfarm land (earlier vigorous sage) is excellent for seeding to grass (Hanson 1928, Short 1943, Stoddart 1946a). As a rule, seed the best land first; it has the highest potential for success (Plummer et al. 1943, Hull and Pearse 1943, Robertson and Pearse 1943). As more experience is accumulated, less favorable sites may be attempted.

Miller (1956) reported that when big sage was found in association with Canby bluegrass *(Poa canbyi)*, needle-and-thread (*Stipa comata)*, fleabane (*Erigeron sp.*), phlox (*P. austromontana* and *P. longifolia*), lupine (*L. latifloris*), wild cabbage (*Caulonthus crassicaulis*), giant gilia (*Leptodactylon pungens*), rubber rabbitbrush (*Chrysothamnus nauseosus spp. consimilis*), death camas (*Zigadenus paniculatus*), and streambank wheatgrass the site was good for seeding. But when sage grew in association with greasewood (*Sarcobatus vermiculatus*), bud sage (*Artemisia spinescens*), white sage (*Ceratoides lanata*), poverty weed (*Iva axillaris*), shadscale (*Atriplex confertifolia*), black sage (*Artemisia nova*), little rabbitbrush (*Chrysothamnus viscidiflorus ssp. puberulus* and *elegans*) hopsage (*Grayia spinosa*), wild onion (*Allium accuminatum*), or giant wildrye (*Elymus cinereus*) the site was not good for seeding.

Annual precipitation is a strictly limiting factor in range seeding. Stewart (1947) and Cornelius and Talbot (1955) specified 23 cm as the lower limit for the Intermountain Region and Northeastern California, respectively. Reynolds and Springfield (1953) reported that on sagebrush ranges in the Southwest, seedings have generally failed if precipitation was below 30 cm. (the seasonal distribution of the precipitation is also important). They advised against attempting to seed slopes in excess of 25 to 30 percent, except for watershed protection. Cornelius and Talbot recommended avoiding slopes greater than 30 percent, as well as rocky or highly erodable soils.

Salinity in the soil indicates possible unsuitability for seeding. Haas et al. (1962) reported that for each increase of 0.10 percent in soluble salts the yield of crested wheatgrass was decreased 65 to 83 kg per ha.

Halliday (1957) conducted studies in Southern Nevada, in an area transitional between northern and southern desert shrub, in a hop sage-black sage association. Annual precipitation averaged 16 cm per year, but was highly variable. In this very difficult situation many species were tried but seeding was not successful.

Stevens et al. (1974) classified sites in big and black sage on the basis of annual precipitation, May precipitation, percent rock in the subsoil, and slope. They obtained positive correlations between the above factors and yield from a mixture of 4 species. They could then identify 5 broad groups of differing site potential.

There is a lower limit beyond which seeding, though it may be successful, cannot be profitable. It is one thing to establish grass on a very dry site, but quite another to maintain the stand under any acceptable degree of grazing use. As the lower limit of precipitation for successful seeding is approached, management of the site for grazing becomes increasingly restricted.

Before seeding, the land manager should thoroughly and very realistically determine that the site has the potential to justify what the operation will cost. He should know every step of the process, including the time the seeded range must be withheld from grazing use, and how he will meet the feed shortage this will create.

The economics of seeding will not be reviewed here, but the following references will assist the land manager in making some important decisions; (Pearse and Hull 1943, Stewart 1949, Meik 1950, Plath 1954, Pingrey and Dortignac 1959, Lloyd and Cook 1960, Caton et al. 1960, Gardner 1961, Myles 1962, Nielsen 1967, and Gee 1973). In order to correct for the steady march of inflation, the land manager must adjust all dollar values to conform to the circumstances under which he will be working.

Reduction of Competition

Reduction of competition, treated in depth in 4 previous papers, will not be considered here. But 3 references will be cited to emphasize its importance for successful range seeding. Robertson and Pearse (1946) in Nevada noted that removal of cheatgrass (*Bromus tectorum*) or sagebrush may delay as much as 7 weeks depletion of soil moisture in the top 30 cm of soil. Cook (1958) in Utah showed that for each percent increase in sagebrush there was a decrease of 9.6 kg per ha in forage produced. Sturges (1973) in Wyoming found that spraying sage with 2,4-D on June 24 reduced loss of soil moisture from the top 183 cm of soil by 24 percent by August 4, the difference lasting to September 30.

Selection of Adapted Species

Selection of adapted species involves two processes. First, the identification of species adapted to the soils and climate of the sagebrush ecosystem. Species native to the area are obviously adapted; introductions must be tested for adaptation. Second, the selection, from among those judged to be adapted, of the ones best able to meet man's requirement. More than just yield, man needs forage acceptable to the grazing animal, and available at the time of greatest need. The species must be capable of establishment by justifiable means. It must be tolerant of the required grazing use. It must be a good seed producer, so that seed will be available as needed. It must either be sufficiently long lived so that seeding will not be a frequently recurring expense, or capable of easy regeneration by management practices compatible with man's needs. In the sagebrush ecosystem it should provide spring grazing,

because this is most often the period of greatest feed shortage.

In view of the shot-in-the-arm that crested wheatgrass gave range seeding in the sagebrush ecosystem, one might think that the search for the ideal species had ended. And indeed, crested is in many respects the ideal species. But crested wheatgrass is not always the highest yielder, and it has some other limitations, so the search continues. Forty five references were found in the literature, in which crested wheatgrass was compared directly, in one way or another, with one or more other grasses adapted to the sagebrush ecosystem. These studies have been arranged in Tables 1, 2, and 3, according to whether crested was superior, not different, or inferior to species with which it was compared. Table 1 lists 25 species (3 are listed twice) in which crested wheatgrass is superior, in one way or another, to one or more species with which it was directly compared. In table 2, 22 studies are reported in which there was no appreciable difference, and in Table 3 crested wheatgrass is reported to be inferior to one or more species with which it is compared in 23 studies (one is listed twice). These data suggest that, depending on the circumstances, crested has about an equal chance of being superior, no different, or inferior to some other species.

Because stand establishment is essential to productivity, and yield is a measure of productivity, the data in tables 1, 2, and 3 that relate to stand and yield have been rearranged in table 4, by species. The units in the table represent numbers of studies. For example, crested was superior to intermediate in 5 studies in both yield and stand,

but inferior to intermediate in 5 studies in yield and in 6 studies in stand. Considering all species, crested was superior in yield in 20 studies and inferior in yield in 17 studies. But look, for example, at big bluegrass (*Poa ampla*). Crested is not superior to it in a single study, but is inferior in 3. Obviously, the data require further analysis if meaningful conclusions are to be reached. In Table 5 the data of Table 4 have been broken out into regions. Note the general inferiority of crested to both intermediate and pubescent in Nevada, the reverse in Southern Idaho and Utah, and the superiority of big blue in the West Coast states. Bug blue was so impressive in tests at Burns, Oregon, that Sneva and Hyder (1965) thought that except for its weak root system it could replace crested wheatgrass there. (In the Spring, when the ground is wet, grazing animals will sometimes pull big blue plants out of the ground. However, Hafenrichter et al. (1968) claim this is not a problem

Table 1. Studies in which crested wheatgrass was judged to be superior to some other species with which it was compared.

Other species	Basis	Reference
Smooth brome, slender wheatgrass	Root fiber production	Stevenson & White (1941)
Smooth brome, slender wheatgrass	Low temperature germination	White & Horner (1943)
Eleven other range grasses	Survival	Short (1943)
Bluestem	Competition 1/	Rummell (1946)
Smooth brome	Yield	Stewart (1947)
Intermediate, pubescent, slender	yield 2/	Stewart (1950)
Russian wildrye	Winter seedling survival 3/	Frischknecht (1951)
Intermediate, pubescent	Stand	Fendley (1953)
Intermediate, pubescent, fairway	Drought resistance	Cornelius & Talbot (1955)
Whitmar beardless	Seedling vigor	Cooper & Hyder (1958)
Intermediate	Stand	Cook (1958)
Intermediate, pubescent, R. wildrye	Yield	Douglas et al. (1960)
Big blue	Stand	Douglas et al. (1960)
Russian wildrye 4/	Stand	Kilcher (1961)
Amur intermediate, Primar slender 5/	Stand at 4 years	Lang (1962)
Intermediate	Survival	Campbell (1963)
Intermediate, bluebunch	Yield, longevity	Hull & Holmgren (1964)
Intermediate, pubescent, R. wildrye	Yield, stand 6/	Cook (1965)
Whitmar beardless	Stand	Robocker et al. (1965)
Pubescent, siberian, fairway, R. wildrye	Yield	Hull & Klomp (1966)
Intermediate, bluebunch, big blue	Stand	Hull & Klomp (1966)
Pubescent	Yield	Cook et al. (1967)
Bluebunch	Survival, spread	Hull (1971)
Fairway	Yield 7/	Hull (1972)
Fairway	Yield	Klomp & Hull (1972)
Russian wildrye	Yield	Bleak et al. (1974)
Intermediate, pubescent	Yield (dry site)	Hull (1974)
Bluebunch, beardless	Stand (dry site)	Hull (1974)

1/ Greenhouse study. 2/ Intermediate was superior to pubescent and slender. 3/ Seeded early and late fall, and spring. 4/ Russian wildrye is sensitive to poor cultural practices; slow seedling growth. 5/ Using Wyoming range seeder. 6/ On Halogeton infested land, whether sprayed or not. 7/ Long-time records from 13 locations in Southern Idaho.

Table 2. Studies in which crested wheatgrass was judged not to be markedly different from some other species with which it was compared.

Other species	Basis	Reference
Smooth brome, slender	Seedling winter survival	White & Horner (1943)
Bluebunch, beardless	Stand	Hull & Stewart (1948)
Intermediate, pubescent	Stand	Cook & Stoddart (1951)
Beardless	Stand	Cornelius (1951)
Many species	1/	Halliday (1957)
Pubescent	Stand	Cook (1958)
Fairway, beardless	Yield 2/	Cooper & Hyder (1958)
Intermediate	Stand	Kilcher (1961)
Amur intermediate, Primar slender	Stand 3/	Lang (1962)
Intermediate	Yield 4/	Cook & Lewis (1963)
Intermediate	Stand	Cook (1965)
Fairway, Whitmar beardless	Yield	Sneva & Hyder (1965)
Siberian	Stand (20 cm rainfall)	Robocker et al. (1965)
Siberian, fairway, pubescent, bluebunch	Yield (7-year)	Hull & Klomp (1966)
Intermediate, pubescent	Yield (Dixie, Idaho)	Hull & Klomp (1966)
Pubescent	Yield (9th yr)	Cook et al. (1967)
Topar pubescent	Yield, stand	Eckert & Evans (1967)
Intermediate, pubescent	Yield, stand	Hull (1971)
Siberian	Yield	Klomp & Hull (1972)
Siberian	Snow mold resistance	Bleak & Keller (1973b)
Amur intermediate	Stand 5/	Eckert (1974)
Big blue	Yield, earliness	Rittenhouse & Sneva (1977)

1/ Very tough site; no species did well; average precipitation 16 cm. 2/5-year average. 3/ Very well prepared seedbed. 4/ After spraying for sage control. 5/ On atrazine fallow, using a deep furrow rangeland drill with disk openers.

Table 3. Studies in which crested wheatgrass was judged to be inferior to some other species with which it was compared.

Other species	Basis	Reference
Alfalfa	Yield 1/	Stewart (1950)
Intermediate	Stand	Cornelius (1951)
Big blue	Yield	Cornelius & Talbot (1955)
Siberian, big blue	Yield	Cooper & Hyder (1958)
Siberian, Whitmar beardless, bluebunch	Yield 2/	Douglas et al. (1960)
Sherman big blue	Earliness	Douglas et al. (1960)
Mixture of native species	Yield, erosion control 3/	McWilliams et al. (1960)
Russian wildrye, western	Seed yield, response to N	Birch & Lang (1961)
Russian wildrye	Yield, stand	Campbell (1963)
Intermediate	Yield 4/	Cook & Lewis (1963)
Big blue	Yield	Sneva & Hyder (1965)
Russian wildrye	Yield (Blackfoot) 5/	Hull & Klomp (1966)
Intermediate, pubescent, western	Yield	Robertson et al. (1966)
Intermediate, pubescent	Stand	Cook et al. (1967)
Amur intermediate	Yield, stand 6/	Eckert & Evans (1967)
Amur intermediate	Stand	Young et al. (1969)
Intermediate, smooth brome	Depth and speed of emergence	McDonough & Matthews (1970)
Greenar intermediate, Sherman big blue	Stand (fall drilling) 7/	Nelson et al. (1970)
Intermediate, pubescent	Stand	Eckert et al. (1972)
Fairway	Spread	Hull (1972)
Intermediate	Resistance to snow mold	Bleak & Keller (1973b)
Intermediate, pubescent	Yield (favorable sites)	Hull (1974)
Intermediate, pubescent	Yield	Marquis et al. (1974)
Russian wildrye	Fall pasture	Kilcher et al. (1976)

1/ Average of 4 sites; 28 cm annual precipitation. 2/ Siberian also earlier establishment, green 10 days longer. 3/ Sixteen-year study; either season-long or spring and winter grazing. 4/ On non-sprayed range with heavy sage re-invasion. 5/ Ten years yield data. 6/ Following atrazine fallow to control cheatgrass. 7/ Counts made the following July; by November the differences were largely gone. 8/ Based on 6 areas in Southern Idaho.

Table 4. How crested wheatgrass compared with other species, in stand and yield, by number of studies.

	Crested wheatgrass was, by number of studies					
	Superior		Not different		Inferior	
Other species	Yield	Stand	Yield	Stand	Yield	Stand
Intermediate	5	5	3	6	5	6
Pubescent	6	2	5	4	3	2
Fairway	3	-	3	-	-	-
Siberian	1	-	2	1	2	-
Russian wildrye	4	2	-	-	2	1
Bluebunch	1	2	1	1	1	-
Beardless	-	2	2	2	1	-
Big blue	-	2	1	-	3	1
Totals for yield	20		17		17	
Totals for stand		15		14		10

when plants are 2 or more years old, on properly managed range. They reported Sherman big blue to be the top yielder from 130 accessions of big blue tested.)

Hafenrichter et al. (1949, 1968), and Schwendiman (1956) have assembled much valuable information on species of grasses (and legumes) applicable to much of the sagebrush ecosystem. Their reports are particularly useful in documenting characteristics of a number of arid range grass selections made by the Soil Conservation Service, and now fairly widely distributed.

An attempt was made in Table 6 to describe the major arid range grass species in terms of several important characteristics. In doing this, it might have been satisfactory to list crested, fairway, and siberian as simply the crested wheatgrass complex, because they are so similar. In like manner bluebunch and beardless wheatgrasses are being generally regarded, now, as one species (Chapman and Perry 1973, Harris and Goebel 1976). Also, intermediate and pubescent wheatgrasses are of questionable specific distinction. There is room for disagreement over some of the values assigned in Table 6. Seedling vigor of the crested group is rated good because these species invade into adjacent lands, even into seeded stands of some other species. The native wheatgrasses do not ordinarily do this (Stark et al. 1946), although Robertson (1971) noted that bluebunch wheatgrass was establishing itself in parts of a protected sagebrush-grass range in Nevada. Heinrichs and Bolton (1950) found crested to be a very vigorous competitor against all native perennial forage species. Intermiediate and pubescent are rated medium in drought resistance, longevity, and winter hardiness because they are short-lived on the Northern Great Plains, as well as on the Central Plains (Hervey and Everson 1956). Note that Russian wildrye is inferior to the crested group only in seedling vigor and seed production, though these are two very important characteristics. Good seedbed preparation is much more essential to the establishment of Russian wildrye than for crested wheatgrass. As partial compensation, Russian wildrye retains good forage quality throughout the season (Heinrichs and Carson 1956) and, unliked crested (which goes into a heat-induced summer dormancy) Russian wildrye comes out of drought-induced dormancy, and greens up, following every good summer shower. But the seedling vigor of Russian wildrye is low, and must be improved if this species is to become widely used in the sagebrush ecosystem. (Should grass breeders be able to develop a strain of Russian wildrye with seedling vigor equal to that of crested wheatgrass, Russian wildrye would assume tremendous importance in range seeding. Canadian seed growers would certainly meet the increased demand for seed.) Those species marked "unsure" in seed production are not necessarily poor seed producers; they have some highly specific requirements which must be understood and met to obtain good seed yields.

Reference has been made to the apparent superiority of both intermediate and pubescent wheatgrasses, over crested wheatgrass, in Nevada. But in conversation with Ray Evans at the Symposium, it appears that this advantage is now in question. The reviewer believes that the experimental studies presented in Tables 1 through 5 do not give a correct picture of the relative merits of the crested group compared with native *Agropyrons*. Experimental plots are generally established under more favorable conditions of seedbed preparation and seeding than can be applied when very large areas are being seeded. Further, once a good stand is obtained, yields are generally by clipping after there has been considerable growth. This escapes the heavy drain on root reserves imposed by early spring grazing, a practice to which the crested group is admirably adapted, and to which the native *Agropyrons* are particularly vulnerable.

Table 5. Regionalization of the data in table 4 for stand and yield.

Area and other species	Crested wheatgrass was, by number of studies					
	Superior		Not different		Inferior	
	Yield	Stand	Yield	Stand	Yield	Stand
Nevada (6 studies)						
Intermediate	-	1	-	1	2	3
Pubescent	-	1	1	1	1	1
Totals	-	2	1	2	3	4
Southern Idaho (11 studies)						
Intermediate	4	1	2	1	1	-
Pubescent	4	-	3	1	1	-
Fairway	3	-	1	-	-	-
Siberian	1	-	2	-	1	-
Russian wildrye	2	-	-	-	1	-
Bluebunch	1	2	1	1	1	-
Beardless	-	1	-	1	1	-
Big blue	-	2	-	-	-	-
Totals	15	6	9	4	6	-
Utah (7 studies)						
Intermediate	1	2	1	2	1	1
Pubescent	2	1	1	2	-	1
Russian wildrye	2	1	-	-	-	-
Totals	5	4	2	4	1	2
West coast states (7 studies)						
Intermediate	-	-	-	-	-	2
Fairway	-	-	2	-	-	-
Siberian	-	-	-	1	1	-
Beardless	-	1	2	1	-	-
Big blue	-	-	1	-	3	1
Totals	-	1	5	2	4	3
Summer rainfall (5 studies)						
Intermediate	-	1	-	2	1	-
Pubescent	-	-	-	-	1	-
Russian wildrye	-	1	-	-	1	1
Totals	-	2	-	2	3	1
TOTAL ALL YIELDS	20		17		17	
TOTAL ALL STANDS		15		14		10

Table 6. Important characteristics of 9 major species adapted for seeding in the sagebrush ecosystem.

Species	Root reserves	Tolerance to grazing	Earliness	Drought resistance	Winter hardiness	Seedling vigor	Seed production	Forage quality		Longevity	Habit
								Young	Mature		
Crested	high	high	early	high	high	good	good	good	poor	long	bunch
Fairway	high	high	early	high	high	good	good	good	poor	long	bunch
Siberian	high	high	early	high	high	good	good	good	poor	long	bunch
Bluebunch	low	low	medium	high	high	low	good 1/	good	poor	long	bunch
Beardless	low	low	medium	high	high	low	good 1/	good	poor	long	bunch
Intermediate	medium	medium	medium	medium	medium	high	unsure	good	fair	medium	spreads
Pubescent	medium	medium	medium	medium	medium	high	unsure	good	fair	medium	spreads
R. wildrye	high	high	early	high	high	low	unsure	good	good	long	bunch
Big blue	medium	medium	early	high	high	2/	good	good	good	long	bunch

1/ But seed shatters freely when ripe (Hafenrichter et al. 1968).

2/ Good for a very small seeded grass. Requires very shallow covering in late fall, winter, or early spring (Hafenrichter et al. 1968). Not competitive, should be seeded alone (Hedrick et al. 1964).

From Table 4, crested is superior to bluebunch and beardless in stand establishment in two studies, but inferior in none. Thus, even in experimental plot studies, crested was more successful in giving good stands. This advantage appears to be further established by the general failure of range seeding prior to the use of crested wheatgrass. And even if a good stand of the natives were obtained, crested still has the advantage of being able to tolerate heavy spring use. Thus, the native *Agropyrons*, bluebunch and beardless, are at a disadvantage, compared with the crested group, on two counts, 1) low root reserves, which are related to ability to tolerate early spring grazing use, and 2) less seedling vigor. These limitations of the natives will have to be removed if they are to assume an important role in future range improvement. In like manner, the potential of big bluegrass warrants a thorough investigation of its root system.

Animal Gain Studies

The ultimate test of a range grass is its production under grazing. Williams (1941) and Williams and Post (1945) report in Montana studies the superiority of crested wheatgrass over smooth brome or native range. Ten years results (1945) showed animal gains of 41.4, 61.0, and 88.1 kg per ha for native range, smooth brome, and crested wheatgrass, respectively. Williams et al. (1942) reported greater gains from wintering steers on fairway than on crested hay, and recommended cutting crested before bloom, to avoid loss of palatability.

Smoliak (1968) found Russian wildrye slightly superior to crested, and both much better than native range. Gains per ha were 29.5, 24.3, and 9.3 kg, respectively. Smoliak and Glen (1974) reported that continuous grazing on Russian wildrye for 6 months yielded 103.8 kg beef per ha, in contrast to 17.9 kg per ha from native range. They recommended crested for early spring use, native range for summer, and Russian wildrye for fall grazing. This system increased beef production from 55 to 66 percent, and reduced hectares per animal unit from 11.3 to 6.5. The seeded grasses were thriftier when grazed in rotation rather than free choice.

Currie (1969a) found big bluegrass superior to crested wheatgrass in Colorado. Beef gains from big blue, crested, intermediate, and Russian wildrye were 87.8, 66.4, 58.6, and 56.7 kg per ha, respectively. Currie (1969b) reported native range only slightly inferior to crested or Russian wildrye for spring grazing, but big blue clearly superior to native range for fall grazing. Currie (1975) recommended grazing big blue in the fall, to supplement native range.

Murray and Klemmedson (1968) reported gains of beef cattle, on cheatgrass at Saylor Creek in the Snake River Valley, of .77, .93, .63, and .37 kg per head per day for early spring, late spring, summer, and fall grazing, respectively. They offered as a comparison cattle gains on crested whatgrass at Benmore, Utah, of 1.22, .85, .45, and .10 kg per head, respectively, for the same periods. (If this is a valid comparison, fall gains on cheatgrass were particularly impressive. But Cook and Harris (1952) reported crested wheatgrass increasingly superior to cheatgrass in nutritional value as the season advanced). Murray (1971) reported gains of 14.5 kg per ha from cheatgrass and 13.3 from native bunchgrass range. The difference was not significant.

Frischknecht et al. (1953) reported on a rather comprehensive study conducted at Benmore in Central Utah in a 30 cm rainfall area. Under 50 to 60 days spring grazing at light (50 percent), moderate (65 percent), or heavy (80 percent) utilization adult cattle gained between .92 and 1.49 kg per day, the total gain per ha being from 5 to 10 times adjacent unimproved native range. In addition, crested pastures were ready to graze 2 to 3 weeks ahead of native range, better meeting a period of critical feed shortage. Reynolds and Springfield (1953) found that yield of crested varied roughly with precipitation, and ranged from 986 to 1479 kg air-dry grass per ha in the sagebrush zone of the Southwest.

Cook (1966) rated Russian wildrye and intermediate wheatgrass best for late spring use, and crested and pubescent wheatgrasses better for early spring use. Cook and Harris (1968) reported Russian wildrye and intermediate wheatgrass more nutritious in late spring than crested or native range, this difference explaining greater gains on the former.

Robertson et al. (1970) reported a study in which sagebrush and rabbitbrush were plowed out and crested wheatgrass broadcast in a single pass over the land in 1944. Grazing started in 1947. Cattle gained 1.1 kg per day, and 26 kg per ha. At 65 percent utilization, 1.8 ha produced 1 AUM.

Gomm (1969) found that big blue produced the most TDN per ha and gains as high as any other species when grazed by sheep. But intermediate wheatgrass was the most palatable species.

Lodge (1971) in Canada, obtained good beef gains grazing Russian wildrye in early May, mid May, or early June, for 28-day periods, or from early May to mid summer for 102 days. June grazing was recommended.

Springfield and Reynolds (1951) reported that cattle selected a wide variety of species when offered free choice. Their choice was influenced by time of day, changing weather, choices available to them, and other factors. They found succulence of the forage an important selective factor in late summer. Cornelius (1950) in Northeastern California reported that in September big blue contained 24 percent moisture while crested wheatgrass had 14 percent, reflecting relative succulence. Gomm (1969) found that sheep discriminated for or against individual plants within a species. Horton and Weissert (1970) concluded that crested would tolerate 60 to 70 percent utilization on Diamond Fork in the upper sage zone receiving 43 to 48 cm annual precipitation.

Sneva (1972) reported on the chemical renovation of a depleted native range, to remove brush. Native grasses present were bluebunch, *Koeleria cristata*, Idaho fescue (*Festuca idahoensis*), squirreltail (*Sitanion hystrix*), and needle-and-thread. Before treatment the pasture produced 254 kg forage per ha and after treatment 763 kg. During the first 10 years brush invasion was slow. Grazing had not been allowed until seed maturity.

The data on grazing trials indicate a general superiority of crested wheatgrass for early spring grazing, and of Russian wildrye and big bluegrass for summer or fall grazing. Intermediate and pubescent wheatgrasses are not ready to graze as early as crested wheatgrass. Their area of best adaptation is probably above the sagebrush zone, in the aspen or oak brush zones, where precipitation is more favorable. This is also the area of best adaptation of smooth bromegrass.

Browse Plants

Browse plants have been of interest for many years and a considerable body of information has accumulated concerning them (Bidwell and Wooton 1925, Dayton 1931, Plumemr et al. 1966, 1968). Robertson (1947a) reported that maximum yields of forage were obtained where sagebrush was killed but left on the ground because it hastened snowmelt and advanced range readiness about 2 weeks. Presumably browse with better forage quality than sage would do the same thing without having to be killed. However, the sagebrush ecosystem has been considered to be a grass range until recently, and little effort has been made to seed browse. (The exception is winter range for deer.) A. D. Wilson (1969) reported that goats eat more browse than sheep, which eat more browse than cattle. Cattle are, therefore, not strongly browsing animals. Wilson also considered browse a protein supplement for cattle during seasons when grass is dry (and very protein deficient). Springfield and Housley (1952) rated four-wing saltbush (*Atriplex canescens*) (highly regarded as a component of winter range for cattle) equal to alfalfa hay in quality. Plummer et al. (1966) predicted that four-wing saltbush would be increasingly used to improve both game and livestock ranges in Utah and the West. Van Epps et al. (1971) advocated seeding browse with grass on the more unfavorable sites.

Van Epps (1975) compared 20 sources of four-wing saltbush seeded in July 1970, at Ephraim, Utah. Following the winter of 1972-1973, survival ranged from zero to 100 percent, for lots collected in different parts of the West. Survival could not be predicted by place of origin of the seed. Springfield (1968) noting great variability between seed lots of different origins, found that seed viability remained good for 6 years, and that storage at 23 to 35°C was as good as in a refrigerator.

Van Epps and McKell (1977) seeded *Atriplex canescens*, *Chrysothamnus nauseosus*, *Ceratoides lanata*, *Artemisia tridentata*, and *Purshia tridentata* into adjusted stands of established crested wheatgrass. They found that for direct seeding, the rows of crested wheatgrass should be at least 100 cm apart. They also transplanted browse seedlings.

Nemati (1977a) compared palatability of four-wing saltbush with *Kochia prostrata* and *Artemisia herba-alba*, two species native to Iran. *Kochia* was highest, four-wing next, and *herba alba* lowest. (The comparison was based on feeding sheep fresh cuttings for about a year.) Nemati stated that in Iran it had long been known that *Kochia* had a higher forage value, and was more paltable, than *herba-alba*. Nemati (1977b) thought range seeding possible in the 200-400 mm sub-steppic zone in Iran, but not in the steppic zone, except where precipitation was near 200 mm and soils were favorable. Nemati (1977c) reported transplanting four-wing saltbush, *Atriplex lentiformis* and *Atriplex halimus*. Four-wing gave the best survival, the best time to transplant being October, using seedlings 20 to 30 cm tall. The experimental areas received 170 to 205 mm annual precipitation. Plants were spaced 3 m apart in rows 4 m apart, and yields tripled.

Nord (1959) found that when stems of antelope bitterbrush (*Purshia tridentata*) touch the ground, they root, a process called stem layering. He also noted that desert bitterbrush (*Purshia glandulosa*) sprouts profusely following fire. He observed evidence of natural hybridization between antelope and desert bitterbrush, wherever their ranges overlap. He claimed some bitterbrush plants live 160 years. Woodmansee and Potter (1970) reported widespread suckering of four-wing saltbush in New Mexico. In one study 70 percent of the plants had arisen by suckering, some as much as 2.4 m from the parent plant. In another study 96 percent of the plants had arisen by suckering.

Giunta et al. (1975) seeded into cheatgrass using a browse scalper-seeder. Fourwing saltbush appeared less affected by cheatgrass competition than antelope sagebrush, Nevada ephedra (*Ephedra nevadensis*) or cliffrose (*Cowania mexicana stansburianna*). All shrubs gave satisfactory stands.

Britton and Sneva (1977), in a two-year study of *Kochia prostrata*, found a green accession more productive than a gray one. Protein content remained at about 6 percent all winter. Oxalates were lowest in March (.49 percent) and highest in July (.98 percent) when water stress was greatest. (These amounts are not dangerous; note that *Halogeton* (Cook and Stoddart 1953) may have oxalates as high as 28 percent.)

Williams et al. (1976) analyzed 13 introduced species of *Astragalus* for NO_3 content. Only *A. falcatus* (Sicklepod milkvetch) was high. Forage from it actually poisoned sheep, cattle, and 1-week-old chicks. The NO_3 content of *A. falcatus* was high from seedling emergence in May until mid September.

The Russians have had much experience with *Kochia prostrata*. Andreev (1938) claimed *Artemisia sublessingiana* and *Kochia prostrata* superior to all other steppe plants and grasses. Popovic (1939) reported *K. prostrata* the most resistant to fire in the *Artemisia taurica-Festuca sulcata-Agropyron pectiniforme* association. Andreev and Saljukov (1938) report *K. prostrata* superior to *Artemisia sublessingiana* as a forage plant, partly becuase it does not drop its leaves in summer. Selekcija (1936) noted that *K. prostrata* seed is short-lived. He suggested drying the seeds to 3 percent moisture, to extend their viability. Begucev (1940) claimed surface sowing much superior to covering the seed, that in no case should the seeds be covered more than 0.5 cm. Use of a nurse crop with *K. prostrata* was disasterous. It should be sown in the fall, at about 3.5 kg good seed per ha. Terenozkin (1934) reported that as a result of overgrazing the steppe was changing from *Artemisia*-grass type to *Artemisia* type to annual ephemeral type. (He could have been writing about the sagebrush ecosystem.) He recommended crested, and siberian wheatgrasses, *Festuca sulcata*,

Medicago falcata, and *K. prostrata*, for improvement.

Plummer et al. (1955) recommended Antelope bitterbrush, fourwing saltbush, or winterfat (white sage - *Ceratoides lanata*) when it was desired to add browse to crested wheatgrass seedings.

Frischknecht (1963) observed that crested wheatgrass was more productive when in close association with rubber rabbitbrush (*Chrysothamnus nauseosus nauseosus*) than with sagebrush. He explained this by differences in time of growth. This should alert range men to search for browse plants that exhibit the rabbitbrush type of compatability with crested wheatgrass.

Moghaddam (1977) has called our attention to *Reseda lutea*, a native Iranian plant found on ranges there having annual precipitation from 100 to 400 mm. He reports it to be earlier than *Stipa barbata*, *Artemisia herba-alba*, or *Salsola rigida;* to posses good heat and cold tolerance; and to be a good seed producer, of seed having good germination.

Many other species of browse merit much fuller consideration for use with grasses on sagebrush ecosystem rangelands.

Seeding

After the land manager has chosen a site needing seeding and having the potential to justify the cost, and has destroyed the competing vegetation, he is ready to seed. Range grasses are like all other plants; they respond favorably to good cultural practices. But the returns from rangeland, in animal gains are not sufficient to justify land preparation practices that are profitable on arable land. If one pass over the land can destroy competing vegetation and plant grass, that procedure will be followed. A number of years ago, in the fall, the reviewer approached a large ranch in Eastern Utah. He stopped to talk to the operator of a caterpillar tractor, pulling a wheatland plow which was killing sage. Attached to the plow was a grain drill, bouncing over the sage, seeding crested wheatgrass. This operation, begun in August, would continue until snowed out. The drill was covering most of the seed. Clearly then, the land manager was operating on the expectation that precipitation sufficient to germinate the seed would not come so early that the seedlings could later perish from drought before late fall moisture was received. If his expectation proved true, his seeding either emerged in late fall or very early spring, and, depending on subsequent weather, could have been highly successful.

Success in range seeding depends on availability of moisture to the seed and seedling, after the planting operation has been completed, and when temperatures are favorable for growth. Because we cannot forecast what these relationships will be, seeding can only be specified in a statistical sense; that is, the procedure most likely to succeed, or least likely to fail. This is the procedure we arrive at as the sum total of our accumulated experience.

General treatments on range seeding have been prepared by C. P. Wilson (1931), Stevenson et al. (1937), Walker and Bracken (1938), Stewart et al. (1939) Clarke and Heinrichs (1941), Flory and Marshall (1942), Franzke and Hume (1942), Short (1943), Stark et al. (1946), Stoddart (1946a), Hull et al. (1950), Barnes et al. (1952), Reynolds and Springfield (1953), Plummer et al. (1955), Cornelius and Talbot (1955), Hull et al. (1958), Valentine et al. (1963). A comprehensive treatment of range seeding trials in Colorado, identifying numerous accessions of important species, was prepared by McGinnies et al. (1963).

Seed Treatment

Arid range grass seeds are slow to germinate, and the period between planting and seedling emergence is always one of anxiety for the land manager. Any means of speeding up germination and seedling emergence should eliminate some of the risk in seeding. Frischknecht (1959) applied vernalization treatments to crested, pubescent, tall, and fairway wheatgrasses, Indian ricegrass (*Oryzopsis hymenoides*), and Great Basin (*Giant*) and Russian wildrye grasses. When spring-planted, vernalized seeds developed much like plants from fall seedings. He noted that seedlings from vernalized seeds emerged a few days ahead of those from non-treated seeds. Keller and Bleak (1968) applied pre-planting treatments to seeds of crested wheatgrass and noted some advantage in time of seedling emergence. Wilson (1972) put seeds in moist soil for periods of 1 to 7 days and then germinated the seeds at 5°C, a realistic temperature for range seeding. As taking up soil moisture proceeded from 1 to 7 days, the time required for the seeds to reach 50 percent germination was shortened from 1.7 to 13.5 days, respectively, compared with control lots. Wilson's observations have tremendous significance for range seeding.

Kreitlow and Bleak (1964) reported the distribution of *Podosporiella verticilata*, a fungus capable of destroying range seedings, throughout the range of cheatgrass. Seed treatment with permitted fungicides offers good control.

Wilson and Harris (1968) demonstrated that seeds of crested wheatgrass containing 50.8 percent moisture would germinate in 5 days; that with 19.1 percent moisture (-130 atm. tension) ATP was synthesized; that with moisture as low as 11.1 percent (-880 atm. tension) there was some activity in the seeds, while there was none at 6.3 percent moisture (-2600 atm. tension).

Method of Seeding

Drilling is, almost without exception, the preferred method of range seeding. Drilling has two unique advantages over broadcasting: 1) it distributes the seed with rather remarkable uniformity, and 2) it provides uniform covering of the seed, to the desired depth (provided the seedbed is fairly uniform in topography). Further, in the process of drilling, seeds can be pressed into close contact with the soil, a very desirable relationship (Hyder et al. 1955, Hyder and Sneva 1956, McGinnies 1962). Broadcasting requires more seed to insure satisfactory distribution, and this adds to the cost of the operation. If the seed is broadcast onto very rough ground, soil sloughing will cover some to much of it. Cook (1958) reported good stands from broadcasting ahead of brush control. Broadcast seedings are more dependent upon favorable weather after planting than are drilled plantings.

Ordinary farm grain drills are most commonly used for seeding grass on rangelands. Stewart (1945, 1947) and Hull and Holmgren (1964) obtained better depth

control with a single disk than with a double disk drill. Most investigators who have used them recommend a deep furrow drill because it places the seed more favorable to soil moisture than the other drills. Deep furrow drills are particularly desirable for early fall plantings if they can place the seeds in moist soil, or where moisture, when it comes, will be available longer. This placement is less important for late fall plantings.

Over the years there have been several surges of interest in seeding arid range from the air (Wagner 1949, Killough 1950, Bleak and Hull 1958, Hull 1959). Hull et al. (1963) have written a comprehensive review of pellet seeding from the air. Whether the seeds are pelleted or naked, air seeding has not met with success, chiefly because the seeds are not covered; in addition, the process using pellets is very expensive.

Many machines have been built for seeding under specific conditions. The rangeland drill, with very sturdy construction and independently mounted seeding units, will successfully seed very rough terrain which an ordinary farm grain drill cannot handle (Hull et al. 1965). Booster (1961) and Hyder et al. (1961) report on the Oregon Press Seeder. This machine rolls over sage that is standing, but killed by herbicides, and plants grass. It is also very effective on sandy or light, fluffy soil. Because it rolls, with no digging parts, it is economical to operate. Several investigators (Becker et al. 1956, Lang 1962, Houston and Adams 1971, Wight and White 1974) have used interseeders. These are not well adapted to sagebrush ranges although Becker et al. (1956) found their interseeder worked well in sagebrush up to 60 cm in height. Hyder and Bement (1969) constructed a roller for use on deeply plowed land having good moisture. The roller left ridges 30 cm apart, between which the seed was planted. Although some technical difficulties were encountered, this machine has possibilities for use on the plains, but probably not in the sagebrush ecosystem.

One of the most common causes of failure in range seeding is a too loose seedbed (Stoddart 1946a) resulting in rapid drying out of the soil and too deep covering of the seed. Whenever land is to be seeded, following plowing for sage control, the plowing should be as shallow as possible. The soil should preferably be given a time to settle before seeding (if the job is to be done in one operation this is not possible). If the seeding is to be made in late fall, allowing the soil to settle before seeding is less important. Studies on methods of seeding have been summarized in Table 7.

Time of Seeding

Nearly all investigators who have made comparisons of spring and fall seeding prefer fall for several reasons: 1) there is a much longer period of time when seeding can be carried out; 2) seedlings normally emerge the following spring far ahead of the earliest possible spring planting, and are larger and better able to survive the coming summer drought; 3) when fall moisture is fairly sure, early fall seeding, ahead of fall moisture, results in fall emergence and still bigger seedlings the following year; 4) when other ranch or farm work is over, fall time has less demands upon it than spring time; 5) fall plantings are less subject to destruction by unfavorable weather during the year following seeding; and 6) late fall plantings, particularly, are less sensitive to depth of seed covering. In areas receiving summer precipitation (the southern and eastern fringes of the sagebrush ecosystem) spring or summer seeding may be highly successful. In northern Arizona and New Mexico summer is clearly the best time to seed. Studies on time of seeding have been summarized in Table 8.

Rate of Seeding

Rate of seeding will be influenced by the size and quality of the seed, the condition of the seedbed, the method of seeding, the amount of competing vegetation left on the ground at the time of seeding, and the threat of sage reinvasion. Under favorable conditions, using a drill, 4 to 6 kg per ha will be ample for crested wheatgrass seed of high viability. If weed control is an immediate objective, a higher rate should be used. When seeding is by broadcasting, or on a poorly prepared seedbed, the seeding rate should be increased 25 percent (Stewart 1947) or 50 percent (Hull et al. 1950). If sage reinvasion is a real threat, heavier seeding rates will tend to suppress sage seedlings, though it will not keep them out. Under good management, seedings tend to improve with time. Stewart (1945) observed that seedings which at first were thought to be failures, looked better after 3 or 4 years. Frequently those who have compared seeding rates report that higher seeding rates are immediately more productive, but that after several years they either had no advantage or were less productive than lower rates. It is quite possible that, in the long view, all seeding rates commonly used are too high. Rate of seeding studies are summarized in Table 9.

Depth of Seeding

Emergence of grass seedlings is usually inversely proportional to the depth at which the seed is placed, provided moisture is present. The ideal depth is the shallowest at which the seeds will have sufficient contact with moisture to insure seedling emergence. Some grasses are capable of emergence from greater depths than others, and the notion that this is proportional to size of seed is a poor guide. Crested wheatgrass is fairly sensitive to depth of seeding. Experience suggests 2 to 2.5 cm as ideal, with 3 or 4 cm maximum under most field conditions. In very heavy soils, and particularly those that form hard crusts, only shallow seedings are likely to succeed, while in sandy or very light soil deeper covering, up to 3 or 4 cm, may be desirable. To gain the benefits of deeper placement--having a more lasting contact with soil moisture--researchers have shown the advantage of seeding in the bottoms of furrows. (The deep furrow drill accomplishes this.) Late fall plantings are relatively insensitive to depth of seeding, so long as the seeds are covered, but not so deeply that the seedlings cannot reach the surface. Depth of seeding studies are summarized in Table 10.

Row Spacing

Closely spaced rows come to high productivity faster than widely spaced rows, but this early gain may not last long, and may in later years be reversed. Blaisdell (1949) found that closely spaced

Table 7. Methods of seeding.

Species	Methods compared	Recommendation	Reference
Crested and others	Drill & broadcast	Drill	Walker & Bracken (1938)
Crested	Drill & broadcast	Drill 1/	Clarke & Heinrichs (1941)
Crested	Drill & broadcast	No difference 2/	Hubbard (1949)
Crested, intermediate, pubescent	Drill & broadcast	Semi d f drill 3/	Cook & Stoddart (1951)
Crested	Drill & broadcast	Drill 4/	Reynolds & Springfield (1953)
Crested, intermediate, pubescent	Broadcast 5/	Ahead of plow	Cook (1958)
Nordan crested	Furrows 2½-10 cm deep	10 cm	McGinnies (1959)
Crested, pubescent, R. wildrye, big blue, Whitmar beardless	d f & broadcast	Deep furrow 6/	Douglas et al. (1960)
Crested, intermediate, R. wildrye, fairway, bluebunch, beardless	Drill & broadcast	Drill 7/	Hull & Holmgren (1964)
Crested, fairway	Drill & broadcast	Drill 8/	Hull & Klomp (1967)
Nordan crested, Luna pubescent, Greenar intermediate, Whitmar beardless, Sherman big blue	Drill & broadcast	Drill 9/	Nelson et al. (1970)
Crested	Ridges, level, furrows 2½, 5, and 10 cm deep	10/	Hull (1970)
Crested, fairway, siberian	16 methods	Deep furrow drill	Klomp & Hull (1972)
Crested, Russian wildrye	Alternate furrows	11/	McGinnies (1972)
Crested, siberian, Luna pubescent Greenar intermediate, beardless, Russian wildrye	Standard & d f drill	Deep ufrrow 12/	Eckert et al. (1974)
Crested, Amur intermediate	Furrows & surface	Furrows	Eckert (1974)
Russian wildrye	Drill & broadcast	Drill 13/	Drawe et al. (1975)

1/ Single disk drill on hard soil; double disk on very weedy land. 2/ No difference in yield after 8 years. 3/ Broadcasting ahead og brush control generally gave good stands. 4/ Superior to broadcasting before or after the plow, and covering ny harrowing. 5/ Before and after brush control. 6/ Double disk was superior to broadcast. 7/ Single disk most widely adapted. 8/ Came to full stands faster; after 4 or 5 years, no difference. 9/ Birds and rodents serious on broadcast. 10/ All good but ridges. 11/ Alternating deep furrow and surface drilling had stand and erosion control advantages. 12/ Atrazine fallow seedbed gave better stands than mechanical fallow. 13/ After 3 years, no difference.

Table 8. Time of seeding studies.

Species	Times tested	Recommendation	Reference
Crested and others	Early & late fall	Late fall	Walker & Bracken (1938)
Crested	Fall & spring	Fall 1/	Clarke & Heinrichs (1941)
Crested, bluebunch	Fall & spring	Fall 2/	Stark et al. (1946)
Crested, bluebunch, intermediate	Early & late fall or spring	Late fall or early spring A/	Robertson (1947b)
Crested	Fall & spring	Fall 3/	Hull (1948)
Intermediate, pubescent, fairway, smooth brome	Fall & spring	Fall 4/	Hull et al. (1950)
Crested, intermediate, pubescent	Fall & spring	Fall	Cook & Stoddart (1951)
Crested, intermediate, pubescent, fairway, bluebunch, Russian wildrye	Fall & spring	Fall	Frischknecht (1951)
Crested	Summer & fall	Summer 5/	Reynolds & Springfield (1953)
Crested, intermediate, pubescent	Fall & spring	Fall	Cook (1958)
Crested, intermediate, smooth brome	April thru November	April 1	McGinnies (1960)
Crested, siberian, Whitmar beardless, big blue	Spring & fall	Fall	Douglas et al. (1960)
Crested	Spring & fall	Fall	Kilcher (1961)
Intermediate, Russian wildrye	Spring & fall	Spring	Kilcher (1961)
Crested, siberian, beardless	Spring & fall	No difference 6/	Robocker et al. (1965)
Intermediate, pubescent	Spring & fall	Fall	Cook et al. (1967)
Nordan crested, Greenar intermediate, Luna pubescent, Whitmar beardless, Sherman big blue	Spring & fall	Either	Nelson et al. (1970)
Crested, fairway, siberian	Spring & fall	Fall 7/	Klomp & Hull (1972)
Crested, Russian wildrye	April & May	No difference	McGimmies (1972)
Russian wildrye	Spring & fall	Fall	Drawe et al. (1975)

1/ Early spring also good stands. 2/ On prepared seedbeds. 3/ Early fall where fall storms are dependable, otherwise late fall. 4/ Very early spring or late fall at lower elevations. Time less critical at higher elevations. 5/ July highest rainfall month in Northern Arizona and Northern New Mexico. 6/ Tough site, no good stands, 20 cm rainfall. 7/ Successful if cheatgrass is reduced to 130 plants per sq m. A/ September 15 thru November 15 for 4 years, April 1 and 15 for 2 years, April 1 as good as late fall.

Table 9. Rate of seeding.

Species	Rates compared (kg/ha)	Recommendation	Reference
Crested	Various rates	4-5 kg/ha	Clarke & Heinrichs (1941)
Crested	1.1 to 13.5	1/	Hubbard (1949)
Crested	4.5 to 13.5	6.7 kg/ha	Reynolds & Springfield (1953)
Crested	2.2, 4.5, 9.0, 13.5, 27.0	9.0 kg/ha 2/	Mueggler & Blaisdell (1955)
Crested, intermediate	2.2 to 10 and 3 to 13.5 3/	4/	McGinnies (1960)
Crested, intermediate, Russian wildrye, fairway, bluebunch, beardless	1.1 to 45 5/	5.6-9.0 kg/ha	Hull & Holmgren (1964)
Crested, intermediate, pubescent	0.7 to 11.2 6/	7/	Cook et al. (1967)
Crested, fairway	1.1, 6.7, and 13.5	8/	Hull & Klomp (1967)
Russian wildrye	6.7, 13.5, and 27.0	9/	Drawe et al. (1975)

1/ No difference in yield after 10 years. 2/ After 6 years, no difference. 3/ 2.2 to 10 kg/ha for crested; 3.0 to 13.5 for intermediate. 4/ Yield effects gone after 3 years. 5/ For crested, other species in proportion to seed size. 6/ Basic seeding rate 2.8 to 11.2 for crested in 18-cm rows. At wider spacings stand improved through 9 yrs for crested. 7/ 8.4 kg/ha in rows not more than 36 cm apart. 8/ All full stands in a few years; heavier seeding rates gave full stands sooner. 9/ Seeding rate yield differences gone after 3 years.

Table 10. Depth of seeding

Species	Depths compared (cm)	Recommendation	Reference
Crested	1.3 to 7.6	1.3 to 2.5 cm	Clarke & Heinrichs (1941)
Crested, bluebunch	0, 1.3, 2.5, 3.8	1/	Plummer (1943)
Crested, intermediate, R. wildrye	2.5 to 6.4	2/	McKenzie et al. (1946)
Crested, bluebunch	1.3 and 2.5	3/	Robertson (1947b)
Crested	0.6 to 3.8	Not over 1.9 cm	Hull (1948)
Crested	1.3 to 7.6	4/	Rogler (1954b)
Crested	Furrows 5/	6/	McGinnies (1959)
Beardless	1.3, 2.5, and 3.8	7/	Vogel (1963)
Crested, siberian, fairway, cheatgrass	1.3, 2.5, and 5.0	8/	Hull (1964)
Crested, intermediate, R. wildrye fairway, bluebunch, beardless	(not reported)	9/	Hull & Holmgren (1964)
Crested, intermediate	1.3, 2.5, and 3.8	1.3 to 2.5 cm	McDonough & Matthews (1970)
Russian wildrye	1.3, 2.5, and 3.8	1.3 to 2.5 cm	McGinnies (1974)

1/ Greenhouse study. 2.5 cm is maximum depth to seed. 2/ Greenhouse study. Maximum depth for crested 2.5 cm, for Russian wildrye 3.8 cm, and for intermediate 5.0 cm. 3/ 1.3 cm for crested, 2.5 cm for bluebunch. 4/ Both field and greenhouse study; larger seeds emerged best at deeper covering. 5/ Seeds were planted 1.3 cm deep in the bottoms of furrows 2.5, 5.0, 7.5, and 10 cm deep. 6/ The best emergence was from furrows 10 cm deep. Soil moisture remained progressively better as depth of furrows increased. 7/ Greenhouse study; emergence inversely proportional to depth of covering. Large seeds best at all depths. 8/ Greengouse flat study; cheatgrass emerged fastest and more completely from all depths. 9/ Up to 2.5 cm for large seeds; less covering for smaller seeds.

rows reduced the vigor of invading sage seedlings, though not the number. Hull and Holmgren (1964) found that rows spaced as widely as 60 cm increased in yield until they exceeded the productivity of closer spaced rows. If close spaced rows are desirable to provide greater erosion control, to reduce weeds, and to discourage sagebrush, a program of eliminating every other row, after a few years, might lead to increased long range productivity. Row spacing studies are summarized in Table 11.

Early Management of Seeded Stands

New seedlings must be protected from grazing until plant establishment is assured. The protection time is related to the potential of the site, the species used, the competition encountered from unwanted vegetation, the prevailing weather, and the initial stand produced by the seeding operation. Grasses with good seedling vigor can come to grazing readiness ahead of those with poor seedling vigor, and full stands are ready ahead of thin stands. Heavy weed competition, especially cheatgrass, not only delays range readiness, but can prevent success of seeding. Regardless of the species used, a site with high potential will come to readiness ahead of one with low potential. Generally, a new seeding should be protected from grazing until the more vigorous of the young seedlings have matured their first crop of seed, usually not before the latter part of the second growing season, and sometimes 2 or more years later.

No seeding operation, however good a stand is obtained, can be considered successful unless the subsequent management assures the continued vigor and productivity of the stand. Stoddart (1964b) recommended seeding half of the site to rye, to use as a temporary pasture, while the other half seeded to grass, is becoming established. This will take the pressure off the new grass seeding. When the grass is ready to graze, the half seeded to rye can be seeded to grass. (Rye, however, should never be seeded in proximity to dryfarm grain land.)

Reinvasion of Sage

Hull (1941) observed that if sage seedlings emerged with the grass seedlings, the vigor of the sage would be reduced, but not the number of sage plants. Blaisdell (1949) seeded sage and crested wheatgrass in various time sequences. If the grass was seeded before, at the same time, or as much as one year later than the sage, the grass developed a full and productive stand. If seeded as much as 2 years later than the sage, the grass had no effect on the vigor of the sage. Bleak and Plummer (1954) reported that three-fifths of all sage present on a crested wheatgrass range grazed 10 years by sheep, had become established with the crested seeding, while only one-fifth had invaded after grass establishment. Pechanec et al. (1954) pointed out that seeding should not be delayed after sage control, because the longer the delay the greater the opportunity for sage invasion.

To reduce sage invasion Stoddart (1946a) recommended plowing sage either in late spring, before sage made seed, or in late fall, after sage seed had sprouted. Hull (1949a) recommended against fall control of sage. Fendley (1953) advised to plow sage in summer, before viable seeds had been produced. Bleak and Plummer (1954) found many more sage seedlings on fall-cleared land than when sage was controlled before it had produced viable seeds. Bleak and Miller (1955) cleared sage from April to November. They observed some sage seedlings on spring-cleared land, none on summer cleared land, but many on land cleared in the fall. Cook and Lewis (1963) found sage invasion rapid on summer cleared land, and Cook et al. (1967) found sage invasion into a seeded crested wheatgrass field inversely proportional to the density of the grass cover. Hull and Klomp (1966) noted that sage rapidly invaded seeded plots where the grass stand was a failure. Johnson and Payne (1968) reported that sage plants surviving the control treatment were the most important single factor in reinvasion. Heavy reinvasion also resulted when sage was plowed after it had matured seeds. Cook (1966) and Shown et al. (1969) recommended plowing twice, if necessary, to obtain good initial control of sage. Robertson et al. (1970) found reinvasion of sage to be closely tied to initial control, as well as to intensity of use of the seeded stand. Grass increased more, and sage less, under light grazing use.

If the kill of sage prior to seeding is incomplete, the manager may find it profitable to spray to kill both old and young sage before their growth lowers productivity of the seeded grass.

The reinvasion of sage into a seeded grass stand is enhanced by the extent to which sage has produced seed that is viable before the grass is seeded, whether it be produced the current year, or a previous year. This probably explains some of the conflicting results reported.

Discussion

To this point the reviewer has interpreted the literature on species and methods for seeding in the sagebrush ecosystem. In the remainder of this paper, consideration of each topic will consider the literature, where available, followed by the reviewer's projection of the direction present events seem to point for the near future. Projections are often wrong; those made in the following pages are to be regarded only as possibilities; future events may fail to verify a single one of them. In some instances the projections may seem logical and natural; in others they may appear to be "far out". The sage, however, is definitely set for some significant, if not dramatic, changes to our approach to range improvement by seeding. The reasons for this will appear clear as the following topics are considered.

Monocultures vs. Mixtures

One striking recent discovery of importance to agriculture is the vulnerability of any agricultural environment represented largely by a monoculture. Of this Harlan (1972) has written that a narrow gene base courts disaster, and that diversity and stability are verly closely associated. A recent example is the outbreak of the southern corn leaf blight (Browning 1972). The U.S. had 19 million ha of corn, 80 percent was susceptible to the "new" race of the fungus *Helminthosproium maydis*, which, under the right set of circumstances, was able to increase to epidemic proportions on millions of ha in a single year. We are aware of similar outbreaks of rush on wheat over the past years. We can recall the abrupt end of Utah's importance nationally as an alfalfa seed producing state, with the appearance of Lygus bugs (*Lygus* spp.). All these events should have alerted us to what is happening on the range.

Table 11. Row spacing

Species	Spacings compared (cm)	Recommendation	Reference
Crested	15, 61, and 91	1/	Reitz et al. (1936)
Crested	15 to 30, and wider	30 cm	Clark and Heinrichs (1941)
Crested	15, 30, 46, and 61	15 cm	Hull (1948)
Crested	15 to 61	30 cm	Reynolds & Springfield (1953)
Crested	15 and 46 cm	2/	Lavin & Springfield (1955)
Crested, intermediate	18, 36, and 53	2/	McGinnies (1960)
Crested, intermediate, R. wildrye, fairway, bluebunch, beardless	15 to 61	25-30 cm	Hull & Holmgren (1964)
Crested, intermediate, pubescent	18, 36, 53, and 71	3/	Cook et al, (1967)
Russian wildrye	20, 40, and 60	4/	Kilcher et al. (1976)

1/ Highest yield over 14 years from 91 cm spacing. 2/ Close spacings best first 2 or 3 years, then wider spacings better. 3/ Highest yields from 18 and 36 cm spacings first few years only.
4/ Wider spacings eventually higher yields, but not necessarily greater cattle gains.

In Wyoming Denning (1948) described the crested wheatgrass bug (also called the wheatgrass bug, and most recently the black grass bug). He reported both hay and seed yields affected, as well as palatability of the hay for cattle. Typical symptoms were stunted plants with leaves turning yellow or white. Denning said the insect was fast-moving, and most abundant in May and June. Nineteen years later Bohning and Currier (1967) reported this bug in 11 of the 14 western states. They believed it to be a native American species, released to epidemic proportions by the increase in seeded wheatgrass. They report damage by the bug to 23 thousand ha in two Utah counties, where it had been in epidemic proportions for 5 years. The bug is susceptible to DDT, but will be found on treated areas the following year. Higgins et al. (1977) noted that the black grass bug was much more abundant on 6 introduced grasses than on adjacent native species. They believed the differences observed indicated varying susceptibility to the bug. Fertilizing the grass increased the bug population.

Maxwell et al. (1972) report numerous outstanding successes in breeding for insect resistance among crop plants. They state, "--only limited screening for a very restricted number of insects has been attempted, hence the veritable gold mine of potential for future exploitation lies before us". Thus one option is to breed grasses resistant to the black grass bug. Another is to plant mixtures where we are now planting single species, to keep the bug in check by dilution of its host. Both approaches should be pursued with vigor. In the long run, mixtures appear to be the sounder approach, because mixtures reduce vulnerability of the environment. But while we seek compatible mixtures and learn how to establish them, grasses resistant to the bug would be of tremendous value to range improvement by seeding. In some situations insecticides may be useful as a short term control, but under no circumstances would they be a satisfactory long term control. A striking example of the long term limitations (or inadequacies) of insecticides to control insects is found in a report titled "The Pesticide Plague" appearing in the "Outlook" section of the Washington (DC) Post for Sunday, March 9, 1978. (The article discussed the tragic condition of cotton (*Gossipium* spp.) growing in the U.S.) Our present monoculture of crested wheatgrass, occupying several million ha, is vulnerable to the devastation of other insects, or diseases, or rodents, with few means that the sites will economically justify, to combat them.

Presumably any dilution of a monoculture would be beneficial in avoiding epidemics of any pest, but how much dilution (how many species) would reasonably eliminate the risk of outbreaks of any kind, is not known, and will have to be arrived at by research, or experience. However, mixtures at once offer at least two opportunities: 1) inclusion of a legume capable of fixing nitrogen for the benefit of associated species; 2) inclusion of a browse plant, to serve as a protein supplement to grasses, and to enhance the value of the site for wildlife. Research will have to determine which species are sufficiently compatible to survive together and be productive. This will not be a simple task; many early range seedings of crested wheatgrass with native species soon reduced to a monoculture of crested wheatgrass. But some unpublished data obtained by Keller, Bleak and Hull suggest crested wheatgrass and Russian wildrye are compatible. The reviewer believes the planting of monocultures should be discontinued, and mixtures used even if of only two species. Mixtures could be seeded in alternate rows, or, if the seed was mixed, differences in seedling vigor, as between crested and Russian wildrye, could be offset by some adjustment in the seeding rate.

A major problem in seeding mixtures involving a legume is that legumes are not successfully established, over most of the sagebrush ecosystem, from fall seedings, the preferred time for grasses. Neither are legumes generally seeded at the first opportunity in the spring, which is necessary for successful spring planting of grasses.

Planting mixtures may not overcome the problem of grass tetany (Grunes et al. 1970) unless some nongrass component of the mixture produced early spring feed. The solution for grass tetany may be a more stable Mg/Ca ratio, bred into the grass. This is a problem worthy of exploration by grass breeders.

Early researchers dealing with seeding the sagebrush ecosystem frequently recommended mixtures (Plummer et al. 1943, Hull and Pearse 1943, Robertson and Pearse 1943). Hull (1944) recommended bulbous bluegrass (*Poa bulbosa*) for seeding with crested wheatgrass on poor to average sagebrush sites, except in southeastern Idaho. Hull (1944) also included big bluegrass in some mixtures. Mixtures, but of other species, were recommended for range lands of Utah by an interagency committee (1951), but another interagency committee (1967) proposed single species for all conditions, with the notation that mixing of grass species was not recommended.

Range Fertilization

Many studies have been conducted on the mineral fertilization of rangelands. Put in broad categories, in three areas nitrogen fertilization has been quite profitable: 1) the better watered parts of the Great Plains; 2) mountain meadows; and 3) rangelands in the Central Valley of California. In general, replicated experiments show a statistically significant reponse to N from grasses in the sagebrush ecosystem, but the value of the forage obtained is seldom sufficient to pay the cost of the fertilizer, because water is generally the chief, and dominant, limiting factor, and also because range grasses are not genetically geared to respond to fertilizer. Evans and Young (1977) found N of no value in seedling establishment; in fact that it may be harmful.

Eckert et al. (1970) reported that there was a build-up of N on fallowed rangeland during spring, summer, and fall. The amount was influenced by precipitation.

Legumes are an alternate method for providing N to range grasses. At present, alfalfa appears to be the best adapted legume for this purpose. Heinrichs and Bolton (1958) in Canada have produced Rambler, and more recently (Heinrichs 1971) Drylander, both creeping rooted alfalfas with considerable promise for grazing lands. Rumbaugh et al. (1965) released Travois. A significant step was taken by Townsend et al. (1976) in the registration of C-3 alfalfa germplasm to serve as

a genetically diverse sources of breeding material for alfalfa adapted to rangeland. Kilcher and Heinrichs (1968) compared several seeding rates of Rambler alfalfa with crested wheatgrass. They concluded 1 lb/a (1.12 kg/ha) of Rambler best. Lie (1971) reported that the yield of N from a legume is a complicated interaction of the genetics of the N-fixing organism and the host plant, with each other and with their environment.

The importance of the problem of range fertilization warrants much more research in this area. For example, Bell and Nutman (1971) found that under humid conditions alfalfa may contribute as much as 300 kg N per ha to the associated species. Under range conditions one-tenth that amount would be ample.

An interesting, important, discovery of the recent past is that some species of plants other than legumes become nodulated and fix nitrogen. W. D. P. Stewart (1967) reports that nitrogen fixation occurs in 15 genera of bacteria, 14 of blue-green algae, 13 of root nodulated angiosperms, and 8 of root nodulated gymnosperms. Further, among the 13 genera of angiosperms, over 200 species are known to fix N, with more almost certain to be discovered. Nitrogen fixing bacteria, as diverse and widespread as are grasses, occur from Antarctica, where they function at near zero C, to the hot springs of Yellowstone Park at temperatures up to 55°C. Blue-green algae are known to fix N in tropical rice paddies, the estimated amount being 30 to 50 kg per ha per year.

Wagle and Vlamis (1961) reported nodulation on roots of bitterbrush, and presented evidence to suggest that N fixation occurred in the nodules. Webster et al. (1967) examined 5 species, all of which gave evidence of N fixation. They wrote, concerning bitterbrush, "...our results imply that it is making a significant contribution to the nitrogen economy of the ecosystems in which it occurs".

Delwiche et al. (1965) claim that nodules had been observed on *Ceanothus* as early as 1912. All species of *Ceanothus* examined fixed N. The amount fixed is not known.

Few appreciate the contribution of nitrogen fixation to man's welfare. W. D. P. Stewart (1967) has expressed it well: "Of the major metabolic processes going on in cells, the two most important in maintaining the productivity of the earth--photosynthesis and nitrogen fixation--are characteristics of the plant kingdom only. ...The total contribution of fixed nitrogen to the earth's surface has been estimated at about 100 million tons of nitrogen per year, 90 percent of which is considered to be biological in origin".

Hardy et al. (1971) explain the aim and objectives of scientists concerned with nitrogen fixation as follows: "Enhanced symbiotic N_2 fixation in the near term and attempts to extend the symbiotic system to cereal crops in the long term are the major potential contributions of N_2 fixation research to a nitrogen-starved but environment concerned world".

Range scientists are well aware of the futility of attempting to increase forage production in the sagebrush ecosystem by the application of synthetic nitrogen. What we need now is a greatly expanded effort to find legumes adapted to the range, to serve as a source of N in the short run, and a vigorous search for nonleguminous plants capable of fixing N and adapted to the range environment, either to supplement legumes, or to be the sole source of N for rangelands in the long run.

Plant Introduction

Vavilov (Imperial Bureaux 1933) conducted a very comprehensive investigation into the centers of origin of cultivated plants. He found the greatest diversity of species, and variation within species in a broad belt extending from China (fruits, ornamentals) across Central Asia (grasses, alfalfa, melons) to the Mediterranean (legumes) across North Africa (cereals, sorghum) to the northern part of South America (corn, potatoes, tomatoes), parts of the world where plant exploration will probably always be most fruitful, although plant migration out from this belt had enhanced many characteristics, as, for example, winter hardiness. We have hardly scratched the surface of the potential offered by the major centers.

Harlan (1950) has reminded us that American flora are poor forage plants. Most of our cultivated forage plants are imports. According to Harlan (1951) we have neither been efficient nor thorough in exploring for superior germplasm among our native species. He states, "The difference in performance between strains of one species is in many cases a far greater variable than the difference between species". (That this may be true is illustrated by Harris and Goebel (1976), who found accessions of bluebunch wheatgrass from the western U.S., after germinating 21 days under controlled conditions, to vary in root elongation from 1.4 cm for the slowest accession to 11.93 cm for the fastest.)

Range improvement by seeding would greatly benefit by a much more intensive program of plant exploration, both at home and abroad, combined with a comprehensive and coordinated program for evaluation of all materials collected.

Grass Breeding

Not a single cultivated crop grown by man lacks named varieties representing some improvement. Grass has benefited, but far less than other crops, many of them not nearly so important to man.

Dillman (1910) describes some early grass breeding work in the U.S., but not until P. V. Cardon left Utah and became Chief of Forage Crops in the USDA in 1935 was a continuing program for grass breeding organized. Nearly 20 years earlier, Kirk, according to Dillman (1946), began grass breeding work in Canada which resulted in such strains as the original fairway wheatgrass, and Mecca, Fyra, and Grazier slender wheatgrasses.

For arid lands in the U.S. one variety, Nordan crested wheatgrass, bred and released by Rogler (1954a) stands out. Nordan has contributed much to arid range seeding. From a heterogeneous mixture of *cristatum* and *desertorum* then on the market (no way of knowing just what one was buying) Rogler produced Nordan, with desirable characteristics, and made it available as certified seed. Thus, for

the first time buyers were able to purchase a named variety, certified as to characteristics, with the assurance of a standardized, quality product. Hanson (1972) listed 38 bred strains from 14 genera of *Agropyrons*. That Nordan remains today, after 25 years, the only important named variety of crested wheatgrass in the U.S. speaks elonquently for the stature of this strain.

Vinall Russian wildrye was bred by Rogler and released by Schaaf and Rogler (1960). Vinall has not gained the recognition that Nordan has, partly because Russian wildrye has not gained the stature enjoyed by crested wheatgrass.

Just as Vasey wrote, about 80 years ago, that the first step in improvement is to know the species, this work continues. During the past 20 years, Doug Dewey, working at Utah State University at Logan, Utah, has greatly extended our knowledge of the *Agropyrons* and related genera through his studies on cytotaxonomic relationships.

Recently Blauer et al. (1975, 1976) have revealed the rather surprising amount of natural hybridization that occurs between species and genera within the Rose and Chenopod families, respectively. Their findings are significant, and no doubt will contribute much toward future forage breeding programs. But judging from the experience to date, from wide crosses with other species, this may not be an immediately fruitful avenue to forage plant improvement. Brink and Cooper (1947) solved the mystery of double fertilization in the angiosperms, and thereby contributed greatly to our understanding of what may be taking place in crosses formerly considered incompatible.

Moss and Musgrave (1971), Wittwer (1974) and Chollet and Ogren (1975) have discussed the common or Calvin pathway of photosynthesis (C-3) in which CO_2 is initially fixed into a 3-carbon compound, and the more efficient (in terms of CO_2) process in which CO_2 is initially fixed into a 4-carbon compound. Three-carbon plants reach light saturation with as little as one-fourth normal sunlight, while 4-carbon plants may not become light saturated even at 10,000 ft candles. Thus, in bright light they may be as much as 50 percent more efficient in the use of CO_2. The C-4 pathway is found in corn, sorghum, sugarcane, and some tropical grasses, and *Atriplex*. It is found in at least 10 major plant families, both monocots and dicots, in nearly 100 genera and several hundred species. The arid western range, with bright sunshine and low plant populations, is an ideal environment for C-4 plants. Love (1970) has called attention to the very inefficient use range plants make of the sun's energy. The time may not be far into the future when range scientists will need to give consideration to efficiency of CO_2 use as a selection criterion in grass breeding.

Mertz and Bates (1964) discovered Opaque-2, a mutant gene in corn which increased the lysine content of the endosperm by 69 percent or more. This discovery has world-wide significance for human nutrition because this mutation gives corn possessing it a quality of protein higher than that characteristic of cereals; more like that of red meat. Grass breeders need to be able to screen their materials for nutritional value. On arid range, where water is a strictly limiting factor, an increase in nutritional quality could proportionately increase the value of the forage without requiring any additional water for its production.

Sneva (1967) reported that treating grass with paraquat arrested movement of NPK and Ca in dry summers, with no yield reduction. Sneva (1973) reported that with 45 kg N per ha, plus paraquat, yield was increased 40 percent, protein content of the herbage 68 percent, and protein yield 148 percent above control plots. Sneva and Turner (1977) reported the paraquat treatment effect on flood meadows, providing an alternate method of winter use by grazing. If paraquat, or some equally effective chemical, should be released for range use, grass breeders will want to know how their products cure, or if quality can be increased.

The reviewer believes that breeding for the improvement of arid rangelands will make its greatest contribution in the future by attacking highly specific objectives, such as:

1. Breeding for resistance to the black grass bug.
2. Transferring the rapid root penetration of cheatgrass and *Sitanion hystrix* to more desirable species.
3. Strengthening the root system of big blue.
4. Increasing seedling vigor of Russian wildrye.
5. Increasing root reserves in spicatum-inerme.
6. Removing awns from needle-and-thread, and *Sitanion hystrix*.
7. Breeding for increased efficiency of water use.
8. Breeding for more rapid germination and seedling establishment.
9. Breeding alfalfa for range forage and range fertilization.
10. Breeding for resistance to *Podosporiella verticillata*.
11. Breeding grasses to avoid grass tetany.
12. Breeding for increased compatibility with other species.
13. Breeding for resistance to grasshoppers (Schlebecker 1953).
14. Breeding for complete removal of rhizomes.
15. Breeding to remove oxalates from browse species.
16. Breeding to improve specific nutritional qualities.
17. Breeding for increased efficiency of use of light or CO_2.
18. Breeding for sustained high nitrogen in range grasses.
19. Breeding for resistance to snow mold.
20. Breeding for low temperature germination, etc.

Breeding Mixtures for the Range

Nearly all plant breeding has involved a single species to be grown in monoculture. Grasses and legumes bred for pasture mixtures have generally been worked with individually. (Even then, the work was more complicated than for cultivated crops because in the final analysis the grazing animal must be the judge.) The first step toward range improvement by use of mixtures should be to plant mixtures in various species combinations to determine compatibility. Such plantings should identify species

which can grow and be productive when in association with one another. Such plantings should involve every species considered to have any potential value in a mixture. They need not all be high yielders individually. (In studying irrigated pasture mixtures Bateman and associates found that a mixture of reed canary grass (*Phalaris arundinacea*) with strawberry clover (*Trifolium fragiferum*) gave far greater yields than reed canary alone. Yet, strawberry clover never grew off the ground sufficiently to enter into the clippings on which yield was based. Obviously the clover provided nitrogen which stimulated the high grass yields.) Trenbath (1974), in a review of the literature, reported that mixture of two species usually gave a yield equal to the mean of the two species when grown separately. However, Bateman and Keller (1957) in a very comprehensive study of irrigated pasture mixtures, found that when dealing with high yielding species, additions up to 7 species contributed to higher yields.

In the initial process of simultaneously choosing superior plants from all of the species intended to make up the mixture, these plants would have to be growing in proximity to one another. Keller (1946) designed arrangements which make this possible, by placing each plant of each species adjacent to the same configuration of plants of the other species. Selection can thus be based directly upon both yield and compatibility.

In the development of mixtures, palatibility is very important (Hull et al. 1958). Any appreciable differences in palatability will result in selective grazing which can profoundly affect the survival of any component.

Producing a compatible mixture is very much more complicated than breeding single species, but the importance of the ultimate goal will, in any event, justify whatever is needed to achieve it.

The all-at-once method has two distinct advantages: 1) any gain made is reflected directly in the yield of the mixture. When species are handled singly this is not the case; for example; assume four species in a mixture, each equally productive. The total yield, 100 percent, is the sum of four species, each contributing 25 percent. One species is then "improved" by the breeder. He is highly successful, producing a strain 40 percent more productive than the original. But when this improved strain is put back into the mixture (assuming it is compatible), it increases the total yield of the mixture by only 10 percent. Few experiments on range land are sufficiently sophisticated to give statistical significance to a gain of 10 percent. Had all 4 components of the mixture been growing together, and selection made from all of them, a more modest improvement of 20 percent would be reflected directly in the yield of the mixture. 2) selecting all components of the mixture at once would seem to insure compatibility of the resulting mixture, whereas if the species are selected separately, compatibility of the mixture will have to be determined later, which could prove to be an inefficient use of resources.

Combinations of species presently available may prove compatible enough that at least one mixture of two species could be identified rather quickly. This will be a start in the right direction. Three or four, or even more species, would be safer and represent the ultimate goal. Kilcher and Heinrichs (1958) studied grass-alfalfa mixtures. They reported that alternate rows were generally superior in yield, especially in dry years, over plots from mixed seed. Hervey and Everson (1956) noted that when the full effect of drought was felt, it was alfalfa, in an alfalfa-crested wheatgrass mixture, which maintained high production.

While two species would be a start in the right direction, for range mixtures, a minimum desirable mixture might be thought of as having two grasses, not of the same genus, one legume, and one shrub.

Spaced vs drilled plantings

How dense a stand to aim for in range seeding has not been decided. In fact, the seeder has little control, even if he knows what density to aim for. Many factors determine density, one of the most important being weather conditions for as much as a year after the seeding operation has been completed. Thick stands in close-drilled rows are known to yield highest during the first few years after seeding, with more widely spaced, thinner stands coming into high, or higher, production some years later. Advocates of close-drilled rows cite the better weed control. They believe nature will thin the stand down to what is right for the site. Others believe nature is too slow doing this. The reviewer, and no doubt many others, wonder why ranges are not seeded in uniformly spaced arrangements, rather than in drilled rows. With a little experience, it is reasoned, any range man could review a site, note the native vegetation, the soil, etc., review the precipitation records, and estimate quite closely the plant spacing which, for that site, would lead to maximum productivity. There would be some sacrifice in yield the first few years, but possibly a substantial gain in the long run. The aim would be to reach a closed community (Robertson and Pearse, 1945). The possible merits of seeding ranges on the basis of plants per ha is one for future range scientists to contend with. (McGinnies (1966) conducted a spot seeding study with crested and pubescent wheatgrasses, and Russian wildrye. He placed one to 8 seeds at each spot. Based on emergence at one seed per spot, he found that higher numbers of seeds yielded fewer than the expected number of spots having plants). Possibly the greatest disadvantage of seeding ranges in a spaced arrangement would be the need for specialized seeding equipment.

Spreaders vs bunchgrasses

The impressive information favoring intermediate wheatgrass over crested in Nevada has been mentioned earlier. The fundamental issue is, can a spreader retain superiority over a bunchgrass on arid range having dry summers? Prior to the advent of the white man and his grazing animals, that part of the arid range which we now call the sagebrush ecosystem, was a sagebrush-bunchgrass association. Rhyzomatous grasses were not absent, but, with the possible exception of western wheatgrass, certainly were not very important. Is a rhyzomatous species physiologically able to compete with a bunchgrass, in the long run, or arid range? Will the rhyzomatous species spread a little each spring, when there is ample water in the soil, so that it builds up a root system out of proportion to the amount of forage the site can produce, so that excessive water is needed to maintain the root system? Or, is the problem met by a rate of root mortality which does not allow this build-up of roots? These interesting questions have

an important bearing on the long-time suitability of a species. Only time will give us the answers we do not now have.

Competition Other Than Sagebrush

Cheatgrass

There are several million ha of cheatgrass in the sagebrush ecosystem, with a heavy concentration in the Snake River Valley of Southern Idaho. Piemeisel (1938) studied plant changes on abandoned lands in the Snake River Valley. He found Russian thistle (*Salsola kali tenuifolia*) first to occupy the land, because of its efficient seed distribution. But Russian thistle, unable to stand crowding (high plant populations), gives way in the third season to mustards (flixweed, *Descurainia sophia*, and tumbling mustard *Sisybrium altissimum*). In the fifth season cheatgrass will replace the mustards, and may retain possession of the site indefinitely. However, if the site is heavily grazed, some Russian thistle may persist in the cheatgrass. Piemeisel (1951) found the above changes to occur independently of weather. (Precipitation and plant density determine the amount of water available for each plant. Of the two, plant numbers are much more variable.)

Cheatgrass is a serious deterrent to successful range seeding (Stewart and Hull 1949, Beetle 1954, Klemmedson and Smith 1964, Harris 1967). Hull (1949b) wrote that, "the only advantage of cheatgrass is that it is present in considerable amounts in some years without the labor of seeding".

Hull and Stewart (1948) tested 6 methods of seeding cheat-infested rangelands. They obtained good stands of crested wheatgrass from all methods that sufficiently reduced the cheatgrass population. Only drilling into undisturbed cheat with an ordinary grain drill failed to reduce cheat numbers. They found that burning in early summer, just as early as cheat would carry a fire, reduced cheat numbers the next season by 87 percent, adequate to successfully establish crested wheatgrass. Klomp and Hull (1972) compared 16 methods of seeding in the field. All methods that reduced cheatgrass to 12 plants per ft^2 ($129/m^2$) gave good stands of crested wheatgrass. The most economical practice seemed to be deep furrow drilling after fall germination of cheatgrass. In a greenhouse study Evans (1961) found that crested wheatgrass could compete quite well with cheat if cheat was no denser than 16 plants per ft^2 ($172/m^2$). At higher cheat densities crested mortality increased rapidly. (Stewart and Hull (1949) found that cheatgrass produced as much as 478 pounds of seed per acre (536 kg/ha) under field conditions. This amounts to 17,000 seeds per m^2.) Evans and Young (1977) have had excellent seeding succession when cheatgrass was controlled by an atrazine fallow. The economics of this practice will need to be analyzed for each site.

Hironaka and Tisdale (1963) reported that under natural conditions squirreltail would invade cheatgrass. They consider this the first specific record of natural invasion of cheatgrass by a perennial grass species. Hull (1940) observed that when seeds of bulbous bluegrass were broadcast on cheatgrass range the plants often became established. He recommended bulbous bluegrass with crested wheatgrass for thin, poor soils of low moisture holding capacity. Hafenrichter et al. (1968) restrict bulbous bluegrass to range below 4000 ft (1220 m). Hull (1963), in a greenhouse study, noted that the cheatgrass root system occupied the soil faster, and more completely than crested wheatgrass, and had a lower water requirement. Hull and Hansen (1974) found that even under ideal conditions all cheatgrass seeds do not germinate the first year. Harris (1967) demonstrated that cheatgrass roots move down in the soil faster than those of bluebunch wheatgrass, this characteristics of cheat largely explaining its superior competitive ability. Harris and Wilson (1970) were able to show that cheatgrass roots grew downward a little faster than roots of crested wheatgrass, whose roots were much faster than those of bluebunch wheatgrass.

Considering all studies, the superiority of cheatgrass over crested wheatgrass is in large measure explained by the high seed production of cheatgrass under natural conditions.

Medusahead

According to Turner et al. (1963) *Taeniatherum asperum* (Sim) Nevski, formerly *Elymus caput-medusae* occupied 800,000 ha in Oregon and 304,000 ha in Idaho. They reported that it spreads into overgrazed cheatgrass range. They present evidence that medusahead was collected in Oregon in 1884, and that George Vasey collected it in Washington in 1901. The first recorded collection in Idaho is 1945, but ranchers claim to have seen it in the early 1930s. Medusahead is a very serious problem because the forage is much inferior to cheatgrass (Sharp et al. 1957, Turner et al. 1963). Lusk et al. (1961) studied palatability of medusahead for sheep. Given free choice, sheep ate some medusahead when it was green. Confined to small plots sheep ate some medusahead even when it was headed and dry. Fertilized medusahead was more palatabile than nonfertilized.

Sharp et al. (1957) report medusahead normally germinates in Oct.-Nov., as moisture is available; that it matures 2-3 weeks later than cheatgrass; that, unlike cheat, seed persists in the head until fall; that it is a good seed producer, the seed having high viability and carrying over in the litter for at least one year.

Harris and Wilson (1970) found that medusahead roots grew downward in the soil slightly faster than roots of crested wheatgrass, but much faster than those of bluebunch wheatgrass when all were growing at 10C for 6 weeks. After 38 weeks cheatgrass had the longest roots, crested was next, followed by medusahead, all rather close together, but bluebunch wheatgrass roots were much shorter. In a somewhat similar study Wilson et al. (1974) found cheatgrass the fastest to germinate at 10C, followed in order by medusahead, crested, siberian, and bluebunch wheatgrasses, and smooth brome. The order of emergence was the same except that medusahead emerged ahead of cheatgrass. Harris and Goebel (1976) reported that seeds of medusahead were clearly able to germinate under higher moisture stress, and at lower temperatures, than either cheatgrass or bluebunch wheatgrass. Harris (1977) noted also that medusahead root penetration was a little faster than cheatgrass.

Hironaka and Sindelar (1973) made the very significant observation that under field conditions squirreltail would invade medusahead dominated range. Young and Evans (1972) were able to convert medusahead range to cheatgrass range by use of diuron.

The reviewer found no reports on seeding crested wheatgrass or other perennial grasses on medusahead infested rangeland. From the general similarity of the species, it is likely that the same procedures effective with cheatgrass would be effective on medusahead infested rangelands.

Halogeton

First found near Wells, Nevada in 1934 (Dayton 1951) *Halogeton* spread rapidly throughtout the western range country, to over 600,000 ha, but much of it is not in the sagebrush ecosystem. The plant, a native of Central Asia, is important because it accumulates oxalates, highly toxic to sheep. *Halogeton* rapidly invades exposed soils or overgrazed range. Tisdale and Zappetini (1953) report *Halogeton* to be a highly prolific seed producer, the seed having high viability for at least one year. *Halogeton* seeds germinate in the spring. The plants build a large root system with little top growth during cool weather, then make top growth during warm weather. Plants have a wide size range, from very small to over 2.5 kg dry weight, and producing as many as 25,000 seeds. Stoddart et al. (1951) emphasize seeding crested wheatgrass to control *Halogeton*, wherever crested is adapted. Roadsides and other disturbed areas should be promptly seeded to grass. Cook and Stoddart (1953) advised seeding crested wheatgrass on *Halogeton* areas having good soil and at least 27 cm annual precipitation. They believed restricted grazing where perennial grasses are present would increase vigor of the grass and crowd out *Halogeton*. Bleak and Plummer (1954) found that *Halogeton* increased rapidly in 4 years after it first entered the area, but only on barren spots or heavily grazed areas. It is not found in full, vigorous stands of crested wheatgrass. Frischknecht (1968) observed that on the Benmore project in central Utah, *Halogeton* first invaded "slick spots" in heavily grazed pastures, but also heavily grazed spots in moderately grazed pastures. Cook (1965) obtained highest yields at 3 years from range summer fallowed prior to fall seeding to crested wheatgrass, Russian wildrye, tall, intermediate, and pubescent wheatgrasses. Spraying the young *Halogeton* with 2,4-D increased forage yields. Next to crested wheatgrass, Russian wildrye was most productive. Robocker (1966) reported *Halogeton* most susceptible to herbicide when young, and increasing in resistance with age. Cronin and Williams (1966) found that when rainfall was minimal for range seeding, treatment of *Halogeton* with 1 kg/ha of 2,4-D volatile ester can make the difference between success and failure of a seeding.

According to Tisdale and Zappetini (1953) *Halogeton* is not a threat on well managed range that has a good cover of perennial grasses. Hull and Holmgren (1964) considered *Halogeton* and Russian thistle quite similar with respect to their resistance to grass establishment. Either could be drilled into directly, without any seedbed preparation.

Squirreltail

If squirreltail is able to invade both cheatgrass and medusahead range, as earlier stated, it may also provide vigorous competition for crested wheatgrass and other desirable perennials. Squirreltail has several valuable qualities. According to Wright (1971) it is more tolerant to fire than needle-and-thread grass because it does not compact its dead plant material. Wright (1967) also reported squirreltail resistant to injury from herbage removal after seed production because the plants enter into dormancy. This needle-and-thread does not do.

Hironaka and Sindelar (1975) conducted a greenhouse competition study in which medusahead was represented by zero to 324 plants per small plot, along with 10 of squirreltail. Even at the highest intensity of medusahead there was no squirreltail mortality. The highest intensity was 7847 plants of medusahead per m^2 (while squirreltail was 237 plants). This is in contrast to Evans (1961) who observed crested wheatgrass mortality in a similar study with cheatgrass when cheat density exceeded 172 plants per m^2.

Young and Evans (1977) found squirreltail to be a good seed producer, although the disarticulating rachis makes seed harvest difficult. The seed has high viability; apparently no germination inhibitors, but the awns are a serious handicap to seeding and must be removed if the seed is to be drilled.

Squirreltail is a species worthy of the attention of grass breeders.

Seeding Annual Forage Crops

Essentially all seeding in the sagebrush ecosystem has as its goal the establishment of perennial grasses. However, Rausi and Lang (1959) seeded 4 annual pastures which were grazed by sheep. Fall-seeded winter wheat was far superior to spring seedings of oats and peas, sweet sudan, or winter wheat. By May 20, fall sown winter wheat was reported to be 50 cm high and to have produced 4 metric tons dry wt per ha. This wheat crop, grazed from May 20 to mid June (a critical feed shortage period in the sagebrush ecosystem) yielded 1349 sheep days grazing per ha.

In Israel, Tadmor et al. (1974) reported on a 12-year study of annual forage for sheep production. They express the logic back of this reasearch as follows: "In many countries modern dryland farming integrates grain cropping and livestock production into a single farm system. Under this system the farmer owns cropland, pasture--and sheep. In 'good' years a grain crop is harvested. In these years the pasture will be plentiful and sufficient for the sheep. In 'drought' years the grain is unharvestable. The pasture will also be insufficient. In such years the drought-failed grain is a welcome high-yielding compliment to the pasture, allowing the farmer to keep his flock alive, on his own land, without buying costly outside feed, and without society-disrupting migration. Such an operation, essentially an adaptation of ley farming to arid conditions, turns separate losses from sheep and grain in a drought year into profit. This makes

the long-term grain-sheep operation in a variable climate profitable where grain farming or sheep alone would be a failure, and leads to sociological and political stability. The inclusion of livestock thus allows grain farming to be pushed into more and more marginal lands".

Tadmor et al. (1974) began with barley but shifted to wheat. In a 250 mm rainfall area they obtained, as a 12-year average, yields of 2 to 4 tons dry matter per ha, depending on rainfall. They claim that 0.6 to 1.0 ha was sufficient to carry one ewe for a year without supplementation.

Range scientists in the sagebrush ecosystem need to take a hard look at these data, and at the possibility of some of our ranchers making annual forage profitable, as a means of safeguarding their operations in drought years, while affording supplemental income in years of sufficient grass.

Efficiency of Water Use

It is inevitable that efficiency of water use will become an increasingly important criteria for identification of species or genotypes adapted to the sagebrush ecosystem. Up to the present time this important characteristic has received almost no consideration. The pioneer work of Briggs and Shantz (1913, 1914) followed by studies by Shantz and Piemeisel (1927), Dillman (1931), and McGinnies and Arnold (1939) indicate the very large differences in amount of water required to produce a unit of dry matter. Even among arid range grasses there is great variation, as for example, according to Shantz and Piemeisel (1927), blue grama (*Bouteloua gracilis*) 338, and western wheatgrass 1035.

Crested wheatgrass is not a highly efficient user of water, having values around 700, but has great drought resistance because it enters into a very complete dormancy during drought or hot weather, and because it maintains high root reserves (Hyder and Sneva 1959) which enable it to recover when the heat and drought are over. Bleak and Keller (1973a) reported significant differences in water requirement between plants of Nordan crested wheatgrass, based on 11 successive harvests in a 689-day greenhouse study. They determined by partition of genetic and environmental variances that 62 percent of the variation among 5 clones of Nordan was genetic, and, since the 5 clones differed significantly in water requirement, selection for water requirement should prove rewarding.

In connection with water use efficiency, Keller (1971) estimated that on the average western range only one-eighth of the precipitation received passes through the forage plant, and that two-thirds of the total precipitation is lost by evaporation from the soil. This gives us some indication how productive the range could be if loss of water by evaporation could be reduced, or stopped.

Grass breeding will have made an important step ahead when strains of crested wheatgrass with low water requirement are developed. Water requirement should be one of the criteria in breeding all forage plants for arid rangelands.

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WILDLIFE NUTRITION AND THE SAGEBRUSH ECOSYSTEM

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Approximately 1 million square kilometers of the western United States are covered by sagebrush according to Beetle (1960). Colorado alone has 78,000 square kilometers of sagebrush range. Obviously such an abundant plant has important implications for the economy of the West. A study of these plants arouses not only the scientific curiosity of the basic researcher but also stimulates the interest of the applied scientist.

The species and subspecies of sagebrushes covering the western part of the North American continent from southern Canada to northern Mexico belong to the genus of Artemisia L. The genus has a worldwide distribution. The plants are annual or perennial, herbaceous or shrubby, usually with aromatic odor. Harrington (1954) listed 24 species of Artemisia which have been found in Colorado.

According to Morrison (1957) various species of sagebrush furnish much of the food consumed by livestock on the arid portions of the west where drought, alkali, and common salt make conditions unfavorable for most common forage crops. Domestic range animals such as sheep and cattle and wild animals such as deer and antelope consume sagebrush especially during the late winter when many other plant species are covered with snow or contain very little nutritive value.

A number of studies (Esplin et al. 1937, Carhart 1944, Stoddart and Rasmussen 1945, Smith 1950, Hoskins and Dalke 1955) recognized big sagebrush as one of the most important mule deer foods in the Rocky Mountain region. Sage grouse utilize sagebrush throughout the year.

According to Smith (1950) big sagebrush (A. tridentata) is probably the most important winter deer forage of the intermountain region. In his digestion trials, however, Smith (1950) found that deer raised in captivity refused to eat sagebrush in appreciable amounts. In these trials only four deer were used. Two, which were raised in captivity and never exposed to sagebrush before, refused to eat sagebrush and were taken off the trial. Two others, which ate native browse species including sagebrush before the 10-day trials, ate only small amounts of sagebrush. Big sagebrush (A. tridentata) was more readily consumed than black sagebrush (A. nova). One deer ate per day on the average 777 g and 86 g of air dry weight of big sagebrush and black sagebrush, respectively, while the other consumed 1,068 g and 57 g, respectively. Both animals lost considerable weight during the trial. It is interesting to note that black sagebrush is considered as a more preferred species by livestock (Wilson et al. 1906). In California Bissell et al. (1955) found that the average daily intake of sagebrush by a 45 kg (100 pound) deer was only approximately 300 g (0.6 pounds) dry weight. Deer lost weight to the extent of more than 450 g per day. They attributed this fact to the low palatability of sagebrush.

During digestion trials conducted with mule deer, Dietz et al. (1962) confirmed the results of Smith (1950) and Bissell et al. (1955). They found that deer consumed only token amounts of sagebrush when it was offered as a sole source of food. Wild deer seem to avoid feeding only on sagebrush except under the most severe winter conditions when "dead deer may hold rumens full, or nearly full, of sage, but show various stages of malnutrition" (Blaisdell 1953). Digestion trials conducted by Smith (1950), Bissell et al. (1955), and Dietz et al. (1962) revealed digestion coefficients for sagebrush ranging from 61.5 to 70.2 percent, 32.1 to 62.2 percent, and 41.6 to 52.3 percent, respectively. These values show from poor to fairly poor digestibility for sagebrush. Dietz et al. (1962) found that when deer were fed a pelleted diet containing sagebrush and alfalfa hay the relative consumption of sagebrush as well as digestibility of sagebrush (by the difference method) increased.

Chemical analyses by various researchers show that sagebrush is a fairly nutritious plant, especially during winter when deciduous browse species are dormant. Hamilton (1958) investigated the nutritive content of a number of wildlife food plants in Wyoming. Among others he presented data on sagebrush. Dietz et al. (1962) discussed the chemical contents of key browse species in Colorado. Some of the data pertaining to sagebrush obtained by these researchers are presented in Table 1 and Table 2.

Table 1. Examples of results of chemical analyses obtained on big sagebrush.

Source	Season	Plant Part	Ash	Crude Protein	Ether Extract	Crude Fiber	N.F.E.[a]	Ca	P
Hamilton, 1959, p. 35	Early spring	Leaves	4.93	9.88	10.68	16.69	51.18		
	Early spring	Twigs	5.43	5.68	4.65	36.83	41.88		
Dietz et al., 1964, p. 46	Early winter	Current annual growth	4.1	11.1	14.6	20.4	49.8	0.60	0.28
	Peak winter		3.2	9.6	13.2	19.2	54.7	0.53	0.20
	Late winter		3.6	10.5	14.1	17.9	53.9	0.62	0.20
	Summer		6.0	12.2	12.9	22.4	46.6	0.72	0.34

[a]Nitrogen free extract.

Table 2. Some results of chemical analysis--three browse species in Colorado (January).[a]

Species	Protein	Crude Fiber	N.F.E.
Big Sagebrush	9.0	18.5	56.1
Bitterbrush	7.7	28.9	56.4
Mt. Mahogany	7.7	32.4	54.4

[a]After Dietz et al. 1962, p. 49.

When Dietz et al. (1962) compared sagebrush to the four deciduous browse species, sagebrush had a lower protein content during spring. However, for late summer, fall and winter sagebrush was significantly higher in protein content than the four deciduous species. As the deciduous species matured their crude fiber content increased. Sagebrush, however, showed a slight but consistent decrease in crude fiber content. The ether extract (crude fat) content of sagebrush was found to be twice as high as that of the deciduous species. It should be noted that most of this ether extract portion consists of volatile oils. The influence of volatile oils on digestion will be covered later. It is important also to know that ruminants such as deer cannot utilize dietary fats in the same manner and as efficiently as monogastric animals.

The calcium-phosphorus ratio of sagebrush was nearly optimum (2:1) year around. This ratio was much wider (5:1) during spring and summer in the deciduous species which were studied by Dietz et al. (1962). The phosphorus content was significantly higher in sagebrush than in the deciduous species for all seasons. The carotene content of sagebrush also compared favorably with that of the other browse species (Dietz et al. 1962).

Short et al. (1966) found that the protein, carotene, ash, phosphorus, sodium, calcium, and magnesium content of sagebrush increased in the spring and summer and slowly decreased during the fall. When compared to other species tested the caloric value of sagebrush was high, due to the high ether extract content.

Gibbs (1978), using the Van Soest method, investigated the chemical content of some browse species in the Piceance Creek Basin of Colorado during winter. He studied three sites and two aspects. He found only a few statistically significant differences in the chemical content of the investigated species due to site or aspect. Some of his results pertaining to sagebrush are presented in Table 3. When compared to other browse species, Gibbs (1978) found that sagebrush was higher in protein content and lower in cellulose and lignin than the other browse species (Table 4).

Dietz and Yeager (1959) reported that they fed a total of nine deer at various intervals over a 2-year period a diet consisting of chopped sagebrush with alfalfa pellets, chopped corn, oats and "calf manna" (a commercial calf feed). Deer appeared to relish this feed although sagebrush made up the largest single fraction of the mix and they maintained or gained weight on this diet.

It is difficult to determine just how important sagebrush is in the diet of wild ruminants such as deer and pronghorn antelope. A number of field studies and digestion trials indicated that sagebrush could be classified as an emergency food, taken mainly when no other or very few other plants are available, that is, during winter when most other plants are covered by snow, contain low nutritive value and are high in crude fiber. Other reports (Carhart 1941, Mustard 1959), however, indicate that appreciable amounts of sagebrush are taken even when other valuable browse species, e.g., bitterbrush, mountain mahogany, serviceberry, are available in ample amounts.

Part of the answer to this question could be that due to the lower nutritional quality of deciduous browse species during the winter, deer are "forced" to eat sagebrush to satisfy their nutritive and energy needs. Several investigators who found a high occurrence of sagebrush in the diet of wild ruminants based their findings on rumen content analysis. This method usually overestimates plant fragments which are less digestible to rumen microorganisms.

Sagebrush is known to contain varying amounts of volatile oils. During the proximate analysis these volatile oils show up in the ether extract (crude fat) fraction along with fats, waxes, and fat soluble vitamins. These oils, although ether soluble, are terpene compounds and derivatives which do not supply energy as true fats and are excreted through the kidneys.

Table 3. Nutritive content of sagebrush in the Piceance Creek Basin of Colorado during early winter using the Van Soest method.[a]

Site	Moisture	Ash	Protein	Cell Contents	Cell Wall Constituents	Hemi-cellulose	Cellulose	Lignin	In Vitro Digestible Dry Matter
Pinyon-Juniper-Mountain Browse	39.5	3.7	10.5	61.4	35.9	7.1	16.1	12.3	61.0
Pinyon-Juniper-Sagebrush	38.5	3.7	11.1	61.0	39.0	8.7	16.1	13.5	58.4
Mountain Browse	39.1	3.6	9.0	61.9	38.1	9.2	17.3	11.4	60.9

[a]After Gibbs 1978.

Table 4. Some results of chemical analysis (Van Soest method)--three browse species in Colorado (January).[a]

Species	Protein	Cell Contents	Cellulose	Lignin
Big Sagebrush	10.5	64.1	16.1	12.3
Bitterbrush	7.5	39.9	21.9	27.3
Mt. Mahogany	8.3	36.9	24.5	25.8

[a]After Gibbs, 1978.

The antimicrobial action of volatile oils has been demonstrated on rumen microorganisms in vitro (Nagy et al. 1964, Nagy et al. 1967, Oh et al. 1968, Longhurst et al. 1968, Nagy et al. 1968, Dietz and Nagy 1976). These works showed that different plants, usually evergreens such as pine, fir, etc., and semi-evergreens such as sagebrush, levander, etc., vary in total amounts, composition, and amounts of individual oils.

Nagy (1960), examining the volatile oil content of A. tridentata tridentata on two sites in Colorado, found that the concentration of the oils peaked (3.5 percent dry matter basis) in August in leaves and twigs with a gradual decrease to approximatley 2 percent in late April. Seasonal variations in the volatile oil content were found in A. nova and A. frigida also. Differences in total volatile oil content (range from 3.04 to 5.34 percent on dry matter basis) were found in samples of big sagebrush collected from several sites in Colorado.

Powell (1970) correlated site factors to volatile oil content in sagebrush. Low volatile oil content was associated with short plants located on shallow rocky soils with a high calcium carbonate content. High volatile oil content was found to correlate with tall vigorously growing plants with an abundance of seeds. These plants were usually found growing in deep sandy loam soils which contained small quantities of calcium carbonate. The oil content on different plots was positively and highly correlated with effective rooting depth, phosphate in the A horizon, nitrogen in the 6 to 12 inch layer, clay in the 0 to 6 inch layer, and sagebrush size. Each of these factors reflects an increase in oil content with an increase in the favorableness of growing conditions for big sagebrush. Oil content was negatively correlated with clay content in the effective rooting depth and potash and magnesium in the A horizon.

According to Powell (1970), plant size, magnesium, and phosphate content in the A horizon were accountable for most of the variance in volatile oil content with magnesiums having the highest correlation. Magnesium ions activate physiological processes, such as respiration. Since volatile oils are metabolic by-products, increased magnesium content in the plant may retard volatile oil production by increasing respiration or by increasing the efficiency of carbohydrate conversion into plant compounds other than volatile oils. However, Carpenter (1976) found that magnesium sulfate fertilizer significantly increased the volatile oil content of big sagebrush on treatment plots in Middle Park, Colorado.

As mentioned earlier, the antimicrobial action of volatile oils is well documented. It should be mentioned and emphasized that in vitro work with deer rumen microorganisms showed that at low concentrations sagebrush volatile oils have no effect on microorganisms. In fact, there is some indication that small concentrations act as mild stimulants on bacterial activity. At higher concentrations, however, the antimicrobial activity suddenly increases. These in vitro observations were substantiated in vivo with a rumen fistulated goat. When increasing amounts of volatile oils were administered daily through the rumen fistula, the goat, receiving a standard pelleted ration, went off feed when the concentration of volatile oils in the rumen reached a level of approximately 15 microliters per 10 ml of rumen fluid. This concentration corresponds to the concentration of greatly increased antimicrobial activity observed in in vitro studies (Nagy et al. 1968, Dietz and Nagy 1976).

Depending on species, subspecies, analytical methods used, and possibly on site factors, there are approximately 20 chemical compounds which could be identified in the volatile oils of sagebrush (Nagy 1966, Buttkus et al. 1977). Gas chromotographic characteristics of these individual compounds could possibly be used as a tool in chemotaxonomic studies. However, there were statistically significant differences in some constituents between sites, seasons and even within a day (Nagy 1966). Buttkus et al. (1977) identified most of the compounds present in the volatile oils of A. tridentata. They found that camphor made up close to 50 percent of the volatile oils.

Longhurst et al. (1968) discussed that from a nutritional standpoint ruminants evolved in such a manner that their food must be compatible with their rumen microorganisms. They suggested that the initial food selection is through olfaction and that plants which are the most inhibitory to the rumen microorganisms are rejected or taken only with caution by the host. Nutrient content of plants is not always correlated with their palatability since unpalatable species have often been found to contain high levels of nutrients. Longhurst et al. (1968) and Oh et al. (1968) found a positive correlation between palatability and preference in most of the plant species they investigated. Oh et al. (1968) separated volatile oils into three fractions: monoterpene hydrocarbons, oxygenated monoterpenes, and sesquiterpenes. Oxygenated monoterpene fractions showed the most inhibitory action in vitro. Dietz and Nagy (1976) discussed a series of food intake trials conducted with mule deer on three juniper species. Deer were able to detect volatile oil levels (0, 1, 3, 5 percent) in a standard pelleted ration and they always preferred the lowest volatile oil containing ration. They also selected against rations containing oxygenated monoterpenes, preferring those containing monoterpene hydrocarbons or sesquiterpenes.

Ability to select sagebrush with low volatile oil content may also be exercised by sage grouse. Gill (1965), examining three subtypes of sagebrush, found that sage grouse fed primarily on two subtypes

which were found low in volatile oil content and used the other subtype (high volatile oil containing sagebrush) mainly for resting. The classification of these subtypes by Gill was based on height of the plants.

Nagy (unpublished data) introduced and raised seedlings of these subtypes in a garden and found that the volatile oil contents of all plants were uniform after one growing season. Plants which contained low volatile oil levels increased their oil content to a level which equaled plants originally with higher volatile oil content.

Barber and Nagy (1969) found that if sage grouse were enclosed in an area containing these subtypes they preferred sagebrush with the lowest volatile oil content and they shifted to those of higher oil content only after their preferred supply was exhausted. Barber and Nagy (1969) found that in sage grouse ceca (where microbial fermentation is taking place) the volatile oil content is much lower than the contents of the intestinal tract. This indicates some mechanism which prevents volatile oils from entering the ceca. Practically all volatile oils seem to be eliminated without entering the bloodstream (Barber and Nagy 1969).

Undoubtedly individual plant and plant part intake by an animal is governed not only by the nutritive characteristics of the plant (protein content, digestibility, etc.) but also by other factors such as smell, taste, and the availability of other plants. In the case of juniper volatile oils, as has been mentioned earlier, deer differentiated between volatile oil levels and volatile oil composition. In the case of rations containing different levels of oils (0, 1, 3, 5 percent), deer, as long as all of these choices were available, selected for "0" level. Once this ration was removed they ate over 90 percent of the 1 percent oil containing ration. If this choice was denied they consumed the next lowest level. Deer behavior showed that "preference" depends considerably on the choices made available.

This feeding strategy has been demonstrated eloquently by Carpenter et al. (Manuscript in prep.). Using an enclosed pasture in which deer were released and kept for 30 days, they observed dramatically changing food habits on this pasture which contained ample supply of grasses and shrubs. As one preferred supply was exhausted the diet shifted to some other plant species which became the dominant food item in their diet. Though sagebrush was superabundant it remained a minor element in the diet for 2 weeks, then its use increased abruptly (up to 30 percent of the diet) as other forage supply was depleted. Deer, however, at that time experienced considerable weight loss and some became ill.

Sagebrush undoubtedly is an important plant species. It supplies food and cover for a number of wildlife species as well as for domestic animals. It is relatively high in most nutrients during late winter when other species are unavailable or low in nutritive value. It seems that during late winter, when possibly it is needed the most as food, it contains the lowest volatile oil levels. The value of sagebrush, however, as food should be examined carefully. The volatile oil content and the composition of the oils are probably important in determining its food value and voluntary intake. Its ultimate usefulness as food may also depend on the availability and abundance of other plants on the range. Indiscriminate destruction of sagebrush stands might be as unsound from a nutritional viewpoint as the preservation of old, decadent, and predominantly sagebrush stands. The manager and the researcher must work together and apply techniques which are necessary to produce healthy animals.

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WILDLIFE HABITAT MANIPULATION IN SAGEBRUSH ECOSYSTEMS

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Introduction

Vegetational management in sagebrush:grass types expressly for purposes of enhancing habitat values for terrestrial wildlife is extremely complex. Not only do habitat requirements of various wildlife forms conflict, immediately interjecting the problem of which species to favor by any treatment, but heterogeneity of types and site specificity of treatment effects make regional generalizations next to impossible. Sagebrush communities do exist as discrete types, but more often they occur as part of vegetational mosaics with grassland, juniper-pinyon, mountain brush, oak chaparral, salt desert shrub, ponderosa pine or other conifers, even aspen. Moreover, sagebrush communities often form only seasonally important habitats for many mobile wildlife species, thus impacts of activities affecting such sites cannot be separated from other vegetational types making complete habitat complexes (e.g. pyramiding effects are potentially possible).

Undeniably most induced change in sagebrush ecosystems has been done for purposes other than wildlife habitat development; namely, to increase livestock forage production, improve watershed protection, or both. The reason for this is that funds generated for such work accrued when dollar returns could be realized, as through sales of forage to permittees and of marketable conversion products (e.g. red meat, animal fiber, and by-products). Consequently, the literature is replete with wildlife impacts papers, but conspicuously poor in habitat development research. Emphasis in this paper will be on: (1) the relatively small amount of purposive manipulation done in sagebrush:grass types for diverse wildlife species, and (2) opportunities that exist, in my opinion, to expand such programs and what they might yield in habitat benefits. I do not intend to dwell on impacts to wildlife from earlier projects because these have been abundantly documented and reviewed elsewhere (Anderson 1960, 1969, Best 1970, Carr 1968, Gill 1965, 1966, Kufeld 1968, Leopold 1950, Martin 1970, Peterson 1971, Pyrah 1971, Tschache 1970, Tueller 1976, Tueller and Monroe 1976, Vale 1974, Ward 1973, and many others).

Untreated Sagebrush:Grass as Habitat

As a start one must know something about the type as wildlife habitat if nothing changes it except traditional livestock grazing and occasional fires. McAdoo and Klebenow deal with this topic in detail, but it is unavoidable that some elements be at least lightly touched upon relative to my assignment. Obviously if extant sagebrush communities are such great habitats, a biologist would accomplish little good by altering them.

The sagebrush:grass zone encompasses great variety within sites dominated just by the big sagebrush (*Artemisia tridentata* spp.) complex, let alone other sagebrush species (e.g. *A. arbuscula*, *A. nova*, *A. tripartita*, *A. bigelovi*, and others). Not only do such sites differ in relative density of sagebrush, but also in number and amounts of associated shrubs, forbs and grasses due to site, successional status or stand condition, time since the last fire, and other factors.

The various species and subspecies of sagebrush differ widely in their relative palatabilities and forage values for each user (e.g. domestic sheep, sage grouse, antelope, jackrabbits, deer, cattle, elk), ranging from essentially nonuse to dominant elements of seasonal diets. Dr. Nagy has reviewed the status of our knowledge on the values and limitations of sagebrushes as forage for deer and other wildlife. Our understanding of their place in the total forage resource is probably best known for mule deer (Smith 1950, Dietz and Yeager 1959, Dietz et al. 1962, Nagy et al. 1964). There is still considerable debate as to the group's importance, but in general it is regarded as valuable when associated with other forage species.

Few animals are adapted to diets heavily dominated by any sagebrush form, and then only as maintenance or submaintenance winter rations (e.g. sage grouse, antelope). Plant mixtures thus become all important to animal well-being and their ability to utilize sagebrush effectively. Casual perusal of the literature on wildlife feeding behavior soon reveals the importance of adventive "weeds" and grasses that have become such ubiquitous additions to native floras (Young et al. 1972). Many of these changes go back less than a century; they have not and probably cannot be adequately evaluated in terms of wildlife population impacts.

What of the nonconsumptive users of sagebrush, dependent upon such communities for cover, insect

foods, nesting sites, associated plant foods, and other amenities? For them, the question also appears to devolve to . . . how much sagebrush and in what configuration is necessary for each user? Perhaps we cannot expect an integrated concept, one that will optimize or even modestly integrate potential user interests, including man's, because the interests often conflict (especially man's).

Moreover, in my experience several issues stand out which place us, as biologists, in rather awkward positions relative to explaining our professional stands. First, we seldom know except in general terms what the optimal requirements are for various species. Research has tended toward all-or-none comparisons, as between intact sagebrush stands vs. crested wheatgrass monocultures. Further, there appears to be a tendency to deny stand dynamism with regard to composition over time, and what that means to specific wildlife forms. It is a common trap for researchers and land managers alike to resist change, cling desperately to what we have out there, and assume all will be right with the world (a stewardship vs. management stance that often is dead wrong in terms of expressed goals). Traditional grazing and active fire suppression have influenced sagebrush:grass communities to the extent that much of the zone is in low "condition" with sparse understories, and heavy dominance of the overstory by sagebrush (Pickford 1932, Stewart 1941). Progression toward something better is usually slow, even with improved management. Seldom have research studies shown that sagebrush in most stands is used or needed by any wildlife species in the superabundance that often occurs. Indeed, if a common thread exists over the sagebrush:wildlife literature, it is that too much is nearly as great a problem as too little, and that most species do best where stands have good mixtures of shrubs, grasses and forbs, and/or a variety of cover types (from fairly heavy brush to grassy openings) occurring in relatively small areas.

Sagebrush Manipulations as Habitat

In the past, wildlife and land management agencies were guided by a principle of optimizing wildlife habitat productivity for at least some species. As demands upon rangelands intensified and more "publics" were heard from, such efforts have become increasingly difficult to justify. Not because the projects were ineffective in most cases, but because we failed to convince those publics that vegetation management was or could be worthwhile in a broader sense than just a means of providing targets for hunters or forage for livestock producers. At present, management agencies have imposed moritoria on vegetation manipulation activities, or are carrying them on at very low levels, in reaction to strong but often poorly-informed public outcry.

Furthermore, few biologists have focused on the positive wildlife reactions to various plant community disturbances, partly because large-scale treatments, often resulting in negative interactions, have been the rule (Roberts 1975). Thus we were to some extent blinded to opportunities for increasing animal diversity in local situations with acceptable readjustments in "undisturbed" faunal relations. That is, we concentrated on the reduction of species tied directly to a parcel of dense shrubland (Brewer's sparrow; least chipmunk?), without seeing that we gained species more suited to grassy openings (horned larks; mountain vole?).

Purposeful change in plant communities can accomplish a number of useful ends for both game and nongame species if change is planned properly and is based upon known animal responses. I see no real difference between Leopold's (1948) early concept of farmland cover type interspersion for bobwhite quail and sagebrush manipulation for sage grouse. The objective in either case is to provide more units of effective habitat per unit area to accommodate more flocks or coveys. By establishing conservative guidelines for sage grouse habitat based solely upon untreated stands (Braun et al. 1977, Western States Sage Grouse Committee 1974), we become locked into sometimes poor situations. I, for one, believe we can make habitat better if we want and if we are careful. This is an area needing research attention.

Few if any animals utilize plants or exist in communities in a random pattern. There is always a potential then to favor any particular animal by altering plant composition or structure in some way to increase the plants or types most useful to that animal. For example, mule deer make but marginal use of many large expanses of sagebrush:grass for winter range unless adequate thermal or escape cover such as juniper-pinyon stands are available (Terrel and Spillett 1975, Lechenby 1976). Tree invasion of sagebrush:grass can provide cover, yet unless the overstory is carefully managed it can occupy the site to the detriment of the shrub:grass understory (Urness 1976).

In addition to increased habitat and faunal diversity, carefully executed type modifications can improve seasonal nutrition for many wildlife species. Techniques are available to increase relative density of better quality indigenous plant species through "thinning" of highly competitive, abundant species of lower quality. The semiarid sagebrush:grass zone is frequently characterized by the latter group. Fertilizer applications may have some utility in certain situations (Bayoumi and Smith 1976). Seeding of introduced grasses and other plants on portions of an area can result in earlier greenup in spring, a critical time for most wildlife (Ammann et al. 1973). Such seedlings often provide high-quality plant foods that aid in more rapid recovery of body condition lost in the stressful winter period. Seeded species can supply significant amounts of green herbaceous forage on many sagebrush winter ranges where native species are either dormant or low in availability. Fall regrowth of crested wheatgrass, Russian wildrye, and some other grasses can serve in a "browse-sparing" capacity; that is, by suppying palatable, nutritious forage in fall and snow-free periods in winter they extend the often limited amount of higher-quality browse so necessary for big game when snow covers lower-growing foods.

Another benefit to wildlife of range seedings that has frequently been overlooked or discounted by biologists emanates from the original purpose seedings were implemented. Chronic spring-fall bottlenecks of forage availability for livestock resulted in severe grazing pressures on foothill ranges across the sagebrush:grass zone. Consequently, condition of these ranges declined and competition for palatable browse and herbaceous forage between livestock and wild ungulates became intense. Smaller

wildlife were caught in the middle. Grass seedings at lower elevations have greatly relieved that situation although certainly not eliminating it (Lamb 1966, Vale 1974). We now need to do a great deal of fine tuning to work out the remaining problem areas of wildlife:livestock conflicts to the extent possible. Meanwhile we need to keep in mind that seedings have done their job, getting better animal distribution over the range, reasonably well. The alternatives for wildlife, in my view, were and are much less attractive.

Habitat Changes Through Fire Treatments

Fire in the sagebrush:grass zone can have both beneficial and deleterious effects on wildlife depending on size and season of burn, preburn plant composition and condition, soil moisture levels, whether or not the area is reseeded, and many other factors (Wright and Britton 1976). Sagebrush species are nearly all highly susceptible to fire, as is bitterbrush (*Purshia tridentata*) a common shrub associate. Other shrubs are fire sensitive, such as serviceberry (*Amelanchier spp.*), or strongly fire resistant including sprouting species of rabbitbrush (*Chrysothamnus spp.*) and horsebrush (*Tetradymia spp.*). Fall burns impact many forbs and grasses lightly and these recover fairly rapidly following release from shrub competition. They usually increase production for a period of years until shrubs resume dominance, assuming proper grazing management.

Where the preburn understory is poor, seeding either single or, preferably, mixed species (Plummer et al. 1968, Heady and Bartolome 1977) is the rule. Success of shrub seedings has varied from excellent to essential failures depending upon site and numerous other factors including seed and seedling losses to wildlife. As yet only modest predictive capability has developed (Medin and Ferguson 1972, Plummer et al. 1970, Stevens et al. 1974), and this appears best if tied into the habitat-typing approach of Daubenmire (Hironaka 1977, Franklin and Dyrness 1969). In contrast, grass seedings especially wheatgrasses (*Agropyron spp.*) are almost routinely successful when applied with a rangeland drill. Seedings with use of aircraft have been generally poor unless some means of seed coverage such as chaining was employed.

Burning as a vegetation management tool is somewhat less controlled in terms of post-treatment configuration than some mechanical or herbicidal methods. Prescribed burns in sagebrush range from complete, within the confines of fire lanes, to highly irregular, leaving fingers or islands of unburned shrubs for good "edge effect". The latter situation is preferred for wildlife and results in a more natural appearance in the post-fire community. Either way, changes of uniform shrubland to a combination with grassland openings increases diversity (Loope and Gruell 1973). It tends to broaden the food base for seed-eating birds, especially where pre-burn stands are strongely sagebrush dominated. Reduced numbers of shrubland adapted animal species are frequently more than compensated by increased species and total numbers suited to more open type (Buttery and Shields 1975, Loa and White 1972, Best 1972, Pyrah and Jorgensen 1974).

Small mammal populations appear to react in a similar way (Balph 1971, Black and Frischknecht 1971, McGee 1976). Reseeded areas can greatly increase seed availability for many rodent species, but livestock grazing intensity strongly influences the actual response. An expanded prey base or easier hunting in grassy openings could conceptually increase values for raptors (Snyder and Snyder 1975) although this has not been investigated thoroughly for sagebrush:grass types specifically (Howard and Wolfe 1976).

Sage grouse may be positively or negatively affected by sagebrush control projects using fire, depending upon advance planning. Wintering areas are most critical where above-snow shrub cover is absolutely necessary for survival and sagebrush leaves are practically the entire diet (Beck 1976). Sage grouse utilize sagebrush for food at other seasons, but they also use more open types (or combinations of openings and dense shrub stands) for strutting, nesting and brood-rearing in spring and summer (Rogers 1964, Swope 1969). Forbs and insects are important summer foods and these are usually most abundant around surface water sources and grassy openings, even cultivated croplands.

Scheegas (1967) challenged the tendency of many biologists who have assumed sage grouse need unbroken sagebrush stands; indeed his view was that bird density has not kept pace with increased sagebrush density on northeastern California ranges. He, therefore, suggested that some sagebrush control would be useful in developing optimal summer range combinations of shrubland, grassland and meadow. Klebenow (1973) and Phillips (1972) concurred and discussed in detail how habitat requirements and range improvements could be integrated.

Few references deal with fire in relation to pronghorn antelope. Heavy seasonal use of sagebrush and associated browse for food would suggest a negative influence with widespread burning on winter ranges (Sundstrom et al. 1973). However, forbs are important in spring-summer diets and habitat modifications with fire could increase forb production. Deming[1/] observed definite attraction of antelope to small burned stands at Hart Mountain Refuge in south-central Oregon; they were seeking forbs on burned sites which were not available in adjacent dense sagebrush. Fire probably has less negative impact on forbs as a class than herbicides so prescribed burning as well as mechanical sagebrush control with seeding has a place in antelope range management (Yoakum 1975). Legumes mixed with grass in some seedings was especially attractive (Heady and Bartolome 1977).

Mule deer use of burned areas has increased or decreased depending largely on the preburn community composition and whether or not the area is reseeded. Burned stands that had good mixtures of browse species usually exhibit much reduced deer use in winter (Leopold 1960, Longhurst et al. 1976). However, fires in monotypic sagebrush stands can increase forage values, especially where seeding (e.g. crested wheatgrass or, preferably shrub, grass,

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[1/] Deming, O. Address presented at the Oregon Game Biologists' Meeting, Oregon State University, Corvallis. February 26, 1965.

forb mixtures) is done (Plummer et al. 1968, Lechenby 1969, Koehler and Lechenby 1970, Urness 1966, 1976). Created mosaics of this type can yield greater variety and increased nutritional value of the total forage resources; actually enhancing use of surrounding sagebrush. Failure to seed on formerly poor stands often results in lower value cheatgrass and sprouting shrubs (e.g. rabbitbrush, horsebrush). Fire can probably be used as a tool to alter sagebrush communities to favor grass feeders such as big horn sheep (Lauer and Peek 1976). Where competition in winter between mule deer and big horn sheep is heavy, burning of shrubland to create grassland on critical areas could benefit the less competitive sheep.

Habitat Changes Through Herbicidal Treatments

Shrub control with 2,4-D began in the early 1950's and since then this method has been applied to vast areas across the entire sagebrush:grass zone. Use of spraying alone has generally occurred in stands supporting a suppressed but satisfactory grass:forb understory (Vale 1974). Grasses are favored, whereas many perennial broadleaved forbs and shrubs are killed or greatly reduced by 2,4-D (Anderson 1969b). Many valuable forbs and shrubs may be only lightly or moderately impacted, suggesting a means of differentially reducing less useful or superabundant species (Blaisdell and Mueggler 1956, Sneva and Hyder 1966, Hyder and Sneva 1962). Forage production for cattle particularly, can show quite spectacular early responses. Time lapse before resumption of sagebrush dominance is highly variable. Occasionally, chemical control was followed by reseeding, although not a common practice. Long term effects of reseeding vary little from burn:seed or plow:seed treatments; dead shrubs disintegrate quite rapidly.

Aerial spraying is cheap and easily applied, consequently large tracts have been treated (Heady and Bartolome 1977). This method's advantage is less soil disturbance and, if carefully planned and executed, it could be highly flexible in regards vegetational patterning. Ground rigs or helicopters would be especially effective in creating desired mosaics.

Many small mammal and bird species likely find sprayed sagebrush better habitats than burned areas because of greater cover values at least temporarily provided by dead standing shrubs (Best 1972). Some forms, Brewer's sparrows for example, do not apprently adjust to sprayed stands at least for some activities such as nesting (Schroeder and Sturges 1975). Loss or reductions of perennial forbs since sprayings occur in late spring could impact some species such as pocket gophers adversely (Turner et al. 1973, Hull 1971), but seed eaters should benefit where grazing is light to moderate.

Sage grouse habitat in relation to herbicidal shrub control has been intensively scrutinized (Carr 1968, Gill 1966, Kufeld 1968, Martin 1970, Rogers 1964, Wallestad 1975). Most workers have concluded that the large treatments so typical in the past for increasing livestock forage are detrimental to sage grouse. Concern has focused on winter ranges (Beck 1976), but impacts on spring-summer breeding complexes can also be severe. Seemingly, attitudes toward past abuses have limited work to determine how herbicides might be used to develop better habitats. Klebenow (1970) and Autenrieth (1969) discussed some potential benefits on sprayed areas. While total forb cover is usually reduced, some prominent species in summer diets, such as dandelion (*Taraxacum sp.*), western yarrow (*Achillea sp.*) and salsify (*Tragopogon sp.*), increase on sprayed areas, an important consideration for brood-rearing habitat (Beck[2/]). The positive responses occurred at relatively high elevation on sites with good precipitation, perhaps drier ranges would respond less well (Western States Sage Grouse Comm. 1974).

Vegetative cover requirements for different breeding activities vary considerably. Open areas are preferred for strutting provided adjacent sagebrush cover is adequate as travel lanes to the strutting ground (Gill 1965). A high percentage of nests are located within three miles of the strutting ground and most nests are under live sagebrush plants of moderate height. These findings have led to adoption of conservative guidelines for integrating sage grouse into range improvement planning (Braun et al. 1977). To date little or no research has been done to determine how much sagebrush is actually needed for either nesting or strutting ground maintenance. Conversely, no one seems to have investigated possibilities of altering breeding complex vegetation to make it better (e.g. preventing shrub invasion onto strutting grounds, clearing brush that has encroached upon meadows, altering size and density of sagebrush to most closely approximate estimated nesting requirements). Autenrieth[3/] suggests brood-rearing areas have greatest potential for direct improvement; research is needed to develop means to increase usable forb production and integrating shrub cover with grassy openings (Schneegas 1967).

Antelope rely heavily upon browse diets during much of the annual cycle; forbs are important in spring and summer. Despite the prominence of sagebrush species in their diets, they appear to do best where shrub cover is moderate and fairly low in stature (Vale 1974, Sundstrom et al. 1973, Yoakum 1975). Potential exists, therefore, to use herbicides in extensive dense stands of tall sagebrush with poor understories. Such treatments can greatly increased herbaceous species and improve the overall mix of all forage classes. Mixed seedings that include forbs such as dryland alfalfas can be highly useful (Heady and Bartolome 1977).

Herbicide treatments in sagebrush:grass for development of deer and elk habitat can yield results similar to those for antelope. Large reductions of sagebrush, even in monotypic stands, are undesirable, but small patches interspersed with intact brush can improve forage variety (Urness 1966). Browse production on chemically thinned or reestablishing sagebrush can exceed amounts in

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[2/] Beck, T. D. I. Colorado Dept. Game, Fish & Parks. Glenwood Springs. Personal Communication.

[3/] Autenrieth, R. E. Idaho Game and Fish Dept., Jerome. Personal Communication.

dense stands where intense intraspecific competition occurs (Anderson 1969a), and such growth may be more attractive to deer. Spraying mixed shrub communities that include palatable shrubs such as bitterbrush, cliffrose, serviceberry, mountain mahogany, and other species is not recommended (Kufeld 1968).

Elk are more plastic feeders than deer and appear better able to exploit change from sagebrush to grass (Ward 1973, Kufeld 1968). Wilbert (1963) observed elk behavior relative to sprayed sagebrush stands in spring, and concluded the increased availability of early green grass and forbs was of benefit in obtaining better animal distribution. Spraying was done on lowland sites where snow depth precluded elk use of sagebrush in winter; something to be considered in localized areas across the entire sagebrush:grass zone. Ability to attract big game animals from concentration areas or to reduce damage to cultivated crops would be a management boon in many locations.

Habitat Changes Through Mechanical Treatments

Mechanical methods of sagebrush control are highly varied in their effects on the post-treatment stand. For example, chaining, railing, and roto-beating usually have light or moderate impacts on soil, but plowing often reduces the site to the appearance of a cultivated field. Such methods are expensive, yet they offer excellent design control to assure adherence to treatment prescriptions. Plummer et al. (1968) recommended sagebrush chaining with or without seeding on game ranges because it does not completely kill out sagebrush and retains native grasses and forbs quite well. Rotobeating is probably even better in this respect, but it is not suited to rocky areas (Hedrick et al. 1966, Urness 1966, Kearl and Brannan 1967, Mueggler and Blaisdell 1958). Plow: seed treatments have been the most widely used and account for most of the crested wheatgrass seedings so common in the Great Basin and aridlands of the Northwest (Heady and Bartolome 1977, Vale 1974).

As environmental concern intensified after the mid-1960's, treatment design has emphasized smaller-sized areas, mixed species seedings, and more natural appearance (Medin and Ferguson 1972, Plummer et al. 1968, 1970). Mixed seedings can create problems in livestock grazing management (Vallentine 1971), but where shrub-grass-forb mixes are successful they have had obvious advantages to big game and other wildlife (Lamb 1966, Buttery and Shields 1975).

Long-term policies of federal, state and private land managers in active fire suppression led to extensive encroachment of juniper and pinyon trees onto sagebrush and grassland areas (Blackburn and Tueller 1970, Burkhardt and Tisdale 1976). Up to a point, tree overstories are beneficial to many wildlife species (e.g. nesting and perching sites, escape and thermal cover, browse and seed production). However, as stands thicken their competitive advantage on semi-arid sites leads to essential elimination of the understory (Tausch 1973, West et al. 1977). Anchor chaining and seeding has been employed extensively to restore a healthy shrub:grass understory (Plummer et al. 1970, Tueller and Monroe 1976). Many older projects were seeded to only crested wheatgrass (Terrel and Spillett 1976) with limited values to deer, but seed mixtures are increasingly used. The objective now is seldom to eliminate trees over large tracts, rather to leave islands, travel lanes, and finger-like projections in smaller, irregular-shaped treatments interspersed throughout woodland areas. These changes should go far in overcoming legitimate objections raised over past projects in terms of visual and wildlife impacts. Indeed, habitats for many wildlife species can be greatly improved while tree-adapted species' niches are maintained in adjacent woodland.

Mechanical treatments on sagebrush sites without juniper or pinyon can have wildlife impacts more or less severe than fire or chemical methods depending upon design. A successful crested wheatgrass seeding, for example, will not differ materially whether it is done on a burned, sprayed or plowed seedbed. The advantages I see in many mechanical methods is their capability to effect controlled or partial treatments, so important in stands containing a variety of shrubs and where only adjustments in relative amounts are desired. Thus part of the shrub and most of the herbaceous components can be retained, avoiding some of the difficulties in getting shrub reestablishment from seed on arid sites (Medin and Ferguson 1971, Holmgren and Basile 1959). Such methods also eliminate uncertainty of size and shape of treatment so embarrassingly frequent with fire and aerially applied herbicides in the past.

Habitat Changes Through Livestock Grazing

Livestock grazing is the most influential factor affecting sagebrush:grass vegetation wherever it is presently found. Relatively little of the zone is without some intensity of use during at least part of the year. Class of livestock determines to some extent the kind of vegetation development, even where use is "proper". Long-term use by cattle can shift succession toward a browse:forb mix away from grass, whereas sheep shift succession toward a stronger grass dominance (Ellison 1954). Separation of animal classes on established allotments is the rule on most public ranges. Also it is the rare ranching operation that is integrated, although this may be developing given the uncertainty of ranching enterprises and recent improvement in range sheep profitability compared to cattle.[4/] Some form of alternating use pattern, if not concurrent integrated systems, would be useful on many ranges, private and public, to assure successional stability at some relative phase identified as desirable for a given array of wildlife.

Wildlife interests have been highly critical of livestock grazing, especially on public lands, as a source of severe conflicts with one or a broad spectrum of wildlife species (Gallizioli 1977, Mackie 1978, Vale 1974). No doubt there has been and is reason for this on many areas (Wagner 1976). However, while recognizing problem areas needing resolution, we should not lose sight of real and potential benefits to wildlife generated by livestock grazing and associated activities. It is fact that past rehabilitation efforts on sagebrush:grass ranges have primarily been done to increase livestock forage, and then only after a prolonged abusive grazing

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[4/] Neilsen, D. B. Utah State University, Logan. Personal communication.

history. Still these activities have produced heterogeneity in otherwise homogeneous types through created developmental vegetations which have seldom if ever been assessed as to their contribution to faunal diversity (Koehler and Leckenby 1970, Urness 1966). Moreover, the food habits literature on deer, antelope, sage grouse, or small mammals and birds reveals a strong use of seeds and foliage from adventive plants introduced to the West by or for livestock. Noone knows what this has meant to wildlife on ranges remaining after extensive land preemption for agriculture, but they are undeniably important in at least seasonal diets of adaptable mid-successional wildlife. Agricultural crops associated with range livestock operations also are used, at times heavily, as attested by damage claims from private landowners on state wildlife agencies.

Water developments for livestock on arid lands can have beneficial effects on wildlife distribution and range use in summer. Antelope, sage grouse, deer, waterfowl and many small and nongame species utilize stock water developments of various types (Heady and Bartolome 1977, Yoakum 1975). Dependability of water sources is important and public land managers should assure water permanence wherever possible (Gibbons and Fisser 1975). The practice of using water availability as a means of livestock control should be discontinued; in this sense fencing of the range is preferable to allowing water sources to dry up.

Fencing has often been cited as a major problem for big game, especially antelope, in free use of rangelands and as impediments to migratory movements (Wallmo 1973). Recent advances in federal land policies regarding fence construction have helped (Spillett et al. 1967, BLM 1975). The other side of the issue of fencing vs. wildlife is only now receiving concerted attention; namely, getting better distribution of livestock over the range to alleviate concentration areas around stream bottoms, ponds, seeps, etc. Few activities could benefit more wildlife species, especially in the more arid sections of the sagebrush:grass zone (Oakleaf 1971, Savage 1969, Buttery and Shields 1975). It is unrealistic and unjustifiable that all such areas be protected, but a start on identified critical areas should be made.

Impacts of livestock grazing upon vegetation has generally been interpreted as adverse to many wildlife species, particularly those more rigidly attuned to climax or near-climax conditions, such as big horn sheep (Lauer and Peek 1976). Conversely vegetational changes wrought by grazing have improved carrying capacities for other species adapted to mid-successional vegetation, mule deer for example (Wagner 1976, Urness 1976, Longhurst et al. 1976). Smith (1949) demonstrated the extent to which cattle grazing of foothill ranges heavily used by deer in winter can maintain shrub dominance. Followup studies have generally not demonstrated increased carrying capacity in the short-term, per se, but have shown that livestock can be managed in a complemental way as to make their impacts negligible (Smith and Doell 1968, Jensen et al. 1972). The long-term effects of livestock use in maintaining a desirable mix of shrubs: grasses:forbs, by placing use on herbaceous species in summer to counterbalance winter use of shrubs by big game should be investigated. Single use by big game on winter ranges can lead to loss of shrubs on more mesic sites where perennial grasses and forbs are strongly competitive.

Management of succession on big game ranges (Leopold 1950) through use of grazing animals, where possible, is a more acceptable alternative, in my opinion, to energy-intensive mechanical or chemical means. Utilizing selective feeding behavior and other characteristics, different types of livestock (even horses) have the potential to alter plant community composition, forage production and availability, and nutritional value for specific wildlife (Smith 1976, Smith et al. 1978, Fulgham 1978). Thus goats have been shown to increase production of more available twig growth on blackbrush (*Coleogyne ramosissima*), an important deer winter forage in the southern Great Basin (Provenza 1977). Opportunities to use grazing animals to manage vegetation for wildlife, including but not exclusively for big game, are numerous; few investigations have been completed or are on-going in this area.

Grazing systems are becoming almost a by-word in western range management. Rest-rotation systems are especially commonplace on public rangelands (Hormay 1970, Herbel 1974). The concept of grazing some units heavily while resting others for recovery of plant vigor may work in areas receiving adequate rainfall. Recovery of plants from heavy use on arid sagebrush rangelands may require considerably longer time than is usually accorded in most extant systems. From a wildlife standpoint, rest-rotation grazing could be either helpful or impacting depending upon species involved, size of grazed units, and possibly their orientation relative to seasonal wildlife movements; either way the question has not been studied intensively. Two reports from Montana dealing with mule deer and elk in relation to a rest-rotation system were inconclusive, although elk appeared greatly influenced by livestock and moved to rested units. Deer exhibited no such mobility (Knowles 1975, Komberec 1976).

Autenrieth[5/] expressed concern for sage grouse in terms of heavy use pastures in rest-rotation systems. Use of certain areas for nesting and brood-rearing is apparently rather inflexible; heavy use by livestock could strongly impact these activities. Such relationships need further study. Gibbons and Fisser (1975) observed no apparent effect of rest-rotation grazing on wildlife populations, although shutting off water sources in rested units affected antelope distribution. The authors indicated there were no observations on wildlife populations prior to establishment of the grazing system and results were complicated by vegetational modifications and fencing. Nonetheless, antelope increased in number and expanded their area of use during the study period.

[5/] Autenrieth, R. E. Unpublished guidelines for sage grouse habitat management. Idaho Fish and Game Department, Jerome. 1977.

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NUTRITIONAL ASPECTS OF NATIVE AND SEEDED SAGEBRUSH RANGE FOR DOMESTIC LIVESTOCK

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INTRODUCTION

Domestic livestock are central to the economy of most western states. Many livestock depend at least in part on sagebrush dominated rangelands to furnish nutrients for production of food and fiber. Although nutrient content of selected range plants has been measured for decades, no attempt has been made to assess the utility of this information with regard to sagebrush ecosystems.

The objective of this paper is to review literature in an attempt to define the "state-of-the-art" from all the fragmented data available and suggest areas for further research. Because of the diversity of the sagebrush (Artemisia spp) region and complexity of nutritional interactions, only major organic and inorganic nutrients will be discussed. Problems concerning poisonous plants will not be discussed, although recognized as an important consideration in management decisions. Discussion will be confined primarily to those regions delineated by Kuchler (1964) as the Great Basin Sagebrush, Sagebrush-Steppe, Wheatgrass-Needlegrass Shrubsteppe and the Grama-Needlegrass-Wheatgrass types. The latter type is included because it is extensively invaded by sagebrush.

The Great Basin Sagebrush type comprises most of the intermountain area and extends eastward to Colorado and southward to Arizona and New Mexico. It supports moderately dense to open vegetation of low to medium tall shrubs. Subordinates are primarily cool-season bunchgrasses and forbs.

The Sagebrush-Steppe extends throughout the Pacific Northwest eastward of the Cascade Mountains to the Rocky Mountains to Montana and Wyoming. The physiognomy is dense to sparse grassland with closed to open shrub aspect. Bluebunch wheatgrass (Agropyron spicatum) is often the dominant subordinate but may exchange or share dominance with other cool-season bunchgrasses.

The Wheatgrass-Needlegrass Shrubsteppe is located in north central Wyoming and southern Montana. The physiognomy is open grasslands, sometimes fairly dense, with scattered dwarf shrubs. Potential dominants are western wheatgrass (Agropyron smithii), needle-and-thread (Stipa comata), and plains bluegrass (Poa arida) (Kuchler 1964).

East of the continental divide, including northeastern Wyoming and eastern Montana, are areas which support primarily Grama-Needlegrass-Wheatgrass communities. The physiognomy of these areas is rather short, fairly dense, open grasslands which often have an overstory of sagebrush.

Throughout the Great Basin Sagebrush and Sagebrush-Steppe types, juniper overstory may be closed to open. Other important Artemisia species include arbuscula, nova, and cana. Although sagebrush taxa are important in recognizing and delineating communties (Winward 1970) and differential preference by deer and sheep have been found (Sheehe 1975), it will not be the purpose of this paper to relate nutritive value to specific subspecies of Artemisia.

Many areas which previously supported big sagebrush (A. tridentata) have been plowed and reseeded to commercial and improved grass varieties, such as the Agropyrons (desertorum, cristatum, sibericum, intermedium, elongatum, etc.). Big bluegrass (Poa ampla) has shown promise in many areas. Few successful seedings of forbs or legumes are known, especially west of the continental divide (Gomm 1974).

NUTRIENT REQUIREMENTS OF DOMESTIC LIVESTOCK

In order to assess the role of range forage in the nutrient requirements of domestic livestock, it is necessary to define their needs. Suggested minimum levels of various nutrients have been given by the National Academy of Sciences - National Research Council (NRC) for cattle (1976) and sheep (1975).

Inadequate nutrition normally has an adverse effect on animal performance, although some weight fluctuations in the mature animal can be expected- and tolerated-throughout the year. Losses of up to 15% of the mature body weight may have a minimal effect on animal production, provided sufficient nutrients are available at critical periods to insure ovarian activity. Topps (1977) indicated that when cows lose a substantial amount of body weight, e.g., 20 to 30% of their mature weight, cyclic ovarian activity ceases. The mechanism by which loss of body weight adversely effects fertility in cows is unknown. Roberts et al (1977) suggested that animals which lose up to 40% of their body weight because of undernutrition in late pregnancy and early lactation develop a pathological disorder whereby efficient utilization of subsequent energy is impaired.

In many instances environmental stress adds to nutrient requirements of animals grazing rangelands. Stresses may be weather oriented--severe cold, wind, snow, rain, and/or temperature extremes or geographically oriented--distance to water, steep slopes or lack of shelter or shade. Van Dyne and Van Horn (1965) reported that in many cases wind movement and speed could have more influence on energy expenditure of sheep than temperature or relative humidity. Raleigh and Lesperance (1972) indicated that energy expenditure in grazing movement probably amounted to almost 20 percent of the digestible energy required for maintenance. Sneva et al (1977) showed that cows and calves trailing greater than 1 to 2 miles and/or drinking every-other-day were stressed and calves did not perform as well as pairs with adequate water.

Currently, defining range-forage quality and prescribing supplementation is as much an art as a science, i.e., "what is the condition of the animal under each set of circumstances, and what performance do I expect?" The most critical factor managers must know in order to satisfactorily answer these questions is how much that animal will voluntarily consume. Unfortunately, no predictors of voluntary intake are known which are applicable under range conditions (Rittenhouse 1976, Cook and Child 1977).

EXPRESSING FORAGE QUALITY

The ultimate criterion of the nutritive value of range forage must be measured in terms of the production response by the animal. Normally, forage quality is expressed in terms of energy, protein, vitamins, and minerals. Energy may be expressed as total digestible nutrients (TDN) or Kcals of digestible, metabolizable or net energy per kilogram of dry matter. Likewise, protein may be expressed as crude protein, digestible crude protein or metabolizable protein (Burroughs et al 1975). It is beyond the scope of this paper to discuss the relative merits of each expression.

The factors influencing the nutritive value of grazed forage are similar in most respects to agronomically grown forages harvested as hay or fodder (Ulyatt 1973, Raymond 1969). A review on the nutrition of grazing ruminants (McDonald 1968) revealed numerous differences between grazing and hand feeding. Assessing the nutritive value of grazed forage is more complex than harvested or stored forage. The problem is even further magnified when assessing the nutritive value of diverse forage on extensive grazing areas, as found in the sagebrush types. Less is known about nutrient utilization of shrubs than other forage classes; however, their importance in diets of domestic livestock and wild herbivores has been shown (Wilson 1969).

Laboratory methods useful in the nutritional evaluation of range forage adequate to predict animal performance are lacking, however, many methods have been developed to estimate nutrient content (Barnes 1973). Although techniques are available to closely approximate digestible energy (Tilley and Terry 1963, Van Soest et al 1966), crude protein, vitamins and minerals of forage, two major obstacles remain: 1) determining the relationship between available nutrients, *in situ*, and selection and utilization of these nutrients by domestic livestock and 2) predicting the quantitative voluntary intake of various classes of livestock in various physiological stages of production.

Upon reviewing the literature to determine how effectively plants meet the nutritive needs of livestock, one must keep in mind that techniques available (see Harris et al 1952, Harris et al 1959, Harris et al 1967, Cook 1964) for such measurements under range conditions have limitations. Many of the estimates of digestible nutrients are based on values calculated from the lignin ratio technique. We know this technique is limiting because of the varied nature of lignin and its varied apparent digestibility. Other internal markers would bear similar criticism. Use of external markers such as chromium oxide, even with double sampling, is subject to large errors and none meet all of the criteria discussed by Faichney (1975). Intake is often estimated using the fecal production-indigestibility ratio technique. Osbourn and Terry (1977) warn that use of the two stage rumen liquor-pepsin *In vitro* technique may not be appropriate for measuring intake because digestibility and consequently indigestibility are known to vary with level of intake. Further, *In vitro* techniques can not account for nutrient imbalances in the rumen.

FACTORS AFFECTING FORAGE AND DIET QUALITY

We find no evidence to suggest that sagebrush, *per se*, has any unique influence on the nutritive quality of subordinate vegetation or vegetation introduced on areas formerly occupied by sagebrush (with or without reestablished sagebrush). One can postulate an indirect influence may exist because of alterations in mineral cycling, energy capture or possibly allelopathy. We know that sagebrush influences spatial distribution, and to some extent, physical availability of forage (Schlatterer and Tisdale 1969; Reece 1974). Sagebrush also competes with understory vegetation for moisture and light and reduces productivity (Rittenhouse and Sneva 1976). However, in general nutritive value of rangeland forage is related to habitat, class of plant, and class and behavioral characteristics of the grazing animal.

A survey of the voluminous literature indicated that plants utilized by domestic livestock exhibit certain common nutritional characteristics as measured by chemical constituents. However, even though generalizations are meaningful, individual species' physiological/ecological characteristics must be examined.

Environment

Climate: Because the sagebrush type is so extensive, climate influences the species and morphology/physiology of plants. The area can be roughly divided north and south near the 26th parallel and east and west by the continental divide. Characteristically, total and/or effective precipitation is low, thus limiting primary production.

West of the continental divide the bulk of the precipitation is received as winter snow and spring rains. Summer convective storms are generally erratic and ineffective. Forage quality as related to crude protein content of the plant declines rapidly with advance in season, regardless of species (Figures 1).

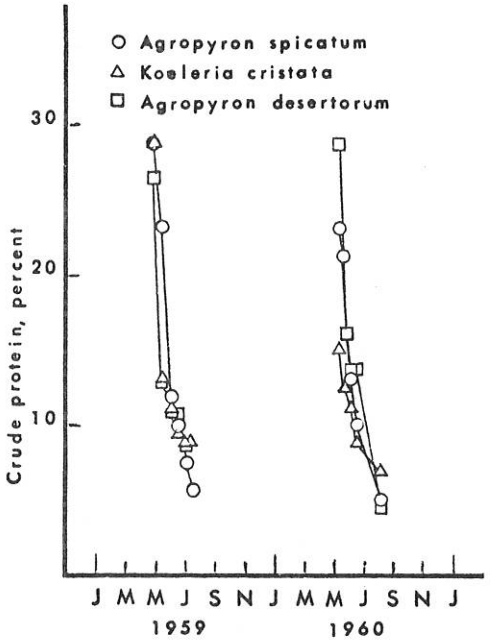

Figure 1. Crude protein content of bluebunch wheatgrass (Agropyron spicatum), Junegrass (Koeleria cristata), and crested wheatgrass (Agropyron desertorum) during 1959 and 1960 near Burns, Oregon (Raleigh 1970).

East of the continental divide precipitation is primarily from spring and summer convective storms, moderated by the influence of rain shadow effect. Opportunity for regrowth in areas east of the continental divide would be expected to be unpredictable throughout the summer months. Even though moisture is the primary limiting factor, high temperatures can markedly affect regrowth of many species. Figure 2 shows the variability of crude protein content of blue grama (Bouteloua gracilis), needle-and-thread (Stipa comata), and western wheatgrass over several years near Miles City, Montana. Protein content of big sagebrush, shadscale (Atriplex confertifolia) and winterfat (Eurotia lanata) have been plotted for the winter months when available.

Generally, crude protein values dropped rapidly as plants matured in all localities. Species at Miles City showed the potential to respond to favorable environmental conditions throughout the entire growing season, whether characteristically warm- or cool-season in nature. Shrubs were higher in crude protein in winter than grasses at all locations. But, in some instances values fell below requirements of lactating animals.

Therefore, climate controls the rate of growth and regrowth of plants as the season advances. Many soluble organic and mineral fractions are subject to leaching following scenescence. Differences in precipitation patterns could influence the extent of this leaching process.

Light and Shading: The canopy of sagebrush significantly alters and/or reduces the quantity and quality of light available to understory plants. Although a dearth of information exists on the direct influence of sagebrush canopy, per se, on the nutritive value of forages, other studies have shown an influence of light/shading on nutrient content.

Perhaps the greatest influence of shading by the sagebrush canopy is its effect on phenology. Reece (1974) found phenology of Junegrass (Koeleria cristata), Thurber's needlegrass (Stipa thurberiana) and squirreltail (Sitanion hystrix) to be variable among locations within the same habitat-type. However, Junegrass and Thurber's needlegrass were more advanced in interstitial zones than beneath sagebrush canopy. Furthermore, Junegrass tended to be more phenologically advanced on south than north sides of the sagebrush plant.

Under tree canopies McEwen and Dietz (1965) observed higher crude protein of plants growing in forested compared to open areas. However, comparisons were confounded with phenology. Species beneath canopies were 1 to 2 weeks behind those in open meadows. Greatest differences were found during early growth stages. By the time nutrient values dropped below requirements for a lactating cow, differences were small and probably not important.

Bailey (1973) and Harkin (1973) suggested that light, as well as other climatic factors, may influence the level of structural carbohydrates and lignin, but these influences are not well documented. In many instances effects may have resulted indirectly from changes in leaf-stem ratios. Mayland and Grunes (1974) found less total water soluble carbohydrates in shaded compared to plants exposed to full sunlight, i.e., crested wheatgrass (Agropyron desertorum), 15 and 20 percent, and Basin wildrye (Elymus cinereus) 11 and 15 percent, respectively. Shaded forage also tended to have a lower dry matter content.

Sagebrush plants may have a direct influence on mineral cycling by transporting elements from lower depths to leaves which eventually fall to the soil surface. Minerals may concentrate beneath the canopy since the root system extends to interstitial spaces. In as much as Mayland and Grunes (1974) showed shade (25% of full sunlight) increased the uptake of potassium, calcium, and magnesium in crested wheatgrass, a possible interaction may exist.

Range site: Cook and Harris (1950b) studied the chemical composition of yarrow (Achillea lanulosa) and mountain bromegrass (Bromus carinatus) on favorable and unfavorable sagebrush sites on typical summer range in the mountainous region of northern Utah (Table 1). Samples were collected between July 8th and September 27th. Mountain bromegrass was higher in dry matter (5%) and cellulose (5%) and lower in protein (17%) on unfavorable compared to favorable sites. Yarrow was nine percent higher in crude protein on unfavorable compared to favorable sites. They concluded that site differences indirectly affected the nutritive value of range forage. They also concluded that differences were more a result of leaf-stem ratios and stage of growth than the chemical content of the soil.

Table 1. Chemical composition (percent) of yarrow (Achillea lanulosa) and mountain bromegrass (Bromus carinatus) on favorable and unfavorable sagebrush sites on summer range areas in northern Utah.[1/]

Site	Dry matter	Protein	Cellulose	Lignin	P	Ca	Stem-leaf ratio
			YARROW				
Favorable	49	6.8	33.8	11.9	.22	.82	1.65
Unfavorable	49	7.4	33.3	11.5	.26	.87	1.13
			MOUNTAIN BROMEGRASS				
Favorable	60	5.2	44.8	8.5	.18	.35	3.51
Unfavorable	63	4.3	47.0	8.6	.17	.34	3.67

1/ From Cook and Harris 1950b.

Demarchi (1973) compared crude protein content of bluebunch wheatgrass and needle-and-thread on ranges in different condition in British Columbia (Table 2). Sagebrush was associated with only one location on a needlegrass/bluegrass (Poa sandbergii) community. Condition class had no influence on the chemical content of needle-and-thread. Components analyzed were crude protein, total ash, calcium and phosphorus. Grazed bluebunch wheatgrass plants were higher in crude protein than ungrazed plants, probably because of a higher leaf-stem ratio.

Results from these and other studies indicated that improvement in range condition will not always result in higher average nutrient content of the diet (Cook et al 1956). Over all, Goebel and Cook (1960) found that good forage species were higher in cellulose and other carbohydrates and poor forage species were higher in ether extract, total protein, calcium, and phosphorus. Cook et al (1962) concluded that nutrient content of herbage on good compared to poor condition ranges depended on species composition.

Table 2. Chemical composition (percent) of bluebunch wheatgrass and needle-and-thread by range condition classes on the wheatgrass/bluegrass zone in British Columbia.[1/]

Component	Growth stage[2/]	Bluebunch wheatgrass		Needle-and-thread	
		Climax[3/]	Fair	Fair	Poor
Crude protein	1	12.7	15.1	15.8	14.7
	2	9.5	12.7	13.2	12.0
	3	6.8	9.4	9.8	9.2
	4	5.5	6.7	8.2	7.1
	5	2.6	3.3	4.5	4.3
	6	2.7	2.8	4.7	4.4
Calcium	1	.33	.43	.40	.37
	2	.33	.38	.39	.27
	3	.35	.40	.31	.27
	4	.32	.37	.30	.24
	5	.51	.54	.39	.41
	6	.46	.55	.39	.37
Phosphorus	1	.22	.22	.18	.19
	2	.17	.18	.16	.20
	3	.13	.12	.14	.15
	4	.08	.08	.10	.10
	5	.03	.03	.05	.04
	6	.03	.03	.04	.05

1/ From Demarchi, 1973.

2/ Growth stages: 1=leaf; 2=flowering heads out; 3-seed-ripe; 4=seeds disseminated; 5=plants cured; 6=plants weathered.

3/ Range condition.

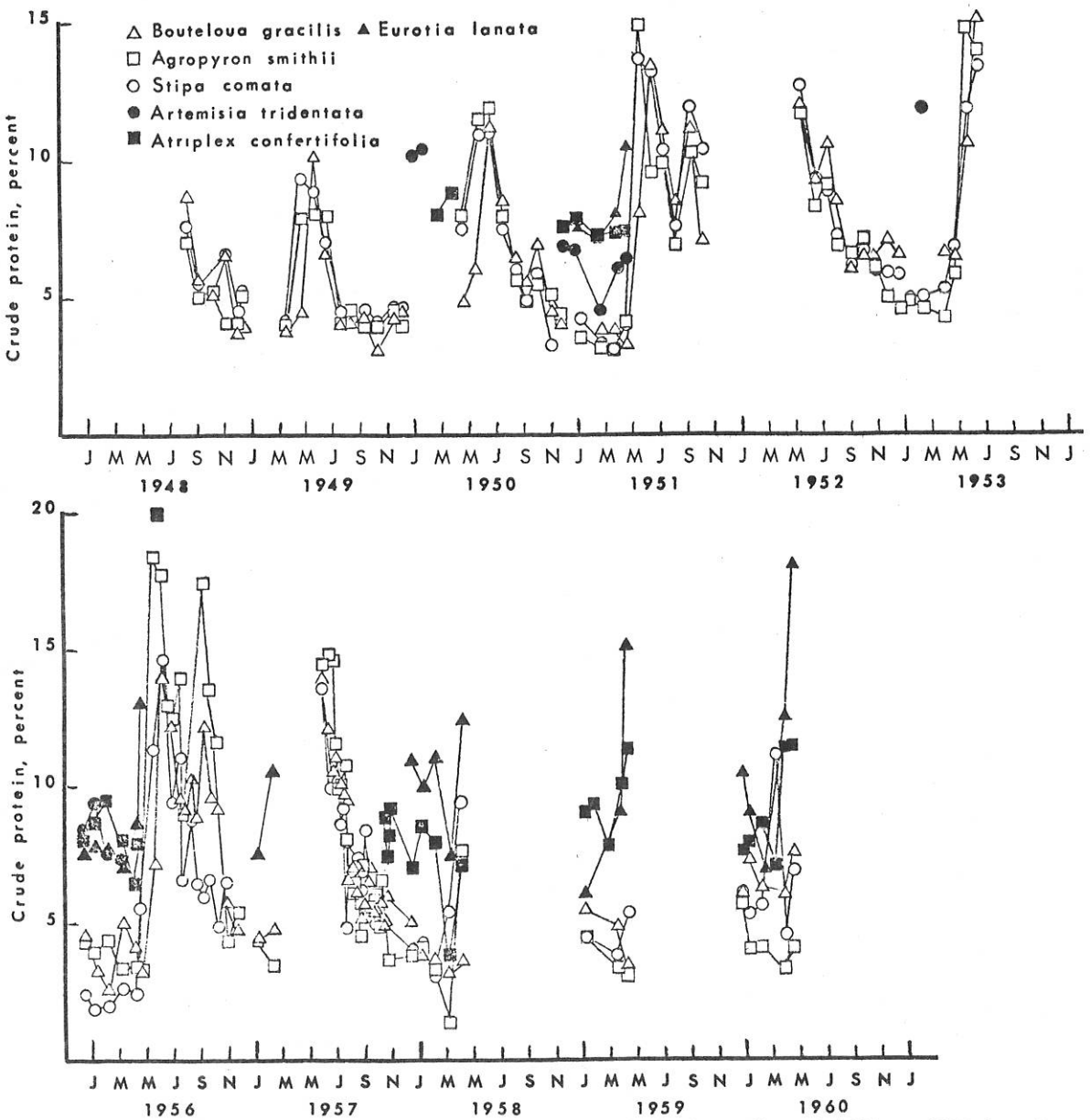

Figure 2. Crude protein content of selected grasses and shrubs collected 1948 to 1953 (Marsh et al 1959) and 1956 to 1960 (Van Dyne et al 1965) near Miles City, Montana.

Cook (1959) reported that seeded plants [crested wheatgrass, intermediate wheatgrass (Agropyron intermedium), and tall wheatgrass (Agropyron elongatum)] on favorable sites had about 50 percent more stems than leaves by weight and plants on poorer sites had about equal portions of leaves and stems. Average protein contents of entire plants on June 15 were higher on unfavorable than favorable sites. Wurster et al (1971) reported higher in vitro digestibility of crested wheatgrass on droughty compared to favorable soil and suggested that the difference might be related to the slower development of structural materials in forages produced under suboptimal conditions.

Range Condition: On ranges in the northern desert shrub region Goebel and Cook (1960) studied good and poor forage species on good and poor condition range. On poor condition range good forage species were higher than poor forage species in percent total protein, cellulose, ash, other carbohydrates and phosphorus; but on good condition range the good forage species were higher only in percent ash and cellulose.

Cook, et al (1965) determined the effect of range condition on daily intake, nutritive content and digestibility of grazing sheep's diet between mid June and September. Studies were conducted on a sagebrush-grass type on mountainous summer range in northern Utah. Total protein in the diet was slightly higher on poor than good condition range, probably because of the high browse content in the diet. Range condition had no influence on animal intake.

Sims and Cook (1970) studied the influence of plant density on forage digestibility of tall wheatgrass, pubescent wheatgrass (Agropyron trichophorum) intermediate wheatgrass, and crested wheatgrass growing in central Utah on areas representative of intermountain foothill ranges. No differences in dry matter digestibility (DMD) were found between high and low density stands. Forage of all species from dense stands had a higher percentage cellulose digestibility (CD) than did samples from sparse stands. Leaves averaged 11 percent more CD than stems. Percent CD decreased with increasing phenological development.

Plant characteristics

Class of plant: Variation in forage quality throughout the sagebrush types reflects the class of plant present, that is, browse, grass or forbs. Reports on the relative content of protein, energy, minerals and carotene among these classes of plants have been given for several decades (McCreary 1927, McCreary 1931, McCreary 1939, Cook and Harris 1950a, Cook and Harris 1950b, Beath and Hamilton 1952, Blaisdell et al 1952, Van Dyne et al 1965). However, degree of nutrient utilization of these plants under range conditions was first reported by Cook and associates (Cook and Harris 1950a, Cook and Harris 1950b, Cook et al 1951, Green et al 1951, Cook and Harris 1952, Cook et al 1953, Cook et al 1954).

Characteristically, crude protein and digestible energy content of plants decline with maturity. Levels of these nutrients needed to support lactation may fall below recommended requirements by early June and mid July, respectively (Raleigh 1970). Opportunity for regrowth would significantly alter available nutrients. During the winter grazing period, Cook and Harris (1968a) reported the average total crude protein content of browse species was 9.1 percent while the average for grasses was 3.8 percent. Grasses furnish about 2100 Kcal digestible energy per Kg on desert-winter ranges (Cook et al 1954).

Many shrubby range plants may not supply as much energy as would be indicated from digestible dry matter or energy coefficients, because much of it is found in essential oils which are excreted in the urine (Cook et al 1952). Smith (1957) reported a total digestible nutrient (TDN) value of 78 percent (about 2780 Kcal metabolizable energy per Kg) for Artemisia tridentata, while Cook et al (1954) reported a metabolizable energy value of only 1265 Kcal per Kg. Cook et al suggest the use of metabolizable energy to express energy availability for animals on winter ranges, especially when species of Artemisia comprise a significant part of the diet.

Total plant phosphorus concentration trends follow a pattern very similar to crude protein. Murray et al (1978) found that total P concentration of several native and introduced grasses in southern Idaho declined rapidly with advance in season and was below recommended levels for maintenance of domestic livestock by the end of June. Similar values were reported by Blaisdell et al 1952, Marsh et al (1959), Van Dyne et al (1965), Demarchi (1973), Cook and Harris (1968a) and others. Generally, P content of browse is higher than grasses and forbs during the winter, but is slightly below recommended requirements for maintenance (Marsh et al 1959, Cook et al 1954, Van Dyne et al 1965, Cook and Harris 1968a). Calcium content of plants is variable among forage species and may increase or decrease with advance in season (Cook and Harris 1950a, Murray et al 1978, Demarchi 1973). Calcium/Phosphorus ratios in forages usually increase with advance in season. A Ca/P ratio of 2:1 is considered optimum. Calcium/Phosphorus ratios of greater than 15:1 were reported by Murray et al (1978).

Forbs usually have a higher nutritive value than grasses during active growth but do not cure as well. Many forbs are fragile and are not available after maturity.

Possible differences between structural carbohydrates of warm-compared to cool-season grasses have been reviewed (Bailey 1973). Generally, cool-season grasses have less hemicellulose than cellulose; whereas, in warm-season grasses the hemicellulose levels may equal cellulose levels. Cool-season grasses usually contain more cellulose than warm-season grasses. No known data exist which compares structural carbohydrates of grasses of warm-or cool-season origin in the sagebrush types under similar conditions. Relative portions of structural carbohydrates in plants may be important if they are variably available to the ruminant animal. Different rates and extent of digestion could affect the voluntary consumption of forage depending on the mix of species in the diet (Colburn et al 1968, Tilley et al 1969). Utilization of various fiber fractions under range conditions have not been reported.

Harkin (1973) compiled lignin values for cool- and warm-season species. Often the difference in lignin among plants within a group can be attributed to varying leaf-stem ratios, as leaves lignify at a slower rate than stems and contain less total lignin on maturation. Warm-season plants tend to be more lignified than cool-season plants but environmental variables may mask taxonomic differences. Environmental variables which alter leaf-stem ratios or rate of maturation affect lignin content of the plant. Agropyron desertorum may have greater than a 100 percent change in lignin (5 to 12 percent) as leaves change from 100 to 15 percent of the total plant composition (Harkin 1973). Blue grama, a warm-season species, acts more like a temperate species and has relatively low levels of lignin and cellulose exceeds hemicellulose content.

Native vs introduced species: Differences in the nutritive value of native compared to introduced plants at comparable stages of maturity under similar environmental conditions are small (Raleigh 1970). Cook and Stoddart (1961) showed that intermediate and tall wheatgrass produced higher spring and early summer gains on cattle than crested or pubescent wheatgrass, probably because they were later maturing species and maintained nutrient quality later into the summer. Sheep performed best on intermediate wheatgrass.

Cook and Harris (1968a) found that advance in season and growth stage of individual grasses had a greater influence on nutritive value than species differences. For example,

western wheatgrass started growth a week later than beardless wheatgrass (Agropyron inerme) and developed much more slowly. Crested wheatgrass produced earlier growth than either western wheatgrass or beardless wheatgrass and matured to the seed shattering stage in less time. Tall and intermediate wheatgrass and Russian wildrye (Elymus junceus) started the same time as western and beardless wheatgrass. However, tall wheatgrass reached advanced growth stages much more slowly than the others. Intermediate wheatgrass matured slightly more rapidly than beardless wheatgrass, which in turn matured more rapidly than western wheatgrass. Russian wildrye appeared to mature about the same time as intermediate wheatgrass but retained a higher nutrient level of the more desirable constituents.

Total protein content in forbs [Russian thistle (Salsola tenuifolia) and smother weed (Bassia hyssopifolia)] was higher than grasses

Morphology: Since in most cases leaves are more digestible than stems, it is desirable to manage in such a manner as to maximize use of leaves without depleting carbohydrate reserves to a critical level. Hyder and Sneva (1963) and Hyder (1972) demonstrated management techniques to accomplish the above objective in the Sagebrush-Steppe region. The opportunity for regrowth of native or introduced species after plants have reached the boot stage of maturity is limited by soil moisture. In most years sufficient moisture is available for significant regrowth if animals are removed in the spring following removal of the apical meristem of most bunchgrasses (4.5 to 7.0 cm stubble height) in the early stages of culm elongation (Hyder and Sneva 1963; Hedrick 1967; Sneva 1973). This has been a common management practice on both native and seeded grasses on the Squaw Butte Range Station for many years. This practice generally increases the number of culmed or culmless vegetative shoots compared to mature reproductive shoots available for dormant-season grazing. These shoots have a higher leaf-stem ratio and are frequently more nutritious (Hyder 1972).

Summary

Plant phenology and advance in season influence the nutritive content of plants to a greater degree than any other factors. All classes of plants furnish adequate nutrients to meet production requirements of domestic livestock during the active plant growth stages. With advance in season crude protein and phosphorus levels decline rapidly. Crude protein and phosphorus levels in grasses and forbs may fall below recommended levels to support optimum lactation and growth by late spring or early summer. Energy levels may fall below recommended levels by early to mid summer. By fall and winter grasses and forbs are markedly low in crude protein, phosphorus and carotene while browse plants usually furnish marginal to adequate crude protein and phosphorus and are exceptionally high in carotene. Browse species are usually low in metabolizable energy in winter while grasses furnish adequate energy for maintenance.

Seeded grasses are not superior to native grasses in nutrient content; however, management can utilize differences in relative phenological development among species to extend the grazing season in some instances. Management of grasses in such a manner as to obtain the highest leaf-stem ratio possible without depleting reserves is a desirable management objective.

Differences in regrowth potential resulting from various climatic regimes prompt different management strategies among sagebrush regions. Climate determines the presence of cool-and warm-season species. Sunlight interception is probably of little nutritional significance in sagebrush communities, however, the canopy has a significant impact on spatial distribution of species.

Mix of plant species, including browse, forbs, and grasses has a greater influence on potential diet quality than range site and condition or whether the stand is composed of "good" or "poor" species.

FORAGE-ANIMAL RELATIONSHIPS

Performance of domestic livestock on rangelands is dependent on the nutrient flow from plant to animal. Unfortunately, the interface of the animal with the forage and behavioral motivation are poorly understood. Individual animal preference and availability largely determine the quality of an ingested meal; and consequently, limits the potential nutrients available for utilization. Further, utilization is dependent on the digestibility and nutrient balance of the meal ingested. These factors are in turn highly related to rate of passage and quantitative intake.

Preference and Palatability

Heady (1964) has defined preference as selection by the animal and as such is behavioral. Palatability was defined as characteristics of the plant which stimulated a selective response by animals. Preference has been the entity most commonly measured because it can be measured by use of the animal and because it is a function of palatability and availability.

Grazing animals are selective and consume one species over another or one plant of the same species over another. Often, specific portions of plants are selected over others. Van Dyne and Heady (1965) have documented cattle and sheep selectivity for specific plant parts. On sagebrush summer and winter ranges in Utah, Cook and Harris (1950a) found sheep were highly selective for certain portions of some plants. On winter range leaves and tender stems were sought out. Sheep may "tire" of a diet of sagebrush (Artemisia nova) and fail to consume adequate amounts to meet requirements according to Cook and Harris. They found no relationship between mineral content and preference.

Cook and Harris (1950b) concluded range site influences the leaf-stem ratio of plants, thereby influencing palatability. Cook (1959) found that palatability of all forage species studied was greater on unfavorable sites in contrast to favorable sites on foothill ranges in central Utah.

Plants on favorable sites produced more stems and cellulose, but less protein. Springfield and Reynolds (1951) postulated that percent moisture or succulence was the most appealing feature that contributed to preference. Sheep and cattle in Utah changed their dietary preference for individual species with season of the year (Cook and Harris 1968a, Cook et al 1956).

Various other factors can alter preference of animals for specific forage species. Mineral deficiencies were shown by Scott (1929) to cause abnormal and preverted appetites in cattle. Reppert (1960) observed cattle ate more shrubs after watering and that snow cover influenced preference by limiting availability.

Numerous attempts to rank the preference or importance of plant species have been made (Cook and Stoddart 1953, Kruger 1972, Van Dyne and Heady 1965, Chamrad and Box 1968, Vavra et al 1977). Indices developed to date can be used to describe certain situations, but precision in predicting diet preference at different points in time or on different areas is low.

Progress toward practical means of assessing the nutrient status of animals can proceed only when some estimate of nutrient quality of the diet can be inferred from available forage. Precise estimates may not be feasible, especially for less selective grazers such as cattle. Yet, objective methods to replace subjective, intuitive guesses or the laborious task of using esophageally-cannulated animals must be found. Studies which systematically define the variables important in selectivity are needed.

More studies to determine avidity coefficients should be examined by nutritional class compared to species composition. Lucas (1974) suggested coefficients also be determined for "search rate," "findability," "appetite," "satiation," and "hunger." He suggested characterizing forage by "fibrousness." Other characteristics, such as, potential digestible organic matter (above or below 5 to 7 percent crude protein and/or within protein solubility classes) and estimated relative potential retention time in the animal tract could be related to the above variables. In other words, preference must be described by variables functional for the animal as well as the plant. The forage components should be translated into "nutritive entities" relative to the animal. Such an approach would more accurately estimate the availability of nutrients on a range area at a given point in time thus allowing better estimates of potential animal productivity.

Intake and Digestibility

Once an animal chooses a food item in its diet, the quantity of subsequent meals is limited. Conrad et al (1964) demonstrated a relationship between total voluntary intake and digestibility and suggested the primary factors limiting intake were volume of the tract and the ability of the animal to process "ballast." The ability of the animal to process "ballast" is primarily a function of rate and extent of digestion and rate of passage of ingested material (Laredo and Minson 1975, Thornton and Minson 1972, Thornton and Minson and 1973). Other factors altering intake would include animal species, weight, fatness, physiological rumen volume, stage of production, and stress.

Rate and extent of digestion: Although total voluntary intake accounts for more of the variability in animal performance than digestibility (Crampton et al 1960), changes in digestibility are important. Blaxter et al (1961) calculated a change in digestibility of dry matter from 50 to 55 percent resulted in a 100 percent increase in weight gain. Digestibility of the aggregate of species selected by the animal depends on factors related to both the plant and animal. Estimates of digestibility of forage consumed by grazing animals must be determined indirectly (Van Dyne 1968, Streeter 1969).

Many factors interact to determine rate and extent of digestion. Those of major importance for this discussion are chemical composition and organizational structure and content of cell walls. Maximum digestibility of forage in the rumen can occur only under optimum nutrient balance. Van Soest (1965) reported a negative association between lignified fiber and digestibility of the fibrous components of forages. Soluble fractions were nearly completely utilized.

Cook et al (1963) compared diets of cattle and sheep grazing sagebrush ranges in northern Utah using esophageally canulated animals. Cattle consumed diets higher in digestible energy components than sheep, because diets were higher in grass and lower in browse content. Cattle apparently also digested cellulose better than sheep (Cook and Harris 1968a).

Rate of passage: Rate of passage, the amount of time required for a meal to pass through the animal, can influence animal performance by influencing digestibility and intake. Specific gravity, particle size, rapidity of digestion and daily intake all have an affect on rate of passage of feedstuffs through the ruminant animal (Church 1969). Forages of low digestibility slow rate of passage because rate of digestion and particle reduction occur over a longer period of time. Waldo et al (1972) suggest that material can be fractioned into two components: one which leaves the rumen because of digestion and one which exits via passage to the lower gut. Rate of removal of each component seems to proceed in proportion to the amounts of material undergoing digestion and passage.

Many researchers have shown a relationship between rate of passage (and consequently retention time) and intake (Thornton and Minson 1972, Thornton and Minson 1973, Laredo and Minson 1973, Ulyatt et al 1967). Literature addressing the effect of the quality of diet selected by domestic animals on rate of passage under range conditions are nil.

As with diet preference, techniques for estimating the total voluntary intake are needed in order to accurately predict expected performance of animals of various physiological stages of production or growth on ranges. There is little reason to believe that simple models to predict total voluntary intake of even known diets will be found.

Although broad relationships between such fractions as cell wall constituents and digestibility are known, precision of such relationships is not acceptable for predictive purposes. Recent work by Thronton and Minson (1972, 1973) and possible practical application of predicting the amount of digestible organic matter intake as a function of retention time of organic matter in the gastro-intestinal tract (Golding 1976) appear to offer new promise in developing methods to assess the nutritive value of range forage. Numerous variables of the vegetation and animal regulate the rate of consumption and consequent satiety of grazing animals. A concentrated effort should be made to identify these variables.

Management and Environment

Rate of stocking and degree of use: The influence of rate of stocking on animal performance has been established in numerous studies over a wide range of conditions (Riewe 1961, Harlan 1958, Cowlishaw 1969, Conniffee et al 1970, Jones and Sandland 1974, Burzlaff and Harris 1969). Hart (1972) calculated that over a wide range of conditions and species (mostly monocultures) animal performance was highly related to available forage per head per day. In most instances performance was reduced on areas having less than 10 to 20 kg per head per day of available forage. Handl and Rittenhouse (1972) showed that steers were able to maximize intake under very light stocking rates porvided 150kg/ha of crested wheatgrass was available. Bement (1969) established a stocking rate guide for blue grama range which developed the relationships of gain per animal, gain per acre and forage production as related to grazing intensity. Similar stocking rate guides could be established on sagebrush ranges.

Changes in diet quality and resultant changes in animal performance were measured on desert ranges in Utah (Frishnecht et al 1953, Cook et al 1962, Cook et al 1956, Pieper et al 1959). Diet quality, voluntary intake and/or performance declined as degree of use increased.

More research on stocking pressure must be conducted before variables influencing preference, nutrient intake, and utilization can be fully understood. However, rarely is stocking pressure considered in the design of grazing experiments or in making management decisions.

Management: Animals grazing sagebrush range exhibit varying degrees of preference for browse, grass and forbs, depending on class, age, and and physiological state of the animal and season and degree of use. Many other factors may interact to also influence performance, e.g., range site and condition, plant ecology/physiology/morphology.

Throughout most of the sagebrush region, range forage contains adequate nutrients to supply the recommended requirements of domestic livestock for only a short period of the year (Raleigh 1970, Vavra and Raleigh 1976). Balancing nutritional requirements with minimum cultural energy expenditure should be the goal of management (Cook 1977). Use of small amounts of supplemental energy or protein to greatly enhance the efficiency of utilization of range herbage has already been demonstrated by Raleigh (1970). However, supplements are known to variably influence intake and utilization of forages (Campling 1970, Cook and Harris 1968b). More basic nutritional studies on the interacting effects of various supplemental sources of protein and energy are needed, such as, the quantitative influence of concentrates on rate of digestion and passage and subsequent forage intake.

Summary

The value of range forage to meet the nutritional requirement of grazing-domestic livestock is a function of the nutrient content, rate and level of intake, rate and extent of digestion, and efficiency of utilization. The usefulness of available nutrients, in situ, for meeting the requirements of domestic animals is further modified by selctive behavior of the animal and physical variables of the range.

Furture studies in range-animal nutrition should consider the system as a whole. Fragemented measurements of such items as chemical content of plant, chemical, in vitro, and/or botanical analyses of material collected via esophogeal fistulae and estimates of voluntary intake, per se, will add little to current knowledge about the nutritive value of range systems.

Defining variables which motivate selection for various "nutritive entities," should be priority. All other aspects of predicting nutritive value of range forage depend on the ability to predict nutrient intake of the animal. "Nutritive entities" available in the standing crop should be described in terms of functional animal variables, such as, potentially consumable digestible organic matter based on "fibrousness" and/or nitrogen content of selectable portions of grasses, forbs, and shrubs.

Complementary metabolism studies involving the influence of rate and extent of digestion, rate of passage of various fiber fractions, and nutrient balance on total voluntary intake of digestible organic matter need to be carried out in stalls on forages similar to those encountered under range conditions. The obvious limitations of studies involving browse are recognized. However, the main objective of these studies would be to determine important variables which could be used to predict digestible organic matter intake under range conditions.

Obviously, greatest nutritional concern involves those circumstances in which nutrient content of animal diets falls below recommended levels for expected performance. However, balancing the nutrient status of both the rumen microflora and the animal at all times would insure optimum efficiency of forage use. Balancing nutrients in the diet for performance at or near genetic potential should be a goal. Greatest opportunity for increased efficiency in growing animals may come during the period of highest nutrient availability. A better understanding of protein and energy balance in the diet would allow prescription supplementation of various classes of animals. More attention should be given to the balance of nutrients in the diet at all times of the year. Any supple-

ment which ultimately results in a decreased rate of passage of fibrous material would be counterproductive, because it would result in a decreased forage intake.

The interacting effect of nutrient content of range forage and stocking intensity need further study. Degree of use of range forage was cited as being second only to advance in season and plant maturity in its effect of diet quality. Most studies reported a corresponding decrease in intake as well. Degree of use in a given period of time is a direct result of stocking intensity. In view of recent literature, it now seems reasonable that relatively small changes in the amount of digestible organic matter in the diet may have a rather pronounced effect on voluntary intake and subsequent performance. This may be especially critical in growing animals where maximum selectivity for the highest possible diet quality is desired.

As we look more and more to our rangelands as a source of protein with minimum fossil fuel expenditure, alternative management stratagies to increase the beef produced from these areas must be found. Grazing methods to possibly allow increased rates of stocking while sustaining the renewable resource, such as those reported by Denny and Barnes (1977), should be investigated. Common use of ranges by more than on animal can be made in many regions (Cook 1977). Research to increase the biological efficiency of the system will allow greatest useful information for making management decisions for the future.

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IMPACT OF SAGEBRUSH MANAGEMENT ON RIPARIAN AND STREAM HABITAT

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INTRODUCTION

The sagebrush ecosystem covers 38.8 million hectares of rangeland from western Nebraska to the crest of the Cascades and from British Columbia to northern New Mexico. Overgrazing has frequently been deleterious to rangeland quality, and range managers have attempted to rehabilitate damaged range by various management methods designed to initiate a conversion in vegetative type from one dominated by sage (Artemisia spp.) to one dominated by grasses and more desirable forage plants. Another management goal has been to optimize on-site water use by plants and decrease erosion. The livestock have been managed to protect and enhance the range by adjusting grazing intensity and time. However, recent public actions and legislation such as the Organic Act, have required that other uses of public lands be considered in range management plans.

The need to consider fish and wildlife habitat in range management has presented problems and incited controversy. For example, on the basis of "widespread experience," one group of authors (Heady et al. 1974), wrote that: "Livestock grazing is being managed and integrated with other uses of federal lands. There is no evidence to indicate that well-managed grazing of domestic livestock is incompatible with a high quality environment." Another author, (Leopold 1974), also on the basis of "long years of observation" wrote: "Fish and wildlife habitat in western range land is undergoing steady, chronic deterioration under existing patterns of multiple use. Livestock grazing in particular may be having cumulative ecological ill effects on productivity of both lands and water." One reason for this lack of unanimity is the paucity of available data on goals and methods for the management of the aquatic and riparian zones of the range. In general, aquatic zones of the rangeland have been studied only to gather information on watershed hydrology. Few studies have evaluated aquatic resources and their response to range management and use.

Fishery biologists were also at a loss to provide information on range management effects on aquatic resources. They had little data to substantiate their suspicions that present grazing practices were having a deleterious impact on fishery resources, and their methods for measuring that impact were imprecise. The scarcity of data on rangeland aquatic habitat, fish habitat requirements, and the effects of grazing on fish populations has been identified as a major inadequacy of grazing environmental impact statements (BLM 1976, Box 1977, Beers 1977). Fishery biologists have begun to earnestly discuss the situation, and no less than three workshops or symposia have been held on the topic of livestock interactions with fish, aquatic environments, and riparian zones within the last year (U.S. Forest Service 1977a, 1977b, U.S. Fish and Wildlife Service 1977).

Besides the general mandate for multiple use of range lands, the increased demand for recreational fishing also justifies the consideration of aquatic resources in a range management plan. Existing inland fisheries cannot adequately support the steadily increasing fishing pressure. In addition, in areas which once supported substantial game fish populations, some streams have been degraded to only marginal quality. Protection and reclamation of rangeland streams would enhance recreational opportunities for rangeland users.

In the West, mining, agriculture, and other developments are reducing grazing land at a rate of 0.57 million hectares per year. This encroachment on the range comes at a time when consumer demand for beef is increasing. It is projected that an additional 28.3 million hectares of forage producing range will be needed in the next 25 years (Heady et al. 1974). The increased demand for recreation areas and protection of watersheds for water quality may be yet another drain on the rangeland available for red meat production. It is to be hoped that this drain can be closely controlled through an interdisciplinary approach to management. The first step is to understand the effects of range management practices on aquatic resources. It is the purpose of this paper to summarize the potential impacts of important range management practices on aquatic habitat and aquatic biota in the sagebrush community.

SAGEBRUSH MANAGEMENT AND AQUATIC RESOURCES

Range management in the sagebrush ecosystem is practiced to improve forage and facilitate its use by livestock. Controlling sage and other shrubs and stimulating the production of more desirable forage are two means of accomplishing this goal (Vallentine 1971). Controlled grazing is the most common method of stimulating forage production. Brush is controlled by mechanical removal, burning, and the use of herbicides. It has been shown that not all of these practices are beneficial to the range itself (Gifford 1975). When these treatments are carried out near streams, they may also have deleterious effects on the riparian and aquatic habitat.

Livestock Grazing

The history of livestock grazing abuse of western range in the overgrazing era is legend (Box and Sisson 1975, Box 1978). About 6.1 million hectares of range in Utah alone were damaged by overgrazing (Vallentine et al. 1963). Few fishery studies were conducted in those days, but the impact of the devastation was noted (Ligon 1927, Tarzwell 1937).

Although progress has been made in range rehabilitation (Box and Sisson 1975), grazing is still believed to have a major deleterious impact on aquatic resources in the West (Bullard 1962, Tarzwell and Gaufin 1955, Behnke and Zarn 1976, Saltzman 1976, BLM 1974, State of Idaho 1976, Gallizioli 1977). At

1/ The Unit is jointly sponsored by the Utah Division of Wildlife Resources, Utah State University and the U.S. Fish and Wildlife Service.

a recent symposium, Platts (1978) summarized the condition of riparian and aquatic habitat in areas under eight different grazing systems. A poor aquatic habitat was usually found in areas where year-long or season-long grazing was in effect. Depending on location, topography, and other land features, poor to fair ratings of the aquatic system resulted from deferred, rotation, deferred-ratotion and rest-rotation, and short duration-hign intensity grazing systems. Only in areas where there was no grazing, were aquatic resources found in good to excellent condition. It is estimated that overgrazing was a major contributor to the loss of about 99% of the native cutthroat trout (Salmo clarki) in the West (Behnke 1972).

The potential effects of grazing and other range management practices can be better understood if the response of terrestrial and aquatic habitat features and the main trophic levels of the aquatic food chain are examined individually (Figure 1). Grazing may have a direct (primary) effect on either the terrestrial or aquatic habitat. Changes in a directly affected habitat feature may also have secondary effects on another component of the system. Third and even fourth-degree effects may also result.

Terrestrial Habitat

Vegetation is of course directly affected by grazing. It is convenient to partition terrestrial vegetation into riparian and upland zones because of the different influence each has on the aquatic zone and because each receives different grazing pressure. The riparian zone may be grazed more heavily than the upland zone (Holsher and Woolfolk 1953, Armour 1977). Any grazing on a watershed usually means overgrazing of the water courses and bottomlands (Leopold 1946) because of the high palatability and moisture content of riparian vegetation and the proximity of water (Ames 1977). Livestock use of the riparian zone has been shown to be site dependent (Cooper 1978). For example, in nonforested areas like the sagebrush type, livestock congregated in the shade of riparian vegetation, whereas in other areas where shade was more abundant away from the stream, livestock use of the riparian zone was reduced. Heavy pressure on the riparian vegetation may reduce its functions in providing bank stabilization, cover for fish, water temperature reduction, and energy to the system.

Riparian vegetation protects streambanks in three ways: (1) by reducing water speed, (2) by protecting the bank from water born objects, and (3) by inducing deposition of sediment along the bank (Parsons 1963). Unstable banks are a major source (50%) of the sediment budget of a stream (Clarie and Storch 1978, Hansen 1971). Reduced stability causes banks to slough into a stream, destroying cover for fish and causing siltation of the stream bottom and destroying stream bottom cover. Bank stability is usually measured by calculating a bank stability index, which is based on subjective visual observations (Dunham and Collotzi 1975, Duff and Cooper 1976). Recently, another method has been tested on several streams in northern Idaho (Cooper 1978). The method incorporates an ungulate damage rating into a standard Forest Service method of evaluating impacts of water yield on stream bank and channel stability (Pfankuch 1975). A significant correlation (95% confidence level) between bank-channel stability and ungulate damage was found. Damage by ungulates was best measured by measuring mast wasting, bank vegetation cover, bank rock content, and bank cutting.

Several field studies have shown a connection between bank stability and overgrazing of the riparian zone. Winget and Reichert (1976) found that grazing reduced bank stability as much as 59% on several Utah streams. They noted that in some streams, the benthic invertebrate populations showed signs of stress due to siltation of bottom substrate from the eroded banks. Within two livestock exclosures on other Utah streams, bank stability increased 100% in one and 740% in another (Berry and Goebel 1978, Duff 1978). Marcuson (1977) credited increased bank stability to the fact that an open and grazed portion of Rock Creek, Montana, had 2.5 times more channel displacement during flooding, than an exclosed area nearby. Kimbal and Savage (1977) noted a 172% increase in bank stability following a 67% reduction in grazing pressure over a 6-year period. Duff (1978) reported that when cattle were illegally allowed to graze within an exclosed area that had been rested for 4 years, riparian vegetation cover declined 14% and bank stability 12% in 6 weeks. Duff et al. (1974) found that bank stability was 36% of optimum in a heavily grazed section of Birch Creek, Utah, and 55% of optimum in a moderately grazed section.

Cover is one of the most important habitat requirements of fish. Binns (1978) found cover to be significant at the 99% confidence level for determining fish biomass in Wyoming streams. Boussu (1954), who simulated riparian vegetation cover over a stream, found that trout biomass increased 258% compared with that in an untreated section of the stream. He also destroyed undercut banks in another section and later found that trout biomass in the altered area was only 33% of that in the area where banks were left intact. Overgrazing the riparian vegetation may destroy cover by cropping overhanging vegetation and fracturing the stream bank, thereby reducing undercut bank areas (Bullard 1962, Tarzwell and Gaufin 1953, Platts and Roundtree 1972). Duff et al. (1974) found that bank cover was only 52% of optimum in a heavily grazed reach of stream, as compared with 81% of optimum in a section with less grazing pressure. Gunderson found that there was 76% more riparian vegetation along ungrazed areas of a stream than in grazed areas and that trout populations were larger in ungrazed reaches. Willows (Silax sp.) are commonly found in the riparian zone and are especially susceptible to overgrazing by livestock and big game (Lovaas 1970). However, once willows reach a large size, they can withstand grazing pressure and protect the stream. For example, Lorz (1974), who studied grazed and ungrazed areas of the Little Deschutes River, Oregon, found that there was no difference in fish populations in an ungrazed section and in a heavily grazed section where willow cover was dense on one or both banks. Grazing affected stream habitat and fish populations only in a section where the willows were not established on either bank.

Shading by riparian vegetation reduces the light intensity in streams and reduces water temperature. This protection is especially important in the sagebrush ecosystem, which is typically hot and

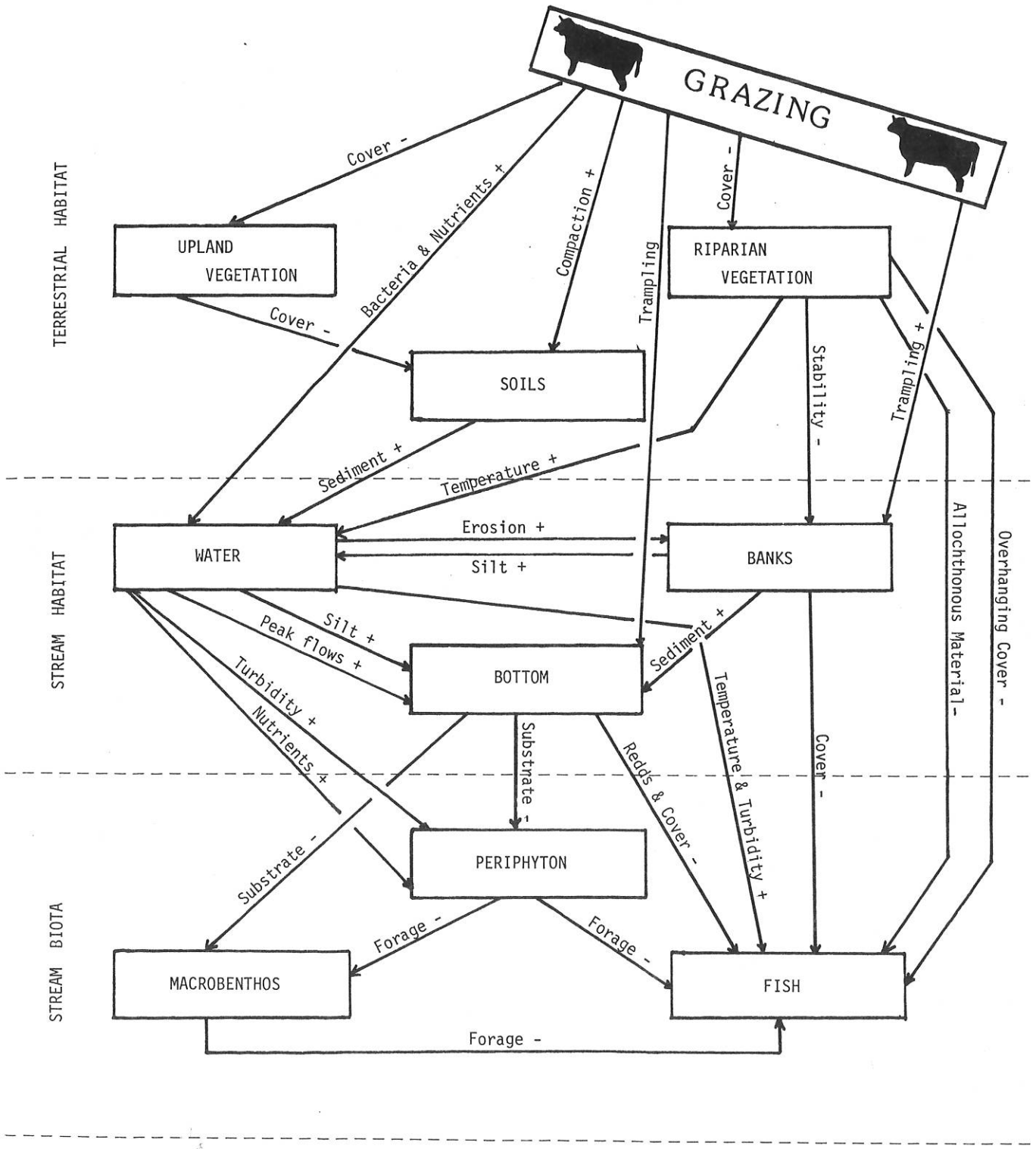

Figure 1. Flow chart diagram of major effects of overgrazing on land and stream features and the resulting effects of changes in these features on the stream habitat biota. A plus sign indicates a net increase in effect and a minus sign a net decrease.

arid. Claire and Storch (1978) demonstrated this principle on a rangeland stream in Oregon; they found that alder (Alnus sp.) and willow shrub canopy in an exclosed area provided 75% more stream shade than that in the area outside the exclosure, which was grazed year-round. Over a 10-year period, average water temperatures within the exclosure declined 12 degrees and temperature fluctuations declined 14 degrees. The fish population shifted from one dominated by dace (Rhynichthys sp.) to one dominated by rainbow trout (Salmo gairdneri). An 80% canopy has been recommended as optimum cover to promote acceptable temperatures in forested streams (Armour 1977).

Organic material which reaches a stream from the surrounding watershed provides over half of the energy budget of a stream (Cummins 1974). This allochthonous material may be especially important in poorly productive rangeland streams. Ensign (1957) found that in Mt. Vernon Creek, Wisconsin, terrestrial insects made up only 4% of the food of brown trout (Salmo trutta) in sections of the stream where cattle had cropped riparian vegetation. In a nearby creek, where cattle were not grazed and riparian vegetation cover was greater, terrestrial insects composed 15% of the diet of the trout.

Reduced cover of riparian and upland vegetation may affect underlying soils. Exposed soils can be compacted by rain and livestock trampling. The reduced infiltration rate of water into compacted soil promotes erosion. Increased runoff also carries away litter and further promotes sediment yield from a watershed. Erosion provides up to 35% of a stream's sediment budget and gully erosion 10% (Claire and Storch 1978). The historical occurrence of erosion, mud slides, and foulded water due to overgrazing is well known. Range watershed management has brought comparative stability to affected areas through restoration of vegetation. But stream sedimentation still occurs, partly due to grazing and partly due to natural sediment yields from watersheds. The unstable soils and steep topography in certain areas of the West, and disturbing climatological phenomena such as droughts and floods, contribute to natural yields of sediment, even on ungrazed watersheds (Copeland 1963). For example, Megahan (1975) noted that sediment production varied greatly in similar, small, undisturbed watersheds in central Idaho. Grazing on fragile watersheds may further increase the sediment yield.

Sedimentation in a stream decreases substrate suitable for invertebrate fish food organisms and reduces instream cover for fish. Many studies have shown that siltation fills the interstices of the bottom rubble habitat frequented by benthic invertebrates, causing a reduction in species diversity and a shift to species indicative of poor water quality. Bjornn et al. (1977) found that when more than two-thirds of the substrate cobble is covered with silt, the production of macrobenthic invertegrates drops. However, production was higher in areas where cobbles were somewhat silted than in those that were completely clean.

Cordone and Kelley (1961) summarized the evidence indicating that sediment reduces the survival of fish eggs in the gravel and reduces instream habitat available to fish. Many studies, have shown silt to be especially harmful to fish reproduction in reducing hatching success and growth and survival of the young (Phillips et al. 1975, Hausle and Coble 1976, Ritchie 1972). A reduction in intergravel water flow, which reduces oxygen supply to the developing embryos, is the causative factor. Fish use instream cover year-round for protection, but this habitat feature is expecially important in the winter. Bjornn et al. (1977) found that trout in Idaho streams move into the interstices in the bottom substrate in winter; fish density in winter was lower in silted streams than in unsilted streams due to the lack of in-stream cover.

In summary, the primary effects of grazing on riparian and terrestrial vegetation may have secondary effects on the underlying soil and on stream banks. Reduced riparian vegetation leads to less stable banks, increased stream temperatures, reduced cover both from overhanging vegetation and from fractured banks, and decreased energy input into the system. Compaction of soil promotes erosion, which carries sediment into a stream. Once in the aquatic environment, sediment reduces suitable substrate for invertebrate fish food organisms and covers in-stream cover used by fish.

Aquatic Habitat

Aquatic habitat features may also be directly affected by grazing (Figure 1). For example, livestock trampling in a stream may disturb bottom substrates and thus destroy invertebrate habitat. More importantly, physical disturbance of fish redds might lead to reduced hatching success and decreased fry survival. Grazing may also have a direct effect on water quality and quantity by affecting the hydrologic characteristics of the watershed (Busby and Gifford 1978). Changes in water quality characteristics such as turbidity, bacterial and nutrient levels, and peak flows, could adversely affect fishery values.

Sediment additions to water reduce its clarity and consequently decrease the amount of light that reaches the stream bottom. It has been repeatedly shown that turbidity interferes with optimal growth of photosynthetic organisms (Cairns 1968). Turbid waters also affect secondary producers, such as macrobenthic invertebrates, by reducing primary productivity and interfering with filter feeding mechanisms. Net building invertebrates are sensitive to highly turbid conditions, which clog the food gathering nets (Roback 1965).

Increased turbidity causes changes in fish behavior. Migrating fish may avoid turbid water. Increased turbidity may interfere with the predator-prey relation by retarding the efficiency of sight feeders (Cairns 1967). Bjornn et al. (1977) found that fish in unsedimented streams defended territories, whereas those in sedimented streams behaved in a hierarchical manner. The net result of turbid water is decreased productivity of the system (Sanders and Smith 1967, Peters 1967). Each level of the food chain is affected.

A potential effect of livestock use of a watershed is bacterial contamination of nearby streams. Many investigators have attributed increased total coliform and fecal coliform levels in streams to livestock or big game or both (Skinner et al. 1974, Darling and Coltharp 1973). The presence of fecal

coliforms is attributable to ungulates, since fecal coliforms rarely appear in wilderness soils (Geldrich 1967). Kunkle (1970) suggested that only bovine fecal material immediately adjacent to a stream was of importance in terms of increasing bacterial counts in the stream. Studies by Buckhouse and Gifford (1976) supported this suggestion. Once in the stream, enteric bacteria may multiply and grow (Hendricks and Morrison 1967, Mack 1974), especially when the stream is also silted (Donsel and Geldrich 1971). Bacterial samples from several Utah streams draining grazed watersheds showed increased coliform levels, but the levels were not considered a pollution hazard (Winget and Reichert 1976).

Snieszko (1974) stated that there was a positive correlation between bacterial contamination of water and the incidence of fish diseases. However, it is doubtful that the degree of bacterial contamination of rangeland streams from livestock use is significant from a fish health standpoint. The potential health hazard to anglers and other recreationists may be more important (Coltharp and Darling 1973), especially after storms (Slawson and Evert 1973).

Peak flows from snowmelt in the spring may be beneficial to a stream's pool habitat by removing silt from bottom substrates and under-cutting banks. However, above-average flows have been shown to dislodge the armor layer of riffles, and completely removed sediment from riffles (Bjornn et al. 1977). As I mentioned earlier, water absorption rate of compacted soils is low, and runoff may be several times greater from a heavily grazed watershed than from a lightly grazed one. Excessive peak flows which might occur from a grazed watershed may have enough energy to scour a stream to the extent that invertebrate and fish habitat is destroyed and the organisms killed.

The organic enrichment (eutrophication) of rangeland streams by livestock waste is an impact of grazing which may potentially affect water quality and fish production. A cow produces a total of about 17 kg total phosphorus and about 57 kg total nitrogen per year (Omernik 1977). Animal wastes are a major source of nitrogen and phosphorus in agricultural land runoff (Robbins et al. 1971). Results from the recently completed National Eutrophication Study showed that nutrient concentrations in 39 representative rangeland streams were intermediate between the lower levels found in streams draining forest lands and the higher levels found in streams draining watersheds used primarily for agriculture (Omernik 1977). Mean total phosphorus ranged from 0.06 to 0.1 mg/l and mean total nitrogen from 1.3 to 1.4 mg/l. Of this quantity, about 40% was organic nitrogen (ammonia, nitrate, nitrite), which is available for biological use. A maximum permissible level of about 10 mg/l is recommended for potable water supplies (Kemp et al. 1971). Levels in streams draining grazed watersheds are significantly below this level. It has been mentioned that only manure deposited in or within a few meters of a stream contributes coliform bacteria to the stream. This is probably true for nutrients as well. Any increase in nutrient levels might stimulate productivity in a depauperate rangeland stream without promoting objectionable water quality. Increased productivity might be desirable from a fishery standpoint.

In summary, the primary and secondary effects of grazing on aquatic habitat features are minor except for sedimentation, which increases turbidity and may decrease productivity of the system. Sediment also destroys benthic habitat.

Aquatic Biota

Periphyton, macroinvertebrates, and fish, which make up the main components of the aquatic biota, are not affected directly by cattle grazing in riparian areas, but may suffer a multitude of secondary and tertiary effects (Figure 1). Most significant are the loss of cover, and increased sedimentation. Although few comprehensive published reports show that these factors are now operating in rangeland streams, there is some evidence they are doing so in some areas. For example, trout were 27% to 400% more abundant in ungrazed than in grazed sections of Rock Creek, Montana (Gunderson 1968). In other studies on the same stream, a livestock exclosure protected a portion of the stream for 5 years. Trout were 2.7 times more abundant in the exclosed area than in the open area (Marcuson 1977). Fish biomass was greater in the exclosed area (239 kg/ha) than in the open area (70 kg/ha).

In central Utah, the reduction of grazing pressure from 23,000 to 9,000 animal unit months on the Diamond Fork watershed (Wasatch National Forest) resulted in a 300% increase in total fish numbers (Kimbal and Savage 1977). In southern Utah, two grazing intensities on the Birch Creek watershed were associated with changes in the trout population: trout biomass was 48 kg/ha in an area of light grazing and only 16 kg/ha in an area of heavy grazing (Duff et al. 1974). Fishery investigations in Oregon, Idaho, and Nebraska have shown similar results. In an Oregon stream producing steelheads (Salmo gairdneri) a lightly grazed section held 2.4 times more fish than did a heavily grazed section (Kennedy 1977). Livestock use was found to be damaging to the overall aquatic habitat and salmonid population of Bear Valley Creek in Idaho (Platts and Roundtree 1972). After 3 years during which grazing was prohibited on the watershed of a small tributary to the North Platte River, the stream produced 20,000 rainbow trout annually. Previously, when grazing was allowed, none were produced (Van Velson 1976).

These studies and others (Berry and Goebel 1978, Lorz 1974, Claire and Storch 1978) indicate a link between grazing use of the range and the fish populations and aquatic habitat of rangeland streams where grazing occurs.

Mechanical Brush Control

In many areas of the 38.8 million hectares of western sagebrush land, dense stands of sage may hamper grazing and retard grass production. Sagebrush control programs to improve the range have been carried out on nearly 10% of this area. Mechanical methods such as ripping, plowing, chaining, and harrowing can be used to control sage (Parker 1978, Pechanec et al. 1965). Range improvements such as furrows, contour trenches, gully plugs, water spreaders, and small reservoirs, have been used to promote better onsite use of water, improve range forage, and prevent erosion (Gifford and Skau 1967).

The beneficial and detrimental effects of range improvement practices on runoff and erosion were

reviewed by Gifford (1977), who concluded that not all range improvement practices were beneficial from the standpoint of runoff and sediment production. Treatments that involved severe mechanical disturbance (e.g., harrowing, chaining, plowing) were most likely to result in wind or water erosion. He suggested that if a 70% cover or greater could not be expected after the treatment, the treatment may be detrimental rather than beneficial to a watershed.

The potential effects of mechanical brush removal on aquatic resources are much more limited than are those of grazing. The riparian zone is grazed heavily, whereas sage control usually takes place away from the stream. Moreover, sagebrush is not usually found in the riparian zone, and lack of mechanical disturbance in this area would leave a buffer strip to protect the stream. The erosion from some areas noted by Gifford (1977) may affect a nearby stream by introducing sediment. Increased siltation (discussed earlier above) results in increased turbidity and decreased primary and secondary production. The silt limits habitat for invertebrate fish food organisms and fish. Turbid water may cause an alteration in fish behavior.

Burning

Sagebrush burning can also be useful in controlling brush and promoting increased production of forage (Britton 1978, Pechanec et al. 1954). Few data are available however. Gifford (1975) summarized that, in the first year after the burning of pinyon-juniper sites, storm water runoff may carry elevated levels of phosphorus and potassium into a stream, but not especially high levels of calcium, sodium, or nitrate nitrogen. Hoffman and Ferreira (1976) reported that two forest fires did not adversely affect the water quality of the Roaring River in California. They did notice increased nitrogen levels in the river downstream from the fire site. Larger nitrogen losses from burned watersheds and more severe water quality disturbances have bee noted following the burning of slash after logging (Fredriksen 1970). Cushing and Olson (1963), who observed the effects of brush burning on the banks of a Washington stream, found that calcium, magnesium, and potassium in the ash deposited on the stream, increased pH from 7.8 to 11.3 for several hours after the burning. Stream temperatures also increased. Native fish moved out of the area in response to the water quality changes, but no mortalities occurred in caged fish. Since a burn does not honor riparian zones, the reduction of streamside cover may adversely affect fish by reducing shade and overhanging brush cover.

The greatest apparent impact of range burning to the aquatic zone is probably a temporary change in water quality as a result of falling ash or increased temperatures. The short duration of a typical rangeland burn and the small amount of combustible material present to produce ash reduce the impact that burning might otherwise have.

Herbicides

An environmental contaminant, such as a herbicide, may elicit several types of response from the aquatic biota. It may be acutely toxic and cause death in a few hours or days, or may be chronically toxic and cause death or reduce growth and reproduction over a period of months. A behavioral alteration, such as avoidance of contaminated waters, may also result. Contaminants may also be bioaccumulated in tissues. Accumulation of chemicals in fish flesh may be important not only from a fish health standpoint, but from a human health standpoint as well. Even though fish may not be susceptible or affected in any way, productivity may decrease if the contaminant is toxic to invertebrate fish food organisms.

Two factors that determine the hazard of herbicides to non-target organism in rangeland streams are the likelihood of exposure to significant doses and the toxicity of the chemical (Norris and Moore 1970). The likelihood of exposure depends on whether the chemical is applied directly (or drifts) into a stream and also whether it moves from terrestrial sites into the stream in surface runoff, after application. Direct fall of the chemical into stream waters represents the greatest hazard because of the potential for high-level exposure. Contamination by surface runoff is greatest after storms that occur immediately after spraying. Normally, herbicides move only short distances in soil (Weise and Davis 1964).

For the herbicides most often recommended for rangeland weed control, a maximum acceptable toxicant concentrations (MATC) to aquatic life have been developed (Table 1). The MATC is determined by applying an application factor (e.g. 1/10, 1/100) to the results of acute bioassays (usually reported as the 96-hr TLm, or the toxicant concentration at which 50% of the test organisms die within 96-hr). The difficulties of applying MATC levels to field situations was discussed by Thut and Haydu (1970). An important point to consider when evaluating the MATC levels for herbicides is that most break down rapidly in water and do not occur in water at constant levels over long periods of time (Mullison 1970). Justification for this approach, however, comes from long-term studies on the effect of toxicants on fish growth and reproduction. For example, Mount and Stephan (1967) determined that the 96-hr TLm for 2,4-D butoxyethanol ester (BEE) to the fathead minnow (Pimephales promelas) was 5600 µg/l. They simultaneously determined through chronic toxicity studies (10 months) that the concentration that caused no change in growth or reproduction was between 200 and 1500 µg/l. Application of a factor of 1/100 to their acute toxicity results (5600 µg/l) suggests an MATC of 56 µg/l. This value may be too restrictive when applied to the fathead minnow but may be realistic when considering more susceptible fish species such as trout. Recent studies have shown that the MATC of 2,4-D BEE for cutthroat trout was 23 to 100 µg/l (D. Woodward, U.S. Fish and Wildlife Service, Columbia National Fishery Research Laboratory, Jackson, Wyoming, unpublished). Macek et al. (1976) found similarity between the limits provided by application factors for herbicide toxicity to three species of fish and two invertebrates and suggested that this finding supported the general validity of the application-factor concept.

There have been few field studies documenting the effect of herbicide spraying on aquatic life in rangeland streams. However, many of the same herbicides have been recommended for control of weeds in water and forests. Strange et al. (1976), who summarized the use of herbicides in reservoirs,

indicated that herbicides were generally regarded as less harmful than other pesticides to fish. In a few field applications, death of warmwater fish was attributed to the direct effect of herbicides, but most applications at recommended levels (usually equal to or greater than recommended application rates for rangeland weed control) did not result in fish kills. They stated that declines in phytoplankton and macrobenthic invertebrates following treatment were usually temporary because of the high reproductive rate of these organisms. Data on herbicide toxicity are available from numerous laboratory studies (Condon 1968, Mullison 1970, Kemp et al. 1971).

Phenoxy herbicides

Phenoxy herbicides--2,4-D, 2,4,5-T, silvex, and MCPA--are recommended for 98% of the weed control work carried out on rangelands. Of the phenoxy herbicides, 2,4-D is the most widely used (Klingman and Shaw 1971). The phenoxy herbicides are usually produced as an acid and converted to an ester or salt compound. Common esters are BEE, isooctyl ester (IOE), and propylene glycol butyl ether ester (PGBEE). Salt formulations are made with potassium or sodium. Esters, which are more toxic than other formulations to both weeds and aquatic life, are chosen most often for range work. The methyl, ethyl, isopropyl, butyl and amyl esters are highly volatile compounds which may produce toxic vapors that are also herbicidal. The application rate commonly used is about one pound per acre (Evans 1978). The toxicity to aquatic life and fate in the environment of this family of herbicides is well documented (Kemp et al. 1971).

Acute Toxicity--The toxicity of an ester of 2,4-D was widely variable among commercial formulations (Hughes and Davis 1962). The mixed butyl and isopropyl ester were no more toxic in combination than alone. The toxicity of 2,4-D compounds to fish was greatest for BEE; IOE, PGBEE salt, and acid compounds followed in decreasing order of magnitude (Hughes and Davis 1963, 1967; Meehan et al. 1974). For example, rainbow trout fingerlings suffered 53% mortality at 1 ppm BEE, 63% at 50 ppm IOE, and nil at 50 ppm pure acid (Meehan et al. 1974). The toxicity of 2,4-D BEE and 2,4-D PGBEE increased with temperature; water hardness and pH had no effect on toxicity (D. Woodward, unpublished). Woodward suggested the MATC concentration of 100 µg/l for BEE and PGBEE, on the basis of continuous flow bioassays. Saunders (1970), who examined the toxicity of 2,4-D compounds to six species of invertebrates, reported the 48-hr TLm toxicity in mg/l for each compound as follows: diethylamine salt, 4.0 to 8.0, BEE; 14.0 to 60.0; and PGBEE, 1.0 to 2.7.

Hughes and Davis (1965) found the 48-hr TLm of various compounds of silvex to the bluegill (Lepomis macrochirus) to range from 1.2 to 20 mg/l; the BEE form was most toxic, followed in decreasing order of toxicity, by IOE, potassium salt, PGBEE, and the triethylamine form. The toxicity of the PGBEE form (Kuron^{R}, the most often recommended compound of silvex) was tested by using two invertebrates and two fish (Cope 1966). Toxicity ranged from 0.76 mg/l to 16.6 mg/l 48-hr TLm; the stonefly (Pteronarcys californicus) was most susceptible and the bluegill most resistant. Naiads of the stonefly were later shown to be much more susceptible (Saunders and Cope 1967). Crosby and Tucker (1966) found that the potassium salt of silvex had a 48-hr TLm of 21.9 mg/l for rainbow trout and 12.5 mg/l for bluegills. Groups of the water flea (Daphnia magna) suffered 50% immobilization at 100 mg/l. (Crosby and Tucker [1966], exposed the water flea to various concentrations of several herbicides for 26-hr, then determined the concentration at which 50% of the test organisms were not able to swim toward light. At these concentrations, Daphnia, that were mobile died 1 to 2 days after exposure.) Saunders (1970) found that the toxicity (48-hr TLm) of PGBEE ranged from 0.18 to 3.2 mg/l and that of BEE from 2.1 to 40 mg/l for common freshwater invertebrates.

The 48-hr TLm of compounds of 2,4,5-T to the bluegill ranged from 1.4 to 144 mg/l; the BEE form was most toxic, followed by the isopropyl ester, oleio-1-3-propylene diamine, PGBEE, IOC, triethylamine, and dimethylamine ester forms, in decreasing order of toxicity (Hughes and Davis 1963). Bond et al. (1960) found that the PGBEE form had similar 24-hr and 48-hr TLm values (about 1.35 mg/l) for the chinook salmon (Oncorhynchus tshawytscha). Ferebee and Guthrie (1973) found no toxic effect of 2,4,5-T on aquatic bacteria at 0.7 to 1.4 mg/l.

Little work has been conducted on the phenoxy herbicide MCPA. Crosby and Tucker (1966) found that Daphnia were not immobilized at 100 mg/l. Hughes and Davis (1964) found it to be the most toxic phenoxy herbicide to bluegills (24-hr and 48-hr TLm, 1.5 mg/l).

Dioxin(TCDD, 2,3,7,8-Tetrachlorodebenzo-dioxin), a possible contaminant in phenoxy herbicides, was identified as a potent teratogenic agent to all animal life in the early 1970's. Later studies showed this chemical to be toxic to fish at nanogram levels (Miller 1973; Hawks and Norris 1977). Since this discovery, dioxin has been removed from the final products, but the possibility of contamination still exists. This possibility is being heavily considered in the reevaluation of registration of the phenoxy herbicides for use.

Avoidance by Fish--Sheepshead minnows (Cyprinodon variegatus) and mosquitofish (Gambusia affinis) avoided 2,4-D at low levels in water (Hansen et al. 1973), and grass shrimp (Palaemonetes pugio) avoided it at 1.0 mg/l. Barnes (1973) observed that fish avoided areas of a reservoir treated with the chemical. Bluegills, rainbow trout, and channel catfish (Ictalurus punctatus) exposed to non-lethal levels of 2,4-D did not avoid netting (Walker 1971). The net-avoidance response returned after accumulated levels of 2,4-D in fish flesh declined. Cope et al. (1970) noted that 5 mg/l 2,4-D PGBEE sprayed in ponds delayed bluegill spawning by 2 weeks. The hatchability of bluegill eggs and survival of fry was not affected by 0.1 mg/l silvex PGBEE (Wilber and Whitney 1973).

Bioaccumulation--Estes (1966) applied silvex PGBEE at 9 kg/ha for aquatic weed control and observed some mortality of pickerel (Esox sp.) in one area of a reservoir, but the kill was not widespread. Maximum accumulation in fish flesh was 0.01 ppm silvex. Gangstead et al. (1973) reported that silvex residues in fish were less than 0.4 µg/g one week after treatment of a Southern reservoir for aquatic weed control. Residues declined to about 0.1 µg/g after 2 weeks. Whitney (1968) found 19 ppm in fish

Table 1. Most often recommended herbicides for control of rangeland plants and maximum acceptable toxicant concentrations (MATC) for aquatic life.[1]

Parent Compound and Form	Active Ingredients	MATC (µg/l)
2,4-D		
Acid	2,4-dichlorophenoxyacetic acid	80 [3]
Salt	"	150 [3]
BEE (butoxyethanol ester)	"	4 [2]
PGBEE (Propylene glycol butyl ester)	"	150 [3]
IOE (isooctyl ester)	"	250 [3]
Silvex		
Acid	2-(2,4,5-trichlorophenoxy) propionic acid	No data
Salt	"	83 [3]
BEE	"	2.5 [2]
PGBEE	"	2 [2]
IOE	"	37 [3]
2,4,5-T	2,4,5-trichlorophenoxy acetic acid	12 [3]
MCPA	4-chloro-2-methyl phenoxy acetic acid	15 [3]
Atrazine	2-chloro-r-ethylamino-6-isoprophlamine-s-triazine	60 [3]
Dicamba	2,3,6-trichloro-o-anisic acid	200 [2]
Picloram	4-amino-3,5,6-trichloro picolinic acid	24 [3]
Paraquat	1,1'-dimethyl-4,4'-dipyridylium dimethyl	11 [3]
Fenac	2,3,6-trichlorophenyl-acetic acid	45 [2]

[1]Cords, and Artz, 1976; Parker, 1978; Alley, et al. 1978.

[2]From Kemp et al. (1971).

[3]Determined by applying an application factor of 1/100 to the most sensitive fish species for which information is available. Recommended MATC levels were not given by the National Technical Advisory Committee for these herbicides because insufficient information was available.

after treating a pond with silvex (PGBEE) at 9 kg/ha. Concentrations decreased to a negligible amount in one to three weeks.

The danger of bioaccumulation of 2,4-D to significant levels appears to be slight. Stalling et al. (1969) found that 2,4-D compounds were not metabolized by fish and were readily excreted by the gill and kidney. They are taken up across the gill membrane however, and may accumulate in fish tissue to concentrations greater than that found in water (Rodgers and Stalling 1972). Schultz and Harman (1974), who treated pond waters with 2,4-D acid, at 2-9 kg/ha and reported that only 45 of 307 fish analyzed over the following 147 days contained residues (range 0.1 to 1.0 mg/kg). Schultz and Whitney (1974), who monitored fish after an aerial application of 2,4-D acid (4.48 kg/ha) for control of water hyacinth, found residue in 19 of 60 fish samples; however, most residues were below 0.01 µg/g.

Field treatments--In two studies of forest spraying with a mixture of 2,4-D and 2,4,5-T (1:1 low volatile ester, 2.5 kg/ha), no caged fish or invertebrates in a forest stream were harmed (Fredd and Kruse 1963, Sears and Meehan 1969). Mullison (1966), who reviewed the silvex literature, concluded that fish species varied in their tolerance to silvex but that fish populations were not seriously affected in most situations where silvex ester was used. The potassium salt of silvex was less toxic to fish than the ester. Silvex esters decreased phytoplankton populations temporarily.

Smith and Isom (1967), who applied 888 tons of 2,4-D BEE to seven TVA reservoirs at rates of 45 to

112 kg/ha, reported little uptake of 2,4-D by fish, but some uptake by molluscs. Samples of hydrosoils contained 42 ppm of the herbicide after 10 months. They reported that larvae of a mosquito (Anopheles quadrimaculatus) survived treatments at 100 mg/l in laboratory studies. No effect was noted when exposed larvae were reared to the F_2 generation. They concluded that high rates of 2,4-D applied to TVA reservoirs did not adversely affect aquatic life. Trichell et al. (1968) discussed the loss of herbicides in runoff waters from treated terrestrial areas. Evans and Duseja (1973), after spraying 2,4-D and 2,4,5-T on Utah rangeland dominated with rabbitbrush (Chrystothamnus spp.), found a maximum of 1.38 mg/l 2,4,5-T in runoff water, but only 100 m of the stream below the treated site was affected. Highest concentrations of 2,4-D found were 4.2 mg/l from a site treated with 2.2 kg/ha; about half that was found from a site treated with 1.1 kg/ha. Runoff from the more heavily treated watershed carried 2,4-D residues downstream 1000 m from the treated site. Krammes and Wellets (1964), who sprayed brush on steeply sloped rangeland with a mixture of 2,4-D and 2,4,5-T and also applied a follow-up treatment with hand spraying, found no herbicide in surface water. In soil samples, small amounts of herbicide were detected 8 days later, but none was found after 1.5 months. After Reigner et al. (1968) treated stream bank vegetation with acid and ester compounds of 2,4,5-T and found only small quantities in water samples, they concluded that 2,4,5-T treatments could be used near public water supplies. Winston and Ritty (1961) found that at least eight species of soil bacteria use phenoxy herbicides as an energy source and that the herbicides are decomposed into carbon dioxide, inorganic chloride ions, and water. Degradation of 2,4-D in forest soils takes about 40 days (Norris 1970). Bailey et al. (1968) found that half of the silvex (PGBEE) applied at 9 kg/ha to a reservoir was hydrolyzed to the acid form in fish in 7 hours, and 99% in 33-49 hr.

Concentrations found in streams after forest spraying of 2,4-D at 2.2-3.5 kg/ha, reached a maximum of 1320 µg/l one hour after treatment. The levels declined to zero in 80 hr (Norris 1969). Demarco et al. (1967) showed that the decline of 2,4-D was rapid; zero levels were reached in about 10 days in warm and cold aerobic waters. A much longer period (about 80 days) was needed for degradation of the 2,4-D acid in cold, anaerobic waters. On the other hand, degradation of 2,4-D acid in natural water has been reported to be much slower -- 120-180 days (Aly and Faust 1964, Schwartz 1967). Runoff water from a forest sprayed with 2,4-D at 7 kg/ha contained only 20 µg/l 30 days after treatment (Norris 1968).

Picloram--Picloram (Tordon^R) is normally applied at 1.1 to 2.2 kg/ha for control of larkspur (Delphinium spp.), rabbitbrush, and juniper (Juniperus spp.). Kenaga (1969), who studied the effects of picloram by using short-term bioassays, found a high margin of safety between toxic levels to plants and toxic levels to fish. The 48-hr TLm was 2.4 mg/l for rainbow trout and 13.3 mg/l for bluegills (Bohmont 1967). Hughes and Davis (1967) found a 24-hr TLm of 43 mg/l for bluegills. The 96-hr TLm for cutthroat trout was 2 to 8.6 mg/l (Woodward 1978). Recent studies by Woodward have established an MATC for picloram by using continuous flow methods which simulated four storms in a 22-day period. He found that picloram was lethal at concentrations greater than 1.3 mg/l, growth of fry was reduced at 0.6 mg/l, and no adverse effect was found at 0.29 mg/l and below.

Picloram is apparently one of the most persistent herbicides that have been recommended for use on the range. In Utah, picloram could be detected 50 days after a small watershed dominated by rabbitbrush was sprayed with 1.1 kg/ha by Evans and Duseja (1973). They found maximum concentrations of 2.7 mg/l in runoff waters, but only 100 m of stream below the treated site were affected. Davis et al. (1968), who applied pelleted picloram at 10 kg/ha (an unusually high rate) on a Colorado watershed, found detectable amounts (maximum, 0.37 mg/l) in stream water after a storm. However, picloram could not be detected in runoff 16 months after treatment.

Atrazine--Atrazine is recommended for control of cheatgrass (Bromus tectorum) at about 1.1 kg/ha. Macek et al. (1976), after testing three invertebrates and three fish species for susceptibility to atrazine, reported 48-hr Tlms of 4.9 to 15 mg/l for all species tested except midges (Chironomus tentans) for which the estimate was 0.72 mg/l. All species were similar in their susceptibility to chronic exposure. The lower limit of the estimated MATC concentrations ranged from 0.06 to 0.21 mg/l. The most sensitive indicator of toxicity was reduction in hatching success for chironomids and growth rate for brook trout. The tendency of fish to bioconcentrate atrazine from water is low. Walker (1964) found that the use of atrazine in fish habitats at recommended rates was not harmful to fish, but did decrease benthic invertebrate populations for 4 to 6 months.

Atrazine is transported in small but significant quantities in runoff from farmland (Axe et al. 1969). A storm 1 hr after treatment caused up to 10 mg/l atrazine in runoff waters (White et al. 1967). Atrazine may persist in soils for one year (Hall et al. 1972).

Paraquat--Paraquat is recommended for control of juniper at 0.6 kg/ha; a level considerably below the 3 to 5 kg/ha recommended for aquatic weed control. Paraquat is rendered biologically inactive once it reaches the soil because of rapid adsorption, and can be detected in soil for months after treatment (Calderbank 1971). When applied directly to water, concentrations decline rapidly (Alkhavein and Linscott 1968).

Calderbank (1972) reported that the 96-hr TLm was 32 mg/l for rainbow trout and over 25 mg/l for brown trout. Paraquat, at 0.5 to 2.5 mg/l, did not harm invertebrates or fish life when used in a pond for weed control (Way et al. 1971). It disappeared from water in 4 to 7 days but persisted in hydrosoils up to one year. In another pond treated with enough paraquat to yield 1.14 mg/l in the water, some mortality of bluegills was observed. Residues in the water disappeared in 8 days but residues in fish flesh (maximum 2.08 ppm) were found for 67 days (Ernest 1971). Newman (1970) stated that 1 mg/l paraquat killed half of the test fish in 13 days. He believed that, since paraquat declined from water in far less than 13 days, herbicidally active concentrations were not toxic to fish. A small amount of paraquat entered the body of fish through the gills but did not accumulate, and no appreciable quantities were found in the flesh. A related dipyridylium

herbicide, diquat, has been shown to have a wide margin of safety to aquatic life (Berry 1976).

Crosby and Tucker (1966) found that 11 mg/l of paraquat immobilized 50% of the test Daphnia. Saunders and Cope (1968) found no toxic effect of 100 mg/l to a mayfly naiad. In stream water, paraquat at 2 mg/l caused an initial reduction of some classes of invertebrates (amphipods and hemipterans), but the populations rapidly recovered (Burnet 1972).

Fenac--Fenac is applied at about 5 kg/ha for control of cheatgrass brome. The sodium salt is more toxic than the acid form to fish (Cope 1965). The sodium salt has a 48-hr TLm of 19 mg/l for bluegills and 7.5 mg/l for rainbow trout (Cope 1966, Crosby and Tucker 1966, Bohmont 1967). Fenac accumulated in viscera and gills of fish (Funderburk and Lawrence 1963).

Crosby and Tucker (1966) found that more than 100 mg/l fenac (Na salt) was needed to immobilize Daphnia. The acid form had a 96-hr TLm of 56 µg/l for larval forms of a stonefly (Sanders and Cope 1968).

Fenac, when used in pond waters for control of aquatic plants, persisted in the water for 29 weeks (Grzenda et al. 1966). Pierce (1966), who applied fenac to ponds at 1 to 3 mg/l, found no effect on plankton, small invertebrates, or fish fry.

Dicamba--Dicamba (Banvel^{R}) is recommended for treatment of leafy spurge (Euphorhia spp.) and scotch thistle (Cirsium sp.) at 3 to 5 kg/ha. It is sometimes mixed with 2,4-D in lower quantities. Bond et al. (1965) determined that the 24-hr TLm for coho salmon was 151 mg/l. Bohmont (1967) found the 48-hr TLm to be 35 mg/l for rainbow trout and for bluegills. Hughes and Davis (1962) determined that the 96-hr TLm for bluegills was 20 mg/l.

Summary--Even though few studies are available on aquatic resource responses to herbicide application on sagebrush habitat, enough information from studies on forested areas and in reservoirs is available to support certain generalizations. Herbicides are not a significant hazard to aquatic life because the likelihood of exposure to significant doses is small. Concentrations recommended for range treatment are equal to or greater than those recommended for treatment of aquatic weeds. The hazard is further reduced by the low toxicity of most herbicides to animal life; the margin of safety between the concentrations at which most herbicides kill plants and the concentration at which they kill fish is large. Also, herbicides are not persistent chemicals in general. They decline rapidly in water and do not bioaccumulate in fish flesh at high concentrations or for long periods. Aquatic invertebrates are more sensitive than fish, and their populations may decrease in number after herbicide contamination. However, because the reproduction rate of these organisms is rapid, the reduction in numbers is temporary.

Because of the above factors, the recommended MATC levels (Table 1) may be too low. The fishery may respond to a herbicide in several ways, however, and although herbicide contamination levels may be too low to cause a fish kill, deleterious changes in productivity of the system may occur. More persistent herbicides, such as atrazine and picloram, may be continually added to streams in runoff water. These chemicals may be potentially harmful to aquatic life when frequent storms follow soon after herbicide applications.

Herbicides as a group are fairly innocuous substances, but this innocuousness depends on the individual chemical. Each formulation should be evaluated independently for field application.

RECOMMENDATIONS

In the previous section, livestock grazing and sagebrush control by mechanical methods, burning, and herbicide spraying were discussed in light of their potential impacts on rangeland riparian and aquatic zones. With certain precautionary measures and planning, these management practices can be used to enhance the quality of both the range and the aquatic resource.

Herbicides

Most herbicides are not considered major hazards to the aquatic resource because of their low toxicity to aquatic life, short exposure time, rapid decomposition, and lack of bioaccumulation. The margin of safety is great between concentrations of herbicides found in water after aerial spraying and concentrations harmful to aquatic life.

Herbicides may enter the aquatic environment by direct fall or overland flow. Entry by direct fall can be controlled by excluding streams and riparian zones from the treatment area and considering atmospheric conditions when spraying is done. Riparian buffer strips of untreated vegetation will protect the stream from herbicides carried in storm-water runoff and continue to provide cover and bank protection. Herbicides should not be mixed nor spraying equipment washed in a stream.

Mechanical Brush Removal

Mechanical brush removal is not considered a major hazard to the aquatic resource, however, there may be a potential for increased erosion after some treatments. If the eroded soil is deposited in a stream, the aquatic habitat and fishery could be adversely affected in a number of ways.

Proper use of mechanical brush control methods are well known (Parker 1978). Choice of the method, proper application of the method, consideration of topography and soil type, and proper timing are all important pretreatment points to consider. Posttreatment management such as seeding with perennial grasses, followup spot treatments, and strict grazing management are also important. The kind of grazing management practice is the most important single factor determining whether sagebrush control results in range improvement or deterioration and how long the range remains free of brush (Pechanec et al. 1967). Mechanical brush removal methods are not usually needed, nor should they be applied in riparian zones. Range management practices should follow those now commonly used in forestry, where buffer strips are left along streams.

Burning

Burning for sagebrush control is not considered a major hazard to the aquatic resource. Where post-burn erosion occurs, stream siltation may affect the fishery. The burn itself would probably be harmless to stream habitat and biota.

Essential points to consider to reduce the hazard of burning are the ability to control the fire, and soil type and slope. Burning should be done only where slopes are gentle and soils are firm, to reduce the likelihood of post burn erosion. A stream's riparian zone may be protected if necessary by a fire line or back burn. Choice of wind conditions in relation to stream position would reduce ash falling in the stream. Grazing should be prohibited for one full year after a burn, and only light, well managed grazing allowed several years thereafter.

Grazing

There is no doubt that red meat production from Western rangelands must be increased to meet growing demand. Like most challenges today, this one can be met by multidisciplinary efforts ranging from the genetics laboratory to the extension office. Most management tools needed to increase meat production and protect the range resources are at hand, but adjustments in technique and approach must be made.

As a first step, the grazing systems now recommended must be applied properly. Much grazing is still unregulated, uncontrolled, and unplanned (BLM 1976) and there is little universal understanding about the principles and procedures involved in rest-rotation grazing management (Box 1974, Beers 1977). Most grazing experiments have shown that range may be improved more rapidly under proper grazing management than with no grazing at all (Heady et al. 1974). But, which management method is best for which type of range? Gifford and Hawkins (1976), who searched the literature for studies that reflected the results of various grazing management systems, found only nine published accounts. This scanty information failed to show that any grazing system consistently or significantly increased plant or litter cover on a watershed. They found no information on the widely advocated rest-rotation systems.

Claims of adverse grazing effects on riparian and aquatic zones have been criticized for being made without the benefit of substantiating data. One of the reasons, as identified by attendees of a recent symposium (Platts 1978), is that many of the substantiating data are in unpublished studies and case histories. However, studies to date have yielded similar results and the trends are fairly clear. Researchers should continue to analyze the problem by gathering more data and at the same time move on to identify and develop grazing systems compatible with rangeland fisheries and the protection of riparian zones. Range management objectives to consider for protecting, restoring, or improving fish and riparian habitats have been recently published (Platts 1978):

1. Completely rest degraded riparian areas from livestock grazing.
2. Defer late fall grazing on streamside areas, when possible.
3. Recognize the specific needs of the different ecological units occurring in range pastures.
4. Distribute livestock in areas that do not border riparian zones.
5. Allocate vegetative cover in the streamside zone for fish at the same time that forage is allocated for livestock grazing.

Methods for meeting the above objectives include recognition of the riparian zone as a unique system with unique needs, consideration of exclosures as a range management tool, and continued innovative research.

Riparian Zones - Unique

Only about 1% of rangeland acreage is riparian but these habitats are key factors in supporting wildlife, fishing, and other forms of recreation. It is generally recognized, by range managers and aquatic biologists alike, that the riparian zone is unique; yet, rangeland is often thought of as homogenous when actually it is heterogenous. The productivity and vulnerability to misuse vary according to habitat type. Presently used grazing strategies may not be capable of solving the problems of riparian zones (McGowan 1977, Armour 1977). The contrast between riparian and adjacent upland environments warrants the use of different land management strategies on each type.

Exclosures as a Management Tool

Exclosures have been suggested as one tool which may be useful in grazing management (Meeuwig 1960, Davis 1977, Claire and Storch 1978, Ames 1977, Armour 1977, Kennedy 1977, Patterson 1976). Berry and Goebel (1978) recently reviewed the use of exclosures as a tool for information and education, research, and management. One recommendation from a recent workshop group was that grazing be prohibited in riparian zones that were not recovering under present grazing systems (Platts 1978). Coltharp and Darling (1973) recommended that fences be placed along streambanks of water supplies to provide a buffer zone between the stream and livestock, to prevent bacterial contamination. Pasture fences are now routinely used to control use and movement of livestock in upland areas and it is reasonable to assume that they can also be used in riparian areas (Schmautz 1977). The fenced area lost to grazing would be inconsequential because only a few meters along each stream needs to be fenced.

Several examples of the present use of exclosures in management are available. After the fencing of a 2-mile section of the headwaters of a stream in the North Platte Valley, Nebraska, where no rainbow trout had been produced, Van Velson (1976) reported that the stream yielded over 20,000 rainbow annually, only 3 years after the fence was installed. Protection of about 20% of the riparian zones on the Coronado National Forest, Arizona, (Ames 1977), and several streams in the Malheur National Forest, Oregon, (Claire and Storch 1978) are being provided with exclosures.

The incorporation of exclosures into a grazing management plan would be costly. Present cost estimates for fencing rangeland vary from $2,000 to $6,000 per linear kilometer (Armour 1977). Exclosure fences could be constructed according to presently used fencing policies and paid for with a part of the

range improvement portion of the grazing fee. The use of the Agriculture Conservation Program could support part of the fencing cost to private land owners. Under certain conditions, the cost-benefit ratio would be favorable. In Camp Creek, Oregon, where exclosure protection increased steelhead production 100%, the cost-benefit ratio was 3.34:1 (Fred Everest, Research Fish Biologist, U.S. Forest Service, Siskiyou National Forest, Oregon, personal communication). The benefit may be just as high on productive streams in the sagebrush ecosystem.

The cost of constructing exclosures can be reduced in several ways. Costs can be amortized over a considerable number of years, whereas short-term improvements in the fishery (e.g., stocking), must be borne on an annual basis (Wydoski and Duff 1978). Exclosure construction cost can be lowered by enlisting the support of sportsman's organizations and other public service groups (Migel 1974). Construction can also be conducted by unskilled and seasonal labor. Exclosures need not be placed on all streams, for many streams are protected by inaccessibility to livestock.

Riparian vegetation and rangeland streams could be inventoried (Brown et al. 1977) and classified (Davis 1977) for their ability to withstand grazing pressure (Cooper 1978). Riparian protection could then be carried out on only key drainages such as those where endangered species occur, those important to the fish life cycle (e.g., intermittent streams where spawning occurs), and those that have good potential for a quality fishery. Fences might be placed only on portions of a stream where sensitive habitat features are identified. For example, Cooper (1978) found that once the bank rock content of a stream reached a certain rating, the bank was susceptible to livestock damage, whereas banks with a higher rating were more resilient.

Exclosures should be used in concert with other management tools and should be a part of the total management plan, rather than constituting the whole plan. The ultimate goal of an exclosure would be to allow riparian vegetation to recover to the extent that it could remain productive and protect the aquatic ecosystem when reintroduced into a grazing program. Riparian plants grow prolifically and once reestablished, may become dense and tall, and be vigorous enough to withstand a certain amount of grazing pressure. With other management tools designed to spread out grazing pressure, the riparian zone can be used by cattle without substantial damage to the stream.

Three studies have shown that properly managed grazing on the riparian zone can be carried out while assuring protection of the aquatic resource. Claire and Storch (1978) exclosed cattle from an area on Camp Creek in Oregon; after 4 years rest, grazing after August 1st did not affect fish populations. Kimbel and Savage (1977) found that a 66% reduction in grazing pressure on the Diamond Fork watershed improved fish habitat and fish population compared with that found during heavy grazing pressure. Lorz (1974) studied areas of a river which were heavily grazed, but had a dense willow stand that resisted grazing pressure, thereby protecting both banks of the river. Cover shade and bank stability were provided. He found no difference in the brown trout population between these and ungrazed areas. Furthermore, sections of the stream that were heavily grazed but where only one bank was protected by the dense willow stand, had only a slightly reduced fish population compared with the ungrazed section. It was only in sections where the willows were not established that grazing severely affected the stream and the fish population.

Caution must be used when reintroducing livestock to an exclosed area however. There is evidense that grazing in sensitive riparian zones or in those where recovery is incomplete may be detrimental. Duff (1978) found that cattle that grazed illegally in an exclosure on Big Creek, Utah, where riparian vegetation had rested for 4 years, quickly reduced the condition of the habitat to a condition similar to that prior to fencing; vegetation cover declined 14% and bank stability decreased 12% in only 6 weeks.

The length of rest needed is undoubtly variable from site to site. Speculations on recovery time for a variety of vegetation in different habitat types is from 3 to 13 years. Most range scientists believe that 3 to 4 years of grazing prohibition is needed to restore hydrologic integrity and vegetative productivity to upland areas (Sartz and Tolstead 1978, Packer 1951, Patterson 1976, Lusby 1970). It has been suggested that 70% cover is sufficent to protect soils (Packer 1951).

The benefits of improved stream habitat to fish has been pointed out. But benefits also occur to the terrestrial zones. When the water table rises, production of riparian vegetation is stimulated and the broader riparian zone produces more forage. Also, less bottomland and pasture is lost by erosion. Livestock may ultimately have more bottomland with better forage. Improved game and fish habitat attract sportsmen; use of private lands for hunting or fishing may be monitarily rewarding to the owner. Increased recreational use of rangeland is one objective of the management methods discussed here.

RESEARCH NEEDS

Many questions must be answered before best range management strategies can be employed (Meehan and Platts 1978, Berry and Goebel 1978, Leopold 1974). Some of the research needs follow:

1. Comparisons of streams in multiple use areas with streams subject to no exploitation on a long term basis.
2. Comparison of grazing systems for their impact on fishery values.
3. Comparison of grazing systems for their ability to promote restoration of streamside vegetation.
4. Determination of rest time needed for streamside vegetation to recover enough to withstand grazing.
5. Comparison of the effect of different types of livestock grazing on range.
6. Improvement of habitat evaluation techniques to reduce error in measurement, and development of new methodology.
7. Evaluation of the utility of using exclosures as a research tool in a predictive mode.
8. Determination of the optimal placement, shape, and construction methods for exclosures in riparian areas.
9. Classification and inventory of riparian habitat in grazed areas.

SUMMARY

The purpose of this paper is to summarize the potential impacts of important range management practice such as grazing, mechanical brush control, and herbicidal application and burning, on aquatic habitat and biota in the sagebrush ecosystem. Livestock grazing is the most important and controversial rangeland use. Case histories showed that grazing may reduce vegetation cover and increase soil erosion, bank instability, stream temperature, stream bottom siltation, and water turbidity. Each change may have secondary effects on a fishery by reducing cover and decreasing primary and secondary productivity. Minor effects of grazing are bacterial contamination and organic enrichment of water, increased peak flows, physical disturbance of spawning areas, and fish behavioral alterations.

Mechanical brush removal and burning may potentially increase erosion. Burning may also cause a temporary change in stream water quality. Herbicides may be acutely or chronically toxic to fish and invertebrates, cause behavioral changes in fish, and accumulate in fish tissues. The likelihood of exposure and a chemical's toxicity determine its hazard to non-target organisms. The hazard is not great for commonly used rangeland herbicides such as the phenoxy herbicides 2,4-D, silvex, picloram, atrazine, paraquat, fenac, and dicamba, because the margin of safety between concentrations lethal to plants and those lethal to fish is large. Also, most herbicides are not persistent in the environment. Exceptions are atrazine and picloram, which may appear in runoff water for several months after spraying.

Riparian buffer zones left between the stream and rangeland which is sprayed with herbicides, mechanically altered, or burned, will reduce the impact of these treatments on aquatic life. The control of grazing is more complicated. Range managers should apply grazing systems properly, follow objectives for protecting fish and riparian habitats, and recognize that the riparian zone is unique in its productivity and vulnerability. Exclosures may be used as part of a grazing management plan with the goal of returning the exclosed area to the grazing program when riparian vegetation has recovered sufficiently.

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Impact of Rangeland Management on Recreation and Aesthetics

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Introduction

One hundred years ago John Wesley Powell completed his "Report on the Lands of the Arid Region of the United States." He opened his discussion of pasturage lands with these words:

> The irrigable lands and timber lands constitute but a small fraction of the Arid Region. Between the lowland on the one hand and the highlands on the other is found a great body of valley, mesa, hill and low mountain lands. To what extent, and under what conditions can they be utilized? (Powell 1878)

Certainly that is an appropriate question today.

The western rangelands remain the largest undeveloped recreation resource in the contiguous states. Open, spacious and public land is highly valued by many people. Recreation use is dispersed and undeveloped. Although outdoor recreation will probably never be as intensive as major recreation areas, it is an important activity on the shrublands. Increased attention will be focused on these lands from individuals and groups concerned with not only recreation, but preservation and wilderness values. It is probable that intensive management programs of the shrub environment will be highly controversial if they are planned only through the eyes of rangeland managers or if such programs are perceived to be threatening recreation and aesthetic resources. Unfortunately the existing research base for outdoor recreation on these lands is almost non-existent. At this point specific conflicts and impacts are largely a hypothesis.

Literature Review

Wildland recreation in the sagebrush environment takes place largely on federal lands. Approximately 80 percent of the shrubland is federally owned. Ten million acres are managed by the Forest Service (FS), 64 million acres managed by the Bureau of Land Management (BLM), and 3 million acres administered by other federal agencies (US Forest Service 1975).

Most recreation research that concerns the shrublands has centered around activities. Two shrubland activities that have been studied in detail are hunting and off-road vehicle use. Information on the scope of these activities, the characteristics, and motivations of the participants is reasonably well understood in general terms. An important finding has been realizing that only a small part of the hunter's satisfaction is derived from bagging game (Plummer, Erickson and Graves 1975). Rangeland management programs that enhance the numbers of game animals as well as domestic livestock have been advocated. However, such programs may be unacceptable to outdoor recreationists for other reasons. In the case of off-road vehicles, researchers have found that recreation subgroups have different objectives and motivations (Peine 1972, McCool et al. 1975). A land management plan may be completely acceptable to motocross racers but unacceptable to a 4-wheel drive club. Even various motorcycle groups may have divergent objectives for their recreation experience. Categorization is difficult.

It has been estimated that on BLM lands in Nevada, Idaho, and Utah 21 million recreational visits took place in 1976 (BLM 1977). Most of this use does not take place in existing developed campgrounds, picnic areas or other managed facilities. Unfortunately most recreation research has focused on the concentration of recreationists on developed sites. The reason is obvious. A study population can be defined, sampling problems are diminished and research costs are low. The rangeland camper and recreationist may not be represented by any of the existing research. Most shrubland recreation is a form of dispersed recreation. For the individuals involved, shrubland recreation may be very important. For example, rockhounding is a major recreational activity for retired people. It is one type of dispersed rangeland activity that is a focus of social activity and in many cases an important income supplement.

The dispersed camper may well be a clearly different type of recreationist. The rangeland and shrubland camper may be in an isolated environment because of the lack of developments. The opportunities for solitude, an absence of regulations and developments could be the most important elements

of their experience. This type of recreationist may also pursue activities such as target practice, nongame hunting and "getting away" as an end in itself. Such activities are prohibited in developed campgrounds and national parks. Campers in developed areas pursue recreation because of the social opportunities. If the dispersed recreationist is a contrast to developed recreationists, then intensive management of shrublands may be offensive or interrupt his sense of isolation and solitude.

Other studies have indicated problems between recreationists and intensive management. Visitor perception of other wildland environments provides some indication of concern for the shrublands. Foti (1977) found that an important element of a "wild" recreational experience was the presence of wildlife. Also a significant number of recreationists in backcountry and wilderness areas were disturbed by the presence of livestock. In many cases the riparian and shaded areas of the shrublands such as aspen stands are desired by both recreationists and livestock. Rangeland developments and increased recreation use may increase this conflict in the future.

Limited research is available on the nature of wildland aesthetics. A person's response to an environment is complex (Litton 1974). While most would regard a response as emotional it can also be considered as a phenomenon of information processing (Wenger and Videbeck 1969). Simple aesthetic measures for wildlands do not exist. According to Schreyer and Royer (1975), to a large extent we like what we are taught to like.

The most obvious application of perception research to the rangelands should be a concern for professional chauvinism which brings with it an orientation toward one type of use or one product. Rangemen perceive the shrub environment with a set of values and experience vastly different from most recreationists. As a regional land use, relatively isolated from national public land policy issues, shrublands seem especially vulnerable to chauvinistic management. Some range managers have regarded livestock as not competing with recreational activities (Heady and Bartolome 1977). The Society of Range Management (1975) has gone so far as to state that not only does livestock not generally conflict with recreational land values but in many instances enhances them. Unfortunately these statements lack any research evidence. What research that is available elsewhere clearly implies that the focus on a recreational activity is but one dimension of complex recreational experiences. The perception of recreation satisfaction and rangeland management through the eyes of a range manager, or a plant biologist or any other professional has many opportunities for misconception.

Future Directions

The first review of the public lands, completed in 1883, had a fairly detailed profile of the one federal recreation area, Yellowstone Park. The second review of the public lands, completed in 1905, had a detailed proposal for the regulation and management of livestock grazing. However, it was not until the fourth public land review, completed in 1970, that both rangeland policy and recreation were considered. It was the report of the Public Land Law Review Commission that first addressed the recreation issue of rangelands. The report stated:

> Emphasis on the Federal recreation management of those public lands not classified as nationally significant should be placed on dispersed types of outdoor recreation requiring only minimum land development and supervision, and few facilities. (PLLRC 1970)

The next specific mention of recreation in the rangeland environment was in the draft national outdoor recreation plan (US Senate 1974); "Some of the greatest untapped recreation land potentials lie in the 450 million acres administered by the Bureau of Land Management primarily in the 11 western states and Alaska." Finally the Resource Planning Act, or RPA assessment and goals established by the Forest Service addressed the rangelands more specifically. The Forest Service projected an increase in dispersed camping of 100 percent over the next 45 years in part because of an annual increase in recreational vehicles that averaged 16 percent from 1961 to 1974. Finally for the National Forest System a formal goal of "increasing the supply of outdoor recreation opportunities and services through Forest Service programs that emphasize dispersed recreation" was established (US Forest Service 1976). Future outdoor recreation policy on public lands seems clearly headed toward dispersed recreation. The potential supply is large, the costs are low and the environmental impacts acceptable. The largest reservoir of dispersed recreation lands are the rangelands.

The National Environmental Policy Act of 1969 has resulted in a major impact on the public lands. However, it was not until the Natural Resources Defense Council lawsuit against the BLM that the impact of NEPA began to significantly impact the rangelands. The lawsuit resulted in the BLM agreeing to write 212 environmental impact statements by 1988.

For the first time the public has the opportunity to closely consider the impacts of the rangeland planning and the potential impacts on other forms of land use such as recreation and aesthetics. A result of over 200 EISs remaining will be a continual process of opening the rangelands planning to public scrutiny. The review process is pursued by many environmental and conservation organizations. Alternatives and impacts are being studied and evaluated. If the dominant land management proposals continue to be rest rotation grazing or other livestock oriented programs, substantial controversy will result.

Another area of rangelands which has attracted the attention of outside publics has been the Wild Horse and Burro Act of 1971. The continual publicity and controversy over the wild horse issue has drawn a new audience into the management of rangelands. This group is not part of the established environmental movement and has not been a constituent of the BLM or the Forest Service. These

groups will continue to look at intensive rangeland and sagebrush management programs in terms of the impact on wild horses and burros. Their values and rangeland perceptions are not shared by traditional rangeland users, the agencies, or the range management profession.

The latest major impact on the growth of interest in the rangelands came with the BLM Organic Act, or the Federal Land Policy and Management Act of 1976 (PL 94-579). The act did two very important things for dispersed recreation on BLM rangelands. First, Section 102(a)8 formally recognized outdoor recreation as a BLM policy. Second, Section 603 mandated a BLM wilderness review on all roadless areas. The wilderness review section will focus the attention of conservation and preservation organizations on rangelands during the 1980s. For the first time the actions and consequences of the rangeland manager will be measured against the land's natural condition and its wilderness potential. Unlike the Forest Service, the details of the wilderness review process mandate a procedure which favors the retention of lands in an undisturbed condition. A clear, detailed, and lengthy wilderness review procedure is required. These differences are in marked contrast with the original wilderness review procedures mandated in the 1964 Wilderness Act for the Forest Service, Park Service, and Fish and Wildlife Service. The result will be years of controversy and public attention directed toward the BLM rangelands.

Research Needed

Without research data the implications of brushland management on the recreationist and aesthetics is largely speculation. Certainly the potential for management controversy focusing on the public rangelands appears great. Rangelands may well be the public land policy time bomb waiting to go off. Protected by the attitude that these were the lands nobody wanted and isolated from national publics and outside influence the potential for conflict and controversy has grown. The launching of large management practices without research data on recreationists and those oriented toward primitive environments is asking for trouble.

What is needed? First, we need to understand the rangeland recreationist. Who are they, what are their values, perceptions and activities? What do recreationists want? We need to understand what the use is, its growth pattern, its economic impact. This information then can be used to test and analyze the reaction of the recreation population to various management practices. Finally, methods to mitigate potential adverse reactions through land management must be developed and tested. Public input from a wide variety of users must be developed and utilized. These answers will likely provide management guidelines rather than absolute concise prescriptions. Without this research, intensive rangeland practices such as chaining, type conversion, rest rotation grazing, and other practices may be intolerable to many.

Interest in the public lands is increasing. It is the result of dispersed recreation, the NEPA and the environmental impact statement process, and new public attitudes. Wilderness review and wild horse legislation will attract even more attention to rangelands. As publics take a closer look at shrublands, they will be critical of any intensive management practices that threaten their interest. Any management practice that serves the objectives of one interest group or that will be seen as a dominant use of the rangelands will not be politically acceptable for public shrublands. Rangeland and shrublands have many years of controversy ahead. Intensive management programs may well be comparable to the clearcutting controversy that faced the Forest Service in recent years. Biologically sound programs supported by economic rationale and professional judgement can still be highly controversial and politically impractical.

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GRAZING SYSTEMS AS A MANAGEMENT TOOL

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Conceptions and Misconceptions

Grazing management is readily defined as manipulation of animal grazing to accomplish a desired result (SRM Range Term Glossary Comm. 1974). Good grazing management is based on achieving the following:

(1 Proper stocking rates and grazing intensity.
(2 Proper kind or combinations of grazing animals.
(3 Proper seasons of grazing and grazing systems.
(4 Proper distribution of grazing.

The application of these grazing management principles are often enabled or greatly enhanced through range improvements and developments.

Although readily classified as a part of grazing management, it has proven difficult to even define the term grazing system. Heady (1975) has concluded that the term grazing plan is more appropriate than grazing system in referring to a schedule for moving grazing animals from one pasture to another but recognized that the term grazing system is here to stay. The grazing system, as a minimum, must provide for systematically recurring periods of grazing and non-grazing during the feasible grazing season, either within or between years, and this enabled by a schedule for moving grazing animals. The term grazing system should be restricted to seasonal patterns of grazing rather than being used to describe the day to day provisioning of livestock feed.

A great variety of grazing systems have been named and described and are available for selection and application; but all must be tailored to fit specific local needs. The great climatic, elevational, floristic, and phenological variations found within the sagebrush ecosystem provide a heterogenous setting for applying the concepts of grazing systems. The extent to which the original climax communities have been modified by accident or design, the kind or combinations of grazing animals to be managed, and the differing objectives of grazing management add further complexity. A first misconception is that there is such a thing as a universal grazing system, one even to be applied throughout the sagebrush ecosystem alone. Thus, grazing systems--not just one system--is the appropriate topic to pursue here.

Secondly, unless the confines of the feasible or realistically maximum season of grazing are first established, the effective application of any grazing system will mostly be thwarted. The factors that determine the feasible season of grazing operate differentially even throughout the sagebrush ecosystem. Such limiting factors include extremely hot summer temperatures, deep snow and frigid temperatures in winter, low quality curing of resident vegetation, unstable slopes when wet, the presence of poisonous plants with specific danger periods, and seasonal drought generally associated with deficits of both stockwater and forage.

A third misconception is that specialized grazing systems are the long-awaited panaceas that will permit ignoring the other principles of grazing management. On the contrary the evidence is overwhelming that they cannot replace the need for proper stocking rates, the use of species of grazing animals adapted both to the terrain and to plant species available on the site for grazing, and the use of a composite of many techniques for distributing grazing. And it becomes apparent that grazing systems are just one more tool to achieve the desired management of grazing.

Expectations and Descriptions

Realistic expectations from grazing systems must be made before being applied. And the realization of these expectations must be carefully evaluated following application. Heady (1970) has pointed out the confusion that occurs when results are ascribed to the grazing system when in fact they are due to the whole range management program of which the grazing system is but one of the practices; initiation of a grazing system is often accompanied by a commitment to improve other factors of management as well. Heady has also rationalized on why seasonally oriented range grazing systems have seemingly been more successful in practical management than in research.

For a grazing system to be effective and practical, the following minimal characteristics are commonly suggested:

(1 Must be based on the physiological requirements and life history of the primary forage plants and be suited to them.
(2 Will improve range condition on low condition range or maintain high condition range.
(3 Is adapted to existing soil conditions, and erosion and puddling will not result from its use.
(4 Is not detrimental to animal gain and will minimize disturbance of livestock.
(5 Must be economically sound; range improvement may be slow and the cost of additional fencing and stockwater development be high.
(6 Must be practical to implement, reasonably simple to operate, and flexible enough to meet fluctuations in forage production caused by climate.
(7 Must fit in with the total grazing management plan for the ranch, operational unit, or allotment.

Several authors have attacked the problems and inconsistencies in the nomenclature and definitions of the various grazing systems (Heady 1970, Heady 1975, Kothmann 1974, and Stoddart et. al. 1975). Because of the complexity and wide differences in various specialized grazing systems, the following outline and descriptions of several major grazing systems is provided to enable further discussion:

1) Continuous grazing--unrestricted livestock grazing or access throughout the entire feasible grazing season, i.e. during most of the plant growing season or also part or all of the plant dormancy period; the grazing period lasting from a few weeks to a full 12 months depending upon the extent of the feasible grazing season; scheduled non-grazing during the feasible grazing season is not provided for.

(2 Rotation grazing--the moving of grazing animals from one pasture to another on a scheduled basis; does not specifically provide for other features such as deferred or delayed grazing or complete annual rest but may alter the sequences of grazing from year to year.

(a Daily strip grazing--animals grazed on a new strip or paddock of fresh forage each day; the grazing, non-grazing cycle repeated a few to several times during the growing season; almost never applied to rangelands in the US.

(b Short rotation (repeated)--grazing each unit in a series for a few to several days until all units have been grazed, and then repeating the cycle one or more times within the same grazing season; adapted in the West primarily to pasture such as irrigated pasture capable of continual rapid regrowth following grazing.

(c Short rotation (unrepeated)--grazing each unit in the system from several days to a few weeks but not regrazing during the current grazing season; the units generally grazed in a different sequence each year; the common "rotation grazing" of native ranges; may be used to enhance uniformity of grazing on rangelands, i.e. high-intensity, low-frequency grazing, or implement the sequences in a deferred-rotation grazing system.

(d Two-crop--repeated short rotation grazing involving grazing to boot stage in the spring and again in the fall after forage plants have cured; has been applied to seeded range primarily.

(e Topping-followup grazing (first grazers, second grazers)--a modification of repeated short rotation grazing in which each grazing period is divided into first grazers and second grazers. An example is topping lush irrigated pasture with yearling steers and then immediately full grazing with cow-calf or ewe-lamb pairs.

(f Repeated seasonal grazing--reserving a native or seeded range unit for grazing at the same time each year, generally for less than for the full feasible grazing season; examples are calving or lambing pasture, breeding pasture, weaning pasture, fattening pasture, or protected areas for mid-winter grazing.

(g Complementary rotation--an expansion of repeated seasonal grazing in which a series of pastures of different plant composition are grazed on a seasonal schedule, i.e. crested wheatgrass in early spring, intermediate wheatgrass in late spring, native sagebrush-grass in the summer, and Russian wildrye in the fall; possibly better referred to as a complementary grazing plan rather than system.

(3 Deferred grazing--not being grazed until after a particular plant development stage, generally seed maturity or equivalent growth stage for the predominant forage species, to insure reproduction and increased vigor and then full grazing during the latter part of the grazing season.

(4 Delayed grazing--delaying grazing early in the grazing season but initiating grazing prior to seedset or equivalent growth stage.

(5 Rest--not being grazed at all during a given year; even the mature forage is left unharvested; shorter periods of non-grazing should not be referred to as rest.

Grazing Systems Research in the Sagebrush Ecosystem

An excellent review and evaluation of grazing systems on western ranges entitled "Specialized Grazing Systems: Their Place in Range Management" was made by Shiflet and Heady (1971). Other reviews suggested for background reading include those of Heady (1975), Herbel (1971 or 1974), Hickey (1966), Jefferies (1970), and Stoddart et al. (1975). These and other literature reviews demonstrate that very few controlled research studies have been carried out on semi-desert, native sagebrush range, only a few more on higher elevation sagebrush range, and an insufficient number even on former sagebrush range converted to introduced range grasses.

Pechanec and Stewart (1949) included rotation grazing and spring deferment in their recommendations for grazing spring-fall sheep ranges of southern Idaho. They concluded that

rotating grazing between different units in the spring but in a different sequence each year was an effective method of maintaining range in satisfactory condition or improving range in unsatisfactory condition because it (1) avoided repeated early spring grazing, (2) avoided grazing during critical plant reproductive periods in some years, (3) encouraged seed production by many of the more valuable species, and (4) avoided grazing seasonally palatable species every year when most palatable. They further recommended that one pasture each year not be grazed in the spring or at least not until after seed set. They cautioned that some leeway and good judgment must be used in adapting to climatically induced plant growth variations from year to year.

Hyder and Sawyer (1951) reported results of a 11-year study on rolling, native, semi-desert, sagebrush-bunchgrass range in southeastern Oregon on which big sagebrush (A. tridentata) was the dominant shrub and with a grass understory of bluebunch wheatgrass (Agropyron spicatum), Idaho fescue (Festuca idahoensis), and Sandberg bluegrass (Poa secunda). The grazing season in the study averaged May 1 to October 1, and cattle were the grazing animals. The three-pasture, three-period (equal length), and one-herd deferred-rotation system used provided a grazing sequence for each pasture of two years of spring use, two years of partial deferment, and two years of full deferment.

The conclusions were as follows: "Broadly considered, season-long grazing was more favorable to both cattle and vegetation, mainly because the rotation system resulted in serious overgrazing during the first foraging period." Seasonlong grazing advantages were (1) an average of 23 pounds more gain per cow during the first grazing period, (2) an average of 9 pounds more gain per cow per season, and (3) a greater increase in both total vegetation density and density of the forage species (particularly Sandberg bluegrass). Advantages of the rotation system were (1) 14 pounds more gain per cow during the last two grazing periods, (2) better distribution of grazing, and (3) a more uniform increase throughout the range of bluebunch wheatgrass and Idaho fescue. A further conclusion was that in a rotation system attention should be given to plant vigor rather than seed production. A need to modify the rotation system to reduce heavy, early spring grazing was apparent.

On a semi-desert, big sagebrush-wheatgrass type in southern Wyoming "implemented under operational ranching conditions rather than as a strictly controlled research project," comparisons were made between 4-pasture rest-rotation, 2-pasture deferred, and one-pasture continous systems grazed by cattle from spring until winter (Gibbens and Fisser 1975). Following a 25 percent reduction in permitted grazing at the beginning of the study, all units improved in range condition without apparent effect on wildlife populations. After 9 years in the study, Gerhart and Fisser (1977) concluded that present stocking rates had not stressed the plant communities enough to detect differences between grazing systems since all treatments had improved range conditions.

Grazing research on sagebrush-grass ranges initially in fair-good condition at the U.S. Sheep Experiment Station near Dubois, Idaho, included a comparison of spring rotation-fall continuous grazing with spring and fall continuous grazing at heavy (40-sheep days per acre) and light (20 sheep days per acre) stocking rates (Laycock 1962). The spring grazing period was May-June and the fall period was mid-November to Christmas. It was concluded that the damage from heavy grazing is increased by early and continuous springlong grazing and by grazing the same area during the same portion of the spring season each year. It was noted that even the heavier rate under spring rotation did not damage the range. Futher conclusions were that rotational grazing during the spring did allow sagebrush-grass range to be more heavily stocked without damage than under continuous grazing but that rotational grazing in the fall was unnecessary. In a related study reported by Laycock (1967) heavy late-fall grazing by sheep improved deteriorated sagebrush-grass range not previously grazed in the spring by reducing the sagebrush (A. tripartita) by 22 percent and increasing the production of grasses and forbs by 36 percent.

A controversial but highly promoted grazing system in the West is rest-rotation grazing. Based on studies carried out on the Burgess Spring Experimental Range in northeastern California, its designers claimed for it the following (Hormay and Talbot 1961): "Under rest-rotation grazing, stocking is based on the production and use of herbage from all the available forage species and not on the key species alone. Under this system, degree of use of plants does not have the same importance as under continuous seasonal grazing, because grazing is limited to a comparatively short time and is always followed by rest planned to be long enough to overcome the harmful effects of grazing. Further, under rest-rotation grazing little attention is paid to classifying plants according to palatability to determine forage production and stocking...Plants are classified simply as forage or nonforage species, and stocking rate is calculated on the basis of production of all forage species." In his training manual for "a course in range management," Hormay (1970) stated, "I have placed special emphasis on rest-rotation management of grazing." He further described periodical rest as "a powerful tool available to the range manager for increasing land productivity" and resolved that "only by this means can the main objectives of grazing management be realized."

After three years of preparatory work, the representative area selected for testing rest-rotation grazing was the Harvey Valley Allotment on the Lassen National Forest in California, and work was begun in 1954 (Ratliff et al. 1972). The test area is found at an elevation of 5,600 to 7,500 feet; receives an average annual precipitation of 18.4 inches; and includes five principal vegetation types: open grassland, silver sagebrush (A. cana), black sagebrush (A. arbuscula), big sagebrush, and ponderosa pine-big sagebrush. The 5-pasture, one herd rest-rotation system set up at Harvey Valley included the following annual sequences in each 5-year cycle: (1) full use (i.e. about 66 percent), (2) rest, (3) deferred and then full use, (4) rested, and (5) moderate use (i.e. about 33 percent).

Utilizing a summer grazing season with cattle beginning annually about June 1, results were compared with continuous summerlong grazing in a nearby allotment.

Based on data collected from this study through 1966, Ratliff et al. (1972) reported that "the response to rest-rotation has not been as dramatic at Harvey Valley as in some other areas" but that "it seems clear that rest-rotation grazing is ecologically superior to seasonlong grazing; and that range health at Harvey Valley relative to nearby allotments is better, and range condition trend upward, because of rest rotation grazing." However, they anticipated from their data that 7 to 20% greater livestock gains could be made from continuous grazing and that the cost-benefit of rest-rotation grazing was not completely satisfactory. It was concluded that rest-rotation grazing was primarily a procedure for restoring range health rather than maintenance. Two major advantages of the system were considered to be that the rest areas could provide emergency use in severe drought years and that it provided opportunities for cultural range improvements.

Based on data collected in the Harvey Valley study from 1965 to 1969, Ratliff and Reppert (1974) reported these somewhat startling conclusions: (1) "continous grazing appears to be more effective in controlling competing vegetation than it is damaging to Idaho fescue," (2) "the full use treatments did not reduce nor did full-season rest improve Idaho fescue vigor on the Harvey Valley plots," and (3) "it appears that range managers cannot key seed production into a set program of rest-rotation grazing." It was found that droughty springs caused the fullest use of Idaho fescue and was most damaging then; but in springs favorable for plant growth, the actual grazing of Idaho fescue under continuous summer grazing was lighter and later, and these actual rest periods accompanied by reduced competition allowed it to maintain its vigor and reproduce under moderate, continuous grazing. A previous observation (Ratliff 1962) was that, although preferential grazing of range areas was continuing under rest rotation, some cattle were being forced into less preferred areas.

From a study on a portion of the Bighorn National Forest in Wyoming (8,000 feet elevation; 31 inches average annual precipitation; Idaho fescue community with big sagebrush being included in some areas), Smith et al. (1967) reported finding no evidence that rotation grazing was better than seasonlong summer grazing and concluded that grazing intensity had more effect on animal production than did systems of grazing. Moderate continuous summer grazing maintained Idaho fescue, the key management species, better in cover and production than did moderate rotation grazing, but the latter reduced somewhat the grazing impact in the meadow communities. No difference was found in daily cattle gains between moderate continuous and moderate rotation, but heavy rotation produced .4 lbs. less daily gain than did moderate rotation. Preliminary results from a grazing study on a big sagebrush-bitterbrush-Griffiths wheatgrass (Agropyron griffithsii) site in the Pole Mountains of Wyoming indicated that both rest-rotation and rotation grazing systems were superior to continuous summer grazing in spreading out the grazing more uniformly and reducing utilization in overgrazed meadows (Johnson 1965).

On crested wheatgrass (A. cristatum) pastures in central Utah (5,700 feet elevation; 13-inch rainfall; spring grazed by cattle April 20 to June 20), a three-division rotation in which each area was grazed twice each spring produced slightly more plants and slightly more ground cover than did continuous springlong grazing (Frsischknecht and Harris 1968). The rotation system generally reduced gains per head slightly while increasing gains per acre (46 vs. 39 lbs. per acre) through increased grass yields.

Grazing studies on crested wheatgrass in southern Idaho (about 4,800 feet elevation; 12 inches average annual precipitation; originally a sagebrush-bluebunch wheatgrass community) including 15 years of data have been reported by Sharp (1970). Forage production and plant vigor was restored to heavily grazed crested wheatgrass stands by resting a year or two, by deferring grazing during the growing season, and/or by alternating the time of grazing during the growing season. A three- or four-unit grazing system in which all units were fenced separately was found to enable more intensive management and greater flexibility. The suggested system was to defer one unit each year, the deferred unit then to be grazed to about 50% of capacity in the fall and grazed first the following spring while alternating the other spring periods among the other units not defered.

Heavy grazing of crested wheatgrass in alternate years in Nevada studies (Robertson et al. 1970) produced downward trend at two of three locations studied. Moderate grazing each year was concluded better than alternate year rest after heavy use. One year's complete rest did not compensate for overgrazing in the previous year.

A two-crop system for grazing crested wheatgrass has been suggested by Hyder and Sneva (1963). Grazing moderately in the spring prior to boot stage and then again in late summer or fall after curing has enabled harvesting a maximum of early feed, permitted good storage levels of carbohydrates by fall, and provided late summer or fall forage that is more palatable and nutritious than if not topped early in the spring. Such a practice permitted spring regrowth for fall grazing providing spring grazing was not continued beyond the boot stage of crested wheatgrass growth. The two-crop grazing system has also been found effective on creasted wheatgrass in Idaho (Sharp 1970), in Utah (Harris et al. 1968), and in Colorado (Currie 1970). For maximum length of spring grazing season or for spring-fall grazing, a rotation combining two-crop and one-crop (i.e. grazing from boot stage to anthesis) and using three pastures units has been suggested by Hyder and Sneva (1963).

Summary

Before a range manager can put together a logical grazing schedule according to Heady (1974, 1975), he must have before him for use in his given situation answers to the following questions:

(1 When does defoliation do the most harm and when is the greatest plant response without defoliation?

(2 What are the criteria for taking animals out of pasture and for selecting the pasture into which they are placed next?

(3 What is the ideal timing, length, and frequency of both the grazing period and the period without grazing?

That grazing systems must reduce the harmful effects of grazing and increase the beneficial effects--there are plenty of both kinds--seems certain. A consideration seldom given adequate attention is whether the same plan is ideal to maintain high condition range compared to improving low condition range.

That grazing systems research on native sagebrush-grass range has been too minimal is obvious from a review of the literature. This has encouraged all too heavy reliance on theories, case histories, and careful to even casual observations subject to the many personal biases. Attempts have been made to draw heavily on facts and conclusions generated from grazing research in very different vegetation types in hopes of filling the void but with varying success. But often only the apparent successes rather than the failures have been observed or reported.

Not only have the number of research studies made of grazing systems in the sagebrush ecosystem been much too few but existing studies have been greately restricted as to number and variation of treatments included. Heady (1974) has postulated that, because of limitations in treatment comparisons, the ideal grazing system for any given situation is most likely never to be found. He pointed out the complexities of grazing systems research by suggesting that the ideal study might well include four animal species combined into 15 different treatments, 10 grazing periods, 6 range sites important in the area, and 3 grazing intensities. If all were replicated 5 times, a total of 13,500 fenced pastures would be needed. The impracticality is obvious, but the alternative of tunnel vision is also implied.

There seems to be no conclusive proof that rest-rotation is more effective than deferred-rotation on most sagebrush ranges. And systematically varing the within-season period of grazing may be as effective as complete deferment on good condition sagebrush-grass range. And even continuous grazing under conditions of proper stocking rates, seasons, and distribution of grazing where vegetation and livestock are not under stress has performed much better than expected.

Heady (1975) has directed some cryptic, possibly deserved comments to the traditional 5-pasture rest-rotation grazing system as follows: "Most other plans include shorter ungrazed periods, many not even qualifying as deferred grazing, and still improve the range. Except for specific purposes, such as providing fuel for prescribed burning, resting of range pastures seems an extravagent use of herbage...This plan is extreme in that 40 percent of the available land and perhaps 40 to 50 percent of the usable forage are ungrazed every year. Increased grazing pressure on the 60 percent that has to carry the grazing load may do harm that will exceed the benefit that can be gained during the three-year sequence of rest-deferred-rest." Problems of rest developing severe wolf-plant problems in some species such as Agropyron desertorum (Heady 1975) and creating more favorable habitat for black grass bugs (Labops spp.) (Haws et al. 1973) have also surfaced.

The above example further substantiates the conclusion that there is no universally best grazing system and that each grazing situation warrants its own blueprint incorporating all of the tools of good grazing management. And last but not least, the indirect benefits of the popularity of grazing systems seem very real. Planning the grazing system has frequently led to a complete ranch or range plan which in turn has led to better husbandry of both land and livestock, pride in the total operation, and a committment for further improvement.

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Methodologies For Determining Cover, Production, and Utilization of Woody Sagebrush Species

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INTRODUCTION

The purpose of this paper is to review techniques available to researchers and land managers which are suitable for estimating or measuring cover, production and utilization of sagebrush. Most of the methods described here have been developed, used, and evaluated for use on shrubs, especially sagebrush. Techniques used for grasses and other herbaceous plants which are not applicable to shrubs have been purposely avoided.

COVER

As a plant ecologist, Daubenmire (1968) considers cover a highly significant concept. It serves as a criterion of relative dominance, of potential productivity, of the influence of plants on precipitation interception and soil temperature, and of the value of vegetation to animals.

Kinsinger et al. (1960) recognized that determining the percentage of ground covered by shrubby vegetation is an integral part of range inventory and of range condition and trend studies.

Estimates of vegetal cover in range inventory studies originated in 1907 with Jardine (Fisser, 1961). This reconnaissance method estimated percentage ground cover and percentage plant composition over large areas. Although used, this technique was criticized because its accuracy depended largely upon the judgement and observational powers of the individuals using it (Smith 1944).

Following the reconnaissance method a number of techniques have been developed for determining vegetal cover. Fisser (1961) felt that an acceptable technique must be accurate, rapid, and consistent among individuals.

Methods widely used for estimating or measuring cover employ: 1) Estimations on plots, 2) lines, 3) points or loops, 4) mapping or charting, 5) distance measurements, and 6) variable-plot.

Estimations on Plots

Stewart and Hutchings (1936) developed the point-observation-plot method, more commonly known as the square-foot density method. This procedure involves the use of the circular plots for estimating cover. Estimates are made to the nearest 0.023 m^2 (0.25 ft^2) and when a 9.29 m^2 (100 ft^2) plot is used estimates can be converted directly to percentage ground cover. This procedure has been used extensively in range surveys and range research either in its original form (Robertson, 1971) or modified by others (Johnson 1969, Young and Evans 1973 and 1974, Tausch and Tueller 1977). Daubenmire (1959) used a 0.1 m^2 quadrat for sampling big sagebrush and found advantages over linear and plotless techniques.

Lines

The line intercept was developed by Canfield (1941) as a method of sampling vegetation based on the measurement of all plants intercepted by the vertical plane of randomly located lines of equal length. His aim in developing this method was to devise a means of sampling areas of vegetation based on actual measurements, as opposed to visual estimates.

Canfield (1941) was aware that size and conformation of plots influenced the efficiency of sampling. In general, oblong or oval plots had proven to be more efficient than square or round plots of equal area. Length was apparantly the factor that gave the oblong plots their superiority and a line develops the length factor to its maximum.

The line-intercept is recognized as an accurate and fairly precise method. Kinsinger et al. (1960) found the line-intercept to be the most accurate of 3 methods when compared to "true cover" calculated by the ellipse-formula. However, they recognized that a large sample was needed for a reliable estimate of cover.

Hanley (1978) found the line-intercept more advantageous than the 0.1 m^2 quadrat method where a high degree of precision and confidence are required. Daubenmire (1959), however, pointed out that much more time was required for the line intercept method than for quadrats. Fisser and Van Dyne (1966) acknowledged that the line-intercept is generally considered to yield accurate results and has been used as a standard for comparison in many methodological studies, although time consuming.

Laycock (1965) found line-intercept readings of shrub canopy were easy to make and had a relatively low coefficient of variation. Hormay (1949) felt the line-intercept was highly adaptable and in combination with other methods could be used to measure density, composition, yield, utilization, vigor and reproduction.

The line-intercept has been used extensively in range studies. It has been used to evaluate the relationship between big sagebrush crown cover and production of crested wheatgrass (Rittenhouse and Sneva 1976); to evaluate the effects of herbicides on sagebrush (Thilenius and Brown 1974, Smith 1969, Sturgess 1977); to determine successional status of sagebrush (Burkhardt and Tisdale 1969); to measure competition between big sagebrush and seeded grasses (Cook and Lewis 1963); to relate sagebrush cover to sage grouse nest sites (Klebenow 1970); to determine canopy coverage as it affected rainfall interception (West and Gifford 1976); and for the description and classification of range sites (Poulton and Tisdale 1961).

Belt transects of various widths are often superimposed over line-intercepts to measure denisty of sagebrush and other shrubs (Smith 1969, Poulton and Tisdale 1961, Burkhardt and Tisdale 1969, and Sturgess 1977). The effectiveness of herbicide treatments on sagebrush has also been evaluated by counts of live and dead plants within belt transects and/or estimating foliage reduction (Blaisdell and Mueggler 1956, Cook 1963, and Cook and Lewis 1963).

Points or Loops

The point method was developed for sampling composition of herbaceous cover in New Zealand (Levy and Madden 1933), and remains a standard sampling technique. Point sampling represents the ultimate reduction in quadrat size down to a dimensionless point. The basic premise behind the method is that if an infinite number of points were placed over an area, the exact cover of each species could be determined by counting the number of points covering each species (Pieper 1973).

The point must be as small as possible to avoid overestimation of cover. Goodall (1952) evaluated the degree of over estimation of cover with blunt points. Several workers have developed optical devices with cross hairs designed to reduce point size. Winkworth and Goodall (1962) developed a tube hung in gimbals with cross wires to each end. Ibrahim (1971) developed an ocular point apparatus in which an upper and lower cross piece are aligned with the ground cover. These optical devices approach a dimensionless point.

A variety of apparatus are used for point sampling. Most point-frames are constructed of channel or angle steel and contain 10 pins guided by pairs of holes drilled into the crossbars of the frame. The distance between pins varies from one frame to another. A number of modifications have been made in point frames resulting in reduction in weight (Neal et al. 1969), or braking systems to hold pins firmly in position and reduce side movement as the pin is pushed through the vegetation (Neal et al. 1969, Smith 1959, and Heady and Rader 1958).

Goodall (1952) reported that when individual points are taken, about one third the number of points are needed for the same level of precision as when points are grouped into a frame. Evans and Love (1957) developed the step-point method in which a single pin is used rather than pins placed in a frame. This technique consists of recording whatever is encountered under a point inserted into a notch at the tip of a boot along a pace transect. The first plant hit by the plant nearest the point in a forward 180° arc is recorded. This technique provides a rapid, accurate, and objective method for determining botanical composition and total cover. Total ground cover and composition, determined by the step-point method, were comparable to the point-frame method and the time required to sample an area was one-sixth to one-eighth as much as required by the point frame (Evans and Love 1957). Owensby (1973) developed a single point frame modification of the step-point as a means of eliminating subconscious bias in point placement.

Branson et al. (1970) used the point frame in conjunction with line transects to characterize plant communities in Montana. Their frame contained 10 vertical pins spaced 5 cm (2 in) apart. The data were reported as abundance (hits/100 pins) computed for each 3 m (10 ft) of transect. Barney and Frischknecht (1974) examined vegetation changes following fire by determining cover of both shrubs and herbaceous species using a point-frame. In this study the pins were spaced at 30 cm (1 ft) intervals.

Brun and Box (1963) tested the efficiency of estimating percentage ground cover and composition with randomly located line-intercepts and point-frame in sagebrush and sagebrush-shadscale communities. The point-frame estimated higher cover for all species and some error could be attributable to large pin size. The point-frame did, however, require considerably less time than did the line-intercept to obtain the same accuracy.

The loop-method was developed by K.W. Parker for determining range condition and trend on U.S. Forest Service lands. The method is a modification of the point sampling, but the point is given dimensions. A 19 mm (3/4 in) loop is used rather than the usual point. Loop readings are usually taken along a transect at 30 cm (1 ft) intervals (Pieper 1973). The loop method is essentially a compromise between frequency and area-estimate methods. The 19 mm (3/4 in) loop is regarded as a minute quadrat when plants are listed by frequency (Parker and Harris 1959).

Several studies have evaluated the loop-method or compared it with other methods. Hutchings and Holmgren (1959) have shown that the loop-procedure overestimates actual plant cover. Kinsinger et al. (1960) found the loop-procedure gave higher mean-cover values than the line-intercept, variable-plot or "true cover" methods. They also found that because of the high variability among plots a large sample is necessary to estimate crown cover by either the line-intercept or loop-procedure. When shrub cover exceeds 5 percent, Kinsinger et al. (1960) reported estimates by the loop method are unreliable irregardless of the size of sample taken.

Cook and Box (1961) found that the line-loop method over estimated percent canopy cover for shrubby species and under estimated it for grasses compared to the line-point of point-frame. They also concluded that the point-frame is more precise and requires less time than the line-loop or line-point.

Mapping and Charting

Mapping and charting were early methods developed for determining numbers of plants and cover. Hill

(1920) reported on the pantograph as a means of rapidly and accurately mapping vegetation on meter quadrats. Nelson (1930) used 2 methods of mapping shrubs to determine density and crown spread. Pickford and Stewart (1935) used a coordinate method of mapping sagebrush and other low shrubs. Their mapping unit was 1.22m X 7.62m (4 ft X 25 ft) and one experienced field investigator could map 6 plots per day in dense sagebrush.

Clavern A (1966) employed a photographic charting method for determining plant composition and cover. He used polaroid film so that it was possible to obtain positive prints immediately. Plant area boundaries were delineated with black carbon ink and cover was calculated with a transparent dot grid. When compared to the pantograph method, the differences in cover were less than 5 percent.

Wells (1971) used a photographic technique that allowed steroscopic determination of cover and composition. Rittenhouse and Sneva (1976) determined sagebrush crown cover directly from 1:600 scale IR 70mm film using an eyepiece with a magnified reticle.

Distance Measurements

Laycock (1965) tested the angle-order method for estimating density, herbage production and ground cover. This method involved a wire frame divided into four quadrants. In each quadrant distances were measured from the sample point to the third nearest plant. Estimates of density, production, and ground cover of the major species were similar to the weight-estimate method and line-intercept. He found the angle-order method was not suitable for sampling entire plant communities because it is too slow and tedious when each species is sampled separately. He acknowledged, however, that it may be an efficient method for sampling density, production, and ground cover of one or more key species.

Hutchings and Morris (1960) evaluated the merits of the "nearest neighbor", "closest individual", and "point-centered quarter" methods in measuring density and spatial distribution of plants in semidesert shrub vegetation. They felt that distance measurement methods are suitable, accurate and effective for determining density of randomly dispersed individuals. Distance measurements are objective, can be compared and evaluated statistically, provided estimates of both density and distribution, and in many instances they increase sampling precision over that obtained by fixed-plot methods.

Variable-plot

Variable-plot method was developed by Bitterlich in Austria, and used to estimate timber volume without the necessity of establishing sample plot boundaries. The usual measured plots or lines are replaced by a series of sampling points distributed at random throughout the survey area. At each sampling point, the observer views every shrub visible from that point through the eye piece of a hand-held angle guage. Those shrubs whose horizontal crown spread appears larger than the crossarm are counted (Cooper 1957).

In dense shrubs stands, many distant shrubs are obscured and accuracy falls off rapidly. This method is rather unreliable where cover exceeds about 35 percent. For this reason it is best suited to sparse desert-shrub types, to open areas of shrub invasion, and to other open types (Cooper 1957). Kinsinger et al. (1960) observed that when cover is twenty percent or more it is difficult to distinguish individual shrubs growing close together. They also found cover estimates by this method are higher than "true cover". Since this was partially due to the inclusion of dead shrub crowns, they suggested a modification to exclude dead crowns from the cover estimates. Cooper (1963) reports that any deviation of shrub outlines from a circle also biases estimates upwards.

Compared to the line-intercept and loop-methods Kinsinger et al. (1960) considered the variable-plot method the most reliable and the number of plots, needed to sample shrub cover adequately was small. Fisser (1961) noted that with a minimum of procedural control the variable plot method of shrub crown cover estimation is a highly satisfactory tool for range surveys. Cooper (1957) concluded that the variable-plot method is faster and easier to apply than any of the standard shrub-estimating procedures in common use.

PRODUCTION

It is often desirable to know total production of the aerial portions of shrubs. Production can be used to express competition between plants, to determine total available browse, to estimate fuel for control or uncontrolled burning, etc. (Rittenhouse and Sneva 1977).

Measurement of production for browse species presents problems not encountered in herbaceous species. In many cases it is difficult to distinguish new twig growth from old, leaves on evergreen shrubs also present a problem when it is difficult to determine current years leaves from older leaves (Pieper 1973).

Some techniques available for estimating or measuring annual above ground standing crop production are: 1) clipping and weighing, 2) weight-estimate, 3) capacitance meters, 4) prediction methods, 5) annual growth rings, 6) dimension measurements, 7) photography, 8) distance measurements, and 9) twig measurements.

Clipping and Weighing

Many, investigators prefer to estimate production by clipping herbage on plots. Clipping has the advantage of obtaining a reliable measure of the herbage produced on the plot at the time of clipping. It is best adapted to uniform vegetation such as seeded range and small research areas, where great accuracy is demanded. The principal weaknesses are that: 1) the method is slow in use so that it is usually uneconomical to use sufficient numbers of plots to obtain a reliable sample of the vegetation on a large area, and 2) clipping the plants may in itself affect the vegetation clipped. Clipping of shrubs is so slow it is impractical as a method of estimating production (National Academy of Sciences 1962).

Springfield (1974) also recognized that the most accurate method of determining production and utilization of shrubs is clipping and weighing, but this is costly, time consuming and affects the physiology of the plant. Cook and Stoddart (1959) used this

method to determine herbage yield of sagebrush.

Weight-Estimate

The weight-estimate method was developed by Pechanec and Pickford (1937b) as an easy, rapid technique for determining forage production. This method provides weight estimates that are reliable and rapid, indicative of yield, and subject to mechanical check. During the training period weight estimates are made and then the unit is clipped for comparison. With this double sampling procedure, the weight-estimate and clipping methods have been combined to take advantage of the rapidity of the weight-estimate method and the accuracy of the slower clipping method. Production on all plots is estimated, then a portion of the plots is clipped and the herbage weights used to adjust the estimates by regression techniques. This procedure adjusts for consistent errors of estimates (National Academy of Sciences 1962).

The weight-estimate method is sufficiently rapid that an adequate number of plots can be used to sample large range areas. It can also be used on permanent plots, because the vegetation on the plots remains undisturbed.

Frischknecht and Plummer (1949) developed a simplified technique for determining production which is essentially an adaptation of the weight-estimate method. They regulated the size of the plots in order to obtain a direct estimate of production in pounds per acre. This procedure is based on the fact that herbage production in pounds per acre is equivalent to grams of herbage produced on an 8.9 m^2 (96 ft^2) plot.

Harniss and Murray (1976) observed that shrub weights are usually estimated with much lower correlations than weights for forbs and grasses. They found that the consistency of ocular leaf weight estimates with big sagebrush differ substantially between individuals. Also, because of the time involved in clipping leaves from shrubs, double sampling may not be applied and only ocular estimates used. Without the regression correction, visual estimates are subject to personal bias of unknown magnitude. They developed a leaf predictor from height and circumference measurements. These measurements gave an unbiased basis for regression of dry leaf weights. Using these estimates in place of ocular estimates they were able to reduce the bias and provide greater consistency between estimators.

The weight-estimate method has been used extensively by land management agencies and research workers. Mueggler and Blaisdell (1958) used the weight-estimate method on 4.46 m^2 (48 ft^2) circular plots to evaluate the effects of sagebrush control methods in Idaho. Laycock (1965 and 1967) used the weight-estimate method to determine herbage production on a sagebrush-grass range. He found that weight-estimates on 0.89 m^2 (9.6 ft^2) plots were easier to make and more accurate than on 8.9 m^2 (96 ft^2) plots.

Passey and Hugie (1963) sampled sagebrush ranges with the weight-estimate method on 0.89 m^2 (9.6 ft^2) plots and Harniss and Murray (1973) used this same method on 9.29 m^2 (100 ft^2) plots on a sagebrush-grass range.

Capacitance Meters

The capacitance meter was first used for estimating herbage weight by Fletcher and Robinson (1956). The capacitance method is based upon the herbage having a high dielectric constant and air a low dielectric constant. By determining the dielectric constant of the plot the amount of herbage can be determined.

Capacitance values customarily are used in a double-sampling technique where a small sample of total plots metered is subsequently clipped for a meter: weight relationship. The linear regression of herbage weight on meter readings from the small sample permits estimating weights from meter readings in the large sample (Carpenter et al. 1973).

Meredith et al. (1976) evaluated meter estimates of total plant yields from low-shrub lands. Their results indicated that the herbage dry matter component of shrub leaves, and succulent stems of grasses and forbs can be estimated very efficiently with the capacitance meter, even with a single reading on a plot. A double-sampling ratio of 1 clipped to 8 metered sagebrush plots yielded an estimate of high precision for herbaceous yield. They also found that the estimate of the woody and partially dead stem yield was much poorer because the dry woody material has a wide range of weight values but little corresponding relationship to capacitance. They therefore concluded that estimate of stem yields would be impractical to obtain.

Carpenter, et al. (1973) found that excluding the woody stems of shrubs improved capacitance-meter estimates of herbage weight because: 1) wood has little capacitance value relative to herbaceous material, and 2) the amount of wood varied so greatly. They concluded, therefore, that large stems should be clipped and measured only if an estimate of total above ground biomas is desired.

Sturges (1977) used the capacitance meter to measure herbaceous production, including sagebrush, in Wyoming.

Prediction Methods

Moisture is the major factor limiting production on most western rangelands and the most common prediction method is that of relating production to precipitation.

Hutchings and Stewart (1953) found a close correlation between precipitation and forage production in western Utah. They determined air dry herbage yield, in pounds per acre, by multiplying 12 month precipitation in inches by 45.8 and subtracting 92.46.

Other studies on the cold-desert ranges of Oregon and on the central Great Plains indicate that forage yields can be predicted from stored moisture and rainfall (Stoddart, Smith and Box, 1975).

Jensen (1977) found a close correlation of plant production to actual evapotranspiration in southwestern Utah and northern Arizona. He produced a correlation coefficient of 0.98 between actual evapotranspiration in inches from February through May and net above ground productivity in pounds per acre.

Annual Growth Rings

McGinnies (1967) discussed correlations between precipitation and herbage yield and concluded that levels of correlation varied from poor to excellent. He then studied the relationship between the width of annual rings of shrubs and range herbage production. His results varied from good to very poor at 11 locations in the western United States. He found a high correlation between big sagebrush growth rings and western wheatgrass production and a poor correlation with blue grama. He speculated this was due to the close relationship between winter precipitation and width of annual rings in sagebrush.

Davis et al. (1972) estimated forage production from shrub ring widths in Nevada. They found that ring widths on species such as big sagebrush that represent annual growth increments appear to reflect annual fluctuations in production. Ring widths of chenopod species may not always represent annual growth increments, but they do reflect the productivity of each site. They used growth rings of several species to derive regression equations to estimate forage production. They stated that average estimated production for a site with plants having sensitive ring series could be determined as far back in time as there are annual rings of the sample shrub.

Dimension Measurements

Studies have been conducted which involve combinations of circumference, height, and diameter measurements in estimating leaf weight estimates (Harniss and Murray 1976), production of phytomass (Uresk et al. 1977), and aerial biomass (Rittenhouse and Sneva 1977).

Harniss and Murray (1976), as reported previously in this paper, developed a dry leaf weight predictor from height and circumference measurements. This technique reduced the bias and provided greater consistency between estimators.

Uresk et al. (1977) used canopy dimension measurements to obtain estimates of sagebrush phytomass. They measured: 1) the longest diameter of the canopy, 2) the longest diameter of the canopy at right angles to the first measurement, and 3) maximum height of each shrub. These dimension measurements combined with clipping, separating and obtaining dry weights of total shrubs and shrub parts were used to develop regression equations. The precision achieved by combining dimension analysis with clipping and harvesting was significantly higher than by only harvesting shrubs. Another of the major advantages of this double sampling procedure is that it is non-destructive. Once a relationship between clipped shrub values and dimension measurement have been established repeated phytomass inventories may be conducted on various sites by obtaining dimension measurements only.

Rittenhouse and Sneva (1977) studied the relationship between various expressions of linear and area measurements and the production of aerial biomass. Whole plants were cut at ground level following measurement of height and two measurements of width. Elliptical crown area was calculated by an appropriate formula. All but 4 to 5 percent in the variability of biomass per plant could be accounted for by simple linear measurements. The functional relationship of width, height, and biomass was independent of site and years.

Photography

Springfield (1974) used a photographic grid to measure production and utilization of shrubs. A 1m (3 ft) square grid was marked off into 2.54 cm (1 in) squares. All 2.54 cm (1 in) squares even slightly obscured or intercepted by plant material were counted. Sagebrush was not used in this study, but he felt the technique could be modified to fit many different species and situations.

Distance Measurements

Laycock (1965) estimated production by the angle-order method. The average dry weight per plant multiplied by number of plants per acre gave an estimate of production per acre for each species or group of species.

Twig Measurements

Smith and Urness (1962) proposed the use of average twig length as an index to production because comparisons are made at one location from year to year, and number of plants per acre and other factors which determine productivity change very little.

Shafer (1963) developed the twig-count method for determining browse production in the northeast. He felt this method was as accurate as the clip-and-weigh method and nearly as rapid as the weight-estimate method. He converted twig counts to weight of browse by the use of an average weight per twig. This method is non destructive and results can be analyzed statistically.

Schuster (1965) studied browse production in relation to twig and stem measurements. He found that, for most species studied in east Texas, total twig length was the single variable most closely correlated with both shoot and twig weight. The best prediction of yield, however, was a combination of twig number and length. He felt that regression equations for estimating forage offer substantial advantages. They are more objective than visual estimates, less time consuming and expensive than clipping and weighing, and permits repeated measurements on the same plant.

Telfer (1969) working with northeastern woody plants found a close correlation between oven-dry weight and basal diameter for twigs of most browse species.

Bayoumi and Smith (1976), measuring the response of game winter range to fertilization, determined the productivity of shrubs by measuring the length of current years twig growth.

UTILIZATION

Determining utilization has been one of the most perplexing problems facing range scientists down through the years (Peiper 1973). Smith et al. (1963) evaluating forage utilization techniques stated: "One may hear the expression that the art and science of range management would be further advanced if all the literature on forage utilization methodology were ground up and distributed on the range for fertilizer. On the other hand, one hears utilization methodology

eulogized as the most important tool in grazing management."

Smith and Urness (1962) recognized the importance of determining utilization in the management of game ranges. They recognized that data revealing the severity of use of forage on winter ranges are of extreme importance. These data form the basis for the management of healthy and productive game herds under conditions that promise continued production of forage from the range. They also observed that despite its importance, few accurate utilization measurement techniques are known.

Methods that have been developed for measuring sagebrush utilization or appear to be suitable for sagebrush are: 1) ocular estimates, 2) weight before and after grazing, 3) twig length, 4) twig counts, 5) diameter-length-weight relations, and 6) photography.

Ocular Estimates

Pechanec and Pickford (1937a) introduced a method of estimating utilization on plots. This method was proposed as a rapid, easy method for large areas and is similar, in several respects, to the weight-estimate method. The chief disadvantage is that estimates are used rather than objective measures. These estimates are subject to personal error among individuals and for the same individual at different times (National Academy of Sciences 1962).

The ocular estimate by plant is similar to the plot method except that estimates are made on individual plants instead of plots. These estimates are slightly less rapid than the ocular estimate-by-plot, but there is less personal error since each observation is confined to a single plant (National Academy of Sciences 1962).

Weight Before and After Grazing

This method was developed by Cassidy (1941) to determine forage utilization by sheep. The method consists of collecting a number of specific plant units before grazing and a similar number after grazing. The plant unit may be a stem, leaf, twig or whole plant. Utilization is the difference in weights before and after grazing. This method is best adapted to forage grazed for short periods where regrowth is not a factor (National Academy of Sciences 1962).

Grimm (1939) developed a similar before-and-after utilization technique for determining utilization on sagebrush game winter ranges. He set up 12 experimental plots of 9.29 m^2 (100 ft^2) in area. The crown of each sagebrush plant within these plots was divided in half by placing a red string over the center of each shrub crown. In October the foliage and green tips of half of each crown were clipped and in April the remaining halves clipped. The differences between the two weights represented utilization during the 7 month period.

Twig Length

This technique involves the marking and measuring of all annual twigs on individual branches of randomly selected shrubs. When applied to winter game ranges, one measurement is made in the fall and another in the spring. The reduction in total length of twigs between the two measurements represents the amount of forage harvested (Smith and Urness 1962).

Nelson (1930) first described this technique of measuring utilization on tagged shrubs. Aldous (1945) described this same method in a winter study of mule deer.

Smith and Urness (1962) noted the greatest variation between individual observers occurred on sagebrush. They outline the difficulties in applying twig-measurements to sagebrush as: 1) failure to differentiate current growth from that of prior years, 2) failure to measure twigs, and 3) remeasuring twigs. On sagebrush the pubescence is not markedly different on current and one year old growth. Location of the bud scar left at the onset of growth in the spring is important to accurate measurement and this may be obscure.

The presence of leaves and a compact broom-like appearance on sagebrush combine to make the location of each twig difficult. Smith and Urness (1962) felt that missed and repeated measurements probably occur frequently. They also observed that the number of ungrazed branches on sagebrush greatly affected utilization estimates.

Smith and Urness (1962) noted that field investigators have been skeptical of the value of sagebursh as a utilization indicator. A common belief is that sagebrush grows during the winter if warm periods occur. Careful observation during the winter indicated that some slight elongation, especially in the terminal leaves, did occur. However, this winter growth did not increase twig measurements more than 5 percent and therefore was not thought to be a source of large errors.

Urness and Jensen (1976) recognized sagebrush as frequently the most important forage plant available to deer during the winter. In view of the difficulties of measuring sagebrush utilization they developed the following guidelines and precautions: 1) Do not measure seed stalks. They may be browsed in late fall, but their contribution to the diet is minor and breakage becomes more important than foraging which biases utilization upward, 2) In the fall measure only the main axis of current shoots between growth ring and tip of longest leaf. The seed stalks are an aid to identifying the base of current years growth since they arise from a lateral bud near the tip of last years growth. The bud scar can also be marked with dark red finger nail polish. Do not measure numerous, short side branches which arise from the main axis of many current twigs, 3) In the spring measure the main axis of current shoot from growth ring to browsed point or unbrowsed tip. Again avoid measuring side branches of current shoots. 4) Make measurements as early as possible in the spring to avoid leaf and stem elongation which begins early in sagebrush. Delay in measurement will bias utilization downward because of growth on unbrowsed twigs, and 5) a greater number of plants should constitute a transect than for other species because of the greater variability in palatability. Recommendation is a minimum of 80 tagged branches on as many plants.

Smith and Urness (1962) found that utilization

determined by this method appeared to have little relationship to deer numbers. They therefore, developed a use index by multiplying mean twig length by mean utilization. Deer days were found to agree much more closely with this statistic than with utilization.

Smith et al. (1963) recognize that browse species such as sagebrush have seasonal growth which is difficult to measure. They recommend that browsed and unbrowsed shrubs be provided to facilitate estimation. Peiper (1973) also felt that if an area is being utilized during a growing season it may be necessary to use protected plants to determine average twig length of ungrazed plants. In this case it is necessary to choose paired plants very carefully so that leader lengths are comparable on both plants.

Twig Counts

Cole (1963) developed a technique based upon the percent of total available leaders showing use. Utilization can be determined by estimating the percentage of twigs browsed or these estimates can be checked by counting the number of browsed and unbrowsed twigs and calculating the percentage of twigs utilized. Only the number of browsed twigs is considered in determining percent utilization not the volume or length removed. Shrubs are selected through the closest plant technique and estimates of utilization are also collected on form and age class. Form classes measure availability and degree of hedging. Age classes include seedling, young, mature, and decandent. Percent utilization, form and age class are combined and assigned to one of five condition rating classes.

Jensen and Scotter (1977) compared the twig length and browsed-twig techniques. They found that estimating the percentage of browsed twigs or calculating the percentages from counts of browsed or unbrowsed twigs resulted in higher utilization values than measuring twig lengths. Estimating percentage of twigs browsed resulted in higher values than when the number of twigs were counted.

Since the percentage of twig length removed closely approximates the percentage of twig weight removed, counting the numbers of browsed and unbrowsed twigs overestimated the volume utilized by as much as 27 percent, and estimating the percentage of twigs browsed overestimated the volume utilized by as much as 32 percent (Jensen and Scotter 1977).

Jensen and Scotter (1977) also report that techniques dependent upon numbers of browsed twigs, without regard to weight consumed, are generally restricted to establishing utilization at levels less than 60 percent of the weight. On big game ranges, however, removal frequently exceeds 50 percent of the key species, and this technique cannot adequately detect this heavy use. They concluded that the twig length method is preferable because it will measure volume removed more precisely from 0 to 100 percent use. They found also, that twig measurement data were more consistent among observers than estimates. However, measuring twig lengths required about four times as many hours as estimating percentages of browsed twigs or counting twig numbers.

Diameter-Length-Weight Relations

A knowledge of the relations between twig diameters and their lengths and weights may provide a means of estimating utilization solely from post browsing measurements and may also permit expressing utilization in terms of either length or weight of twigs (Basile and Hutchings 1966). This method uses regression equations to predict unbrowsed twig length or weight.

Ferguson and Marsden (1977) recognize that the primary disadvantage of the before and after method is the necessity to locate, tag, and measure twigs on a number of shrubs before browsing begins, and to relocate and remeasure the same twigs after browsing.

The primary advantage of the regression method is the time saved by not having to locate and permanently tag a number of shrubs, which must be remeasured after browsing. A second advantage is that an estimate of utilization by weight can be obtained (Ferguson and Marsden 1977).

Although this method has been used primarily on shrubs other than sagebrush (Basile and Hutchings 1966, Telfer 1969, Lyon 1970, Ferguson and Marsden 1977, and Provenza 1977) it is included here because of its apparent suitability for sagebrush.

Basile and Hutchings (1966) found that unless length-diameter and weight-diameter relations differ significantly from year to year a prediction equation need be computed only once for a given area. They felt that future savings of time and expense should more than compensate for the cost of determining the equation.

Lyon (1970) working with Amelanchier alnifolia found significant variations in regression related to site, plant size, and twig location on the plant. However, relatively small samples of browsed twigs were shown to provide precise estimates of browse utilization.

Ferguson and Marsden (1977) found the difficulty of accounting for the total use of some twigs to be a disadvantage of this method. The omission of completely utilized twigs from the sample results in a biased estimate of utilization. This only occurs, to a significant extent, on areas where browsing is very heavy and average utilization is in the 75 to 90 percent range. On such areas, the calculation of the percent utilization would be slightly lower than the actual utilization, which would not be of any practical importance when utilization is that great.

Provenza (1977) quantified the utilization of blackbrush (Coleogyne ramosissima) using three methods: 1) before-and-after length measurements on tagged branches, 2) regression approach relating twig length, twig diameter, and twig weight, and 3) determination of kilograms browsed.

He found a close relationship between the three methods. The utilization values from the regression method were all within 3 percent of the values obtained by the before-and-after method. The computed estimates of weight removed also compared favorably with the before-and-after and regression approaches.

Provenza (1977) concluded that a strong relationship exists between utilization in Kg per hectare and predicted (regression) utilization, and utili-

zation in Kg per hectare and observed utilization (before-and-after). The greatest time saving results if the regression approach is used to predict percent utilization, and percent utilization is then converted to Kg of forage removed.

Photography

Springfield (1974) used a photographic grid to estimate utilization of shrubs. This technique was used to determine browsing preferences by adult deer. The grid used in this study was also used for estimating production and was described earlier in this paper. He considered this technique easy to use, but sufficiently precise to detect daily utilization. He cautioned that: 1) the grid must be placed the same distance behind all plants, 2) the distance from camera lens to plants should be approximately the same, and 3) photos should be taken when no strong shadows are cast on the board.

SUMMARY

A large variety of techniques are available for determining cover, production, and utilization of sagebrush and other woody shrubs. A choice of methods should be governed by the required accuracy and precision, and the time, personnel, and funds available.

This paper has discussed and evaluated several techniques that have proven useful or appear to be suitable for woody sagebrush species.

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FACTORS AFFECTING CHOICE OF MANAGEMENT STRATEGIES WITHIN THE SAGEBRUSH ECOSYSTEM[1]

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Description of the Ecosystem

The sagebrush ecosystem is one of the largest range ecosystems in the western United States. The range of the major species, big sagebrush (*Artemisia tridentata*), in the United States includes North and South Dakota, Nebraska, Colorado, New Mexico, and all states to the west. When other species of sagebrush are included, the range goes far into Canada and Mexico and also includes Oklahoma and Texas in the United States. Estimates of total area of the sagebrush type vary from a low of 35 million ha (87 million acres) (Platt 1959) to a high of 109 million ha (270 million acres) (Beetle 1960). The bulk of the sagebrush occurs in Nevada, Wyoming, Idaho, Oregon, Montana, Utah, and Colorado. Within the vast acreage of sagebrush, some stands are characterized by scattered sagebrush plants with a productive understory while others are closed stands with an impoverished understory.

In the Great Basin, the major area where sagebrush is dominant, sagebrush occurs mainly at elevations of approximately 1500 to 2100 m (5,000 to 7,000 ft), although generalizations about elevations can be misleading. It occurs above the salt desert shrub type and below the pinon-juniper type (although it is interpersed with the latter in many locations). *Artemisia tridentata* ssp. *vaseyana* is common up to 3000 m (10,000 ft) in the mountains, especially on south-facing slopes (Beetle 1960). *Artemisia tridentata* ssp. *vaseyana* f. *spiciformis* occurs mainly at 2700 to 3000 m (9,000 to 10,000 ft) and *Artemisia rothrockii* occurs only at 2600 to 3000 m (8,500 to 10,000 ft) in the mountains. At the lower elevations, *Artemisia bigelovii* and *Artemisia rigida* have been found as low as 900 m (3,000 ft) in the Great Basin area, and both *Artemisia tridentata* and *Artemisia tripartita* occur as low as 900 m in the Pacific Northwest. *Artemisia cana* is common on river bottoms on the western part of the Great Plains at relatively low elevations.

Amount and distribution of precipitation received in the sagebrush ecosystem vary considerably with latitude, elevation, and major storm paths. Garrison *et al.* (1977) stated that much of the sagebrush type occurs in the 13 to 30 cm (5 to 12 in) range but, in some places, precipitation is almost 51 cm (20 in). However, some of the high elevation big sagebrush areas in Colorado receive more than 64 cm (25 in) (Hull *et al.* 1950). Most of the references consulted listed 20 to 23 cm (8 or 9 in) as the approximate lower limit of the sagebrush type and it is doubtful that very much, if any, of the true sagebrush type occurs in areas with precipitation as low as 13 cm (5 in). Typically, one-half to two-thirds of the total precipitation in the sagebrush ecosystem occurs during the winter and spring and much is in the form of snow.

Need for Proper Management Strategies

In view of the current and future energy shortage, coupled with pressures to reduce or eliminate grains fed to livestock, rangelands offer tremendous opportunities to increase red meat production with relatively low input of fossil fuel energy. Because of the extremely large area available and the rather large increases in amounts of livestock forage that are possible on better sites, the sagebrush type probably has the greatest potential for increasing red meat production of any range vegetation type in the United States. If properly done, this increase can be achieved without diminishing the value of the type as a whole for wildlife or other purposes. Sagebrush occurs over a wide range of sites and the better sites with deeper soils and adequate amounts of rainfall can be very productive. Early observers used the vigor of big sagebrush as an indicator of sites suitable for agricultural production (Robbins 1917; Aldous and Shantz 1924).

A historical perspective must be considered before one can evaluate different management strategies for the sagebrush ecosystem. How widespread was the sagebrush type before European man came on the scene and how dense was the sagebrush within that type? Beetle (1960) stated that "No evidence has been found of extensive changes in recent times of the distribution of the sagebrush type." Vale (1975) reviewed 29 journals and diaries of early explorers and travelers throughout the western United States and came to essentially the same conclusion. He stated that "The early writings suggest a pristine vegetation visually dominated by shrubs." He further indicated that many of these early diaries described stands of shrubs (mainly sagebrush) that were very often quite dense with little understory of grass for food for livestock.

The range management concepts developed in the United States have not always promoted maximum productivity of rangelands. The "Clementsian" concept of climax has dominated our thinking in a development of standards for range condition and trend. Thus, we generally judge ranges on how closely they fit the concept of what is "natural" rather than what species composition would produce a maximum sustained yield of products consistent with maintaining the basic soil resource. In many parts of the

[1] Cooperative investigations with the Colorado State University Experiment Station (Scientific Series Paper No. 2365).

world, range is judged on the basis of its ability to provide edible herbage for red meat production and still conserve the soil and water resource rather than its closeness to "climatic climax" (Laycock 1975). In the sagebrush type, the choice of philosophy of management is especially important because the sagebrush plant uses water and nutrients that could be used for plants with a greater production potential, both on areas devoted primarily to livestock production and in areas where wildlife is important.

To the untrained eye, the sagebrush type may appear to be very uniform (monotonous). Yet the variety in the type is great, both in species, subspecies, and growth of the dominant plant (sagebrush) and in the number and abundance of associated plant species.

Reasons for Changes in Management

There are many reasons for adopting a particular management strategy for a specific piece of sagebrush land. Some of the possible reasons are listed below approximately in order of importance:

1. Increase forage for domestic livestock. This includes the amount, availability, season of growth, and nutritional quality of forage.

2. Improve wildlife habitat.

3. Improve watershed conditions. This includes reducing erosion, increasing quantity or timing of runoff, or improving water quality (dissolved nutrients or sediment).

4. Increase diversity of habitats either for aesthetics or wildlife.

5. Maintain "natural" conditions. This is appropriate only in natural areas, wilderness areas, or similar areas set aside for preserving representative vegetation types. However, because fire was a part of the natural environment, periodic natural or prescribed fire may have to be used to maintain the "natural" conditions.

The elevation process leading up to the choice of one or more management strategies will vary considerably with the ownership of the land. According to the FRES study (Forest-Range Task Force 1972), 11 percent (4 million ha-10 million acres) of the sagebrush ecosystem occurs on National Forest land, 71 percent (27 million ha-67 million acres) occurs on other federal lands, and 18 percent (7 million ha-17 million acres) occurs on private or other non-federal lands. On federal lands, agencies have their own laws, regulations, policies, and procedures to comply with as well as the National Environmental Policy Act, laws dealing with clean air, clean water, etc., and the Multiple Use and Sustained Yield Act. Before any action can be taken on federal lands, an environmental analysis must be made and an environmental impact statement must be filed for projects that are large, have major impacts, or are controversial. The procedure for choosing a management strategy on private sagebrush lands is somewhat simpler. Private landowners can get advice from the Soil Conservation Service, County Extension Agents, private consultants, or make decisions based on their own knowledge and experience.

The remainder of this paper deals with some of the things that must be considered before an appropriate management strategy can be chosen for any given piece of sagebrush land.

Site, Habitat Type, or Community

The first step in deciding on any particular management strategy is to classify the site, the plant community or habitat type. If appropriate research has been conducted, such a classification can provide the basis for determining the productivity potential of the land under different management systems or treatments based on comparison with similar sites. Various classifications that might be considered include the range site concept used by the Soil Conservation Service, the habitat type originally proposed by Daubenmire, soil type, or any other vegetational community classification that is applicable.

One of the main considerations in determining the appropriate community classification is the question "Was sagebrush natural to the site?" This affects management decisions because, if sagebrush was a natural part of the community, it will eventually return, unless it is vigorously managed against. The time required for sagebrush to return will depend on the subspecies of sagebrush, the management of the area and also on some poorly understood climatic factors that produce "seedling years" for sagebrush in some years, sometimes immediately after treatment. If no community classification is available, there are other ways to estimate the site potential. One is the species or subspecies of sagebrush present and its vigor. Another is an evaluation of the associated species. If many other species are present, the appropriate community or site potential may be assessed fairly accurately. If the site is depleted by overgrazing, other clues will have to be used—such as soil characteristics, height of sagebrush, and comparison with nearby sites in better conditions. Obviously you must make such comparisons carefully.

Species and Subspecies of Sagebrush

An accurate determination of the sagebrush present is important because different species react differently to treatments. For example, *Artemisia tripartita* and *Artemisia cana* often sprout after fire. *Artemisia cana* is also fairly resistant to most herbicides. *Artemisia nova* is a valuable forage species for sheep and big game and probably is best left untreated. *Artemisia arbuscula* may indicate a site with low productive potential.

Within the major sagebrush species, *Artemisia tridentata*, the subspecies differ in volatile oil content, palatability to livestock and big game, germination requirements, rate of recovery after treatment, growth rate, response to herbaceous competition, and other factors. All are important in the choice of a treatment or management strategy.

Other Species Present

The presence and amounts of other species not only determine the community classification, but also what treatments might be feasible for the site. If native grasses or other desirable forage plants are abundant, reseeding probably is not necessary or desirable. If other valuable shrub species are present, such as bitterbrush (*Purshia tridentata*), the effect of the proposed treatment must be considered. Horsebrush (*Tetradymia* spp.) and rabbitbrush (*Chrysothamnus* spp.), if abundant, may rule out use of fire because they usually increase in abundance after burning. Other shrubs need similar considerations. If the area is a sheep range containing abundant desirable forbs, you may decide against spraying because of the possible adverse effects on these forbs.

Present and Future Uses of the Land

If the land is and will be used primarily for livestock grazing, both the kind of livestock and season of use are important. On sheep winter range, an open stand of sagebrush may be desired for protection and emergency feed. Little or no sagebrush is desirable on summer cattle range.

The species of animal and the season of use are also important on big game ranges. On deer winter range, a heavy stand of shrubs may be desirable for emergency winter feed and cover but this will depend on how deep the snow will get and what other species of shrubs are present. A mixture of shrubs is better than a pure stand of sagebrush. If the area is mainly spring or summer deer range, an open stand of sagebrush with a good understory of grass and other species may be the most desirable. Even areas seeded to grass interspersed with shrub stands may be highly desirable because they will attract the deer at some seasons and take the pressure off native stands. Antelope eat large quantities of sagebrush where it is present and sagebrush appears to be important on antelope winter ranges. However, antelope do well in some areas where there is no sagebrush.

In areas occupied by small game birds, the habitat requirements of the species and age classes must be considered. For sage grouse, the requirements for adults and chicks are completely different. Sagebrush control usually has been considered bad for sage grouse but spring burning in Nevada (Beardall and Sylvester 1976) created openings which simulated meadows and furnished forbs and other species necessary as food for chicks (Klebenow 1973). The season of use by sage grouse or other game birds is also important. A nesting site might be treated differently from winter range or a site that includes strutting grounds.

The effects of density of sagebrush and sagebrush control on other game and nongame species of birds and mammals mainly is unknown. Habitat requirements for each age class of each species need to be determined. With this knowledge the manager can design range improvement practices to have little impact or even improve habitat for desirable wildlife species.

Two other things that need to be considered in present and future uses of land are recreation and aesthetics. The impacts of recreation on other uses is quite variable. Rock hounding and similar pursuits cause little conflict with other uses. Off-road vehicle use, however, can be quite disruptive to livestock operations and big game, and can also damage watersheds. Aesthetics can be a very controversial subject. An extremely thick stand of sagebrush may be looked at by some as "natural" even through the sagebrush might not have been as thick originally. Natural fire probably created mosaics of vegetation in much of the sagebrush type in which some areas were free of sagebrush because they had burned recently, whereas adjacent areas had rather thick stands.

Management Alternatives

Grazing Management

Grazing can maintain existing composition of vegetation or it can be used to manipulate amounts of sagebrush and composition of understory vegetation. Inadvertent manipulations caused by grazing have taken place in some sagebrush areas over the entire sagebrush ecosystem. Overgrazing has resulted in dense stands of sagebrush with little herbaceous understory in many areas. Frequent fires in southern Idaho, coupled with improper grazing, have converted vast sagebrush areas into an annual grassland dominated by the introduced cheatgrass brome (*Bromus tectorum*).

If the density of sagebrush and composition and production of other vegetation is satisfactory, i.e. an open stand of sagebrush with a productive understory, proper grazing management is essential to maintain that condition. The "best" system of management cannot be determined by any formula because of the great variation within the sagebrush ecosystem, the kind of grazing animal, time of grazing, and many other factors. Many sagebrush ranges are grazed year-round but others are grazed only in the winter, in the spring and fall, or at other seasons. Spring and early summer grazing require the most careful selection of grazing system and intensity because the defoliation coincides with the growing season of the herbaceous species. Fall or winter grazing generally is less critical. Because cattle and sheep diets may vary considerably, the effects of their grazing can be quite different even during the same season.

Specialized grazing systems can be used to manipulate amounts of sagebrush present. Heavy fall grazing by sheep, coupled with rest during the spring, has been shown to be an effective way to reduce amount of sagebrush under specific conditions (Laycock 1967). Periodic heavy fall or winter grazing by sheep can also be used to reduce sagebrush density on cattle ranges (Frischknecht and Harris 1973). Goats have been used to control other species of shrubs and should be useful in the sagebrush type.

On critical big-game winter ranges, increasing shrub density sometimes is a management objective. Heavy spring grazing by either sheep or cattle generally reduces the vigor and production of herbaceous species and results in an increase in sagebrush. Controlled spring and summer livestock grazing have been used to improve big-game ranges in Utah (Smith and Doell 1968, Jensen *et al.* 1972). However, relying on sagebrush as the main source of winter feed for game may be questionable because of the

deleterious effects of the volatile oils in sagebrush leaves on rumen activity and digestion of both sheep and deer (Nagy *et al.* 1964). A dense stand of sagebrush may appear to be ideal for deer winter range but a manager might get better results by replacing the pure stand with a mixed stand of several shrub species. Wallmo *et al.* (1977) found that dense sagebrush stands on deer winter range in Colorado did not furnish minimum protein requirements for the deer and furnished only about one-half of the energy needs in late winter.

Complete protection from grazing, at least on sites where sagebrush is a natural part of the vegetation, may be relatively ineffective in reducing the amount of sagebrush because of the long life and competitive ability of sagebrush (Laycock 1967).

Introduction of animals that can utilize sagebrush to produce meat or fiber is another management alternative that has received little attention. Martin (1967) noted that many of the large herbivores that became extinct in North America during the late Pleistocene, such as camels, ground sloths, and mammoths, were browsers and may have been a factor in keeping shrub density low in many different shrub types. He theorized that these browsing niches are now empty, resulting in increases in the range and density of many shrubs, especially in the southwestern United States. If animals could be found which could subsist largely on sagebrush and produce salable food or fiber products, some of the problems of management in areas where sagebrush is too thick might be solved. Some possibilites are domestic goats and some of the large African browsing game animals, such as the eland.

Other Methods of Manipulating Shrub Density

Ranges with a thick stand of sagebrush and little or no perennial herbaceous production in the understory generally will not respond to a change in grazing management. Therefore a manager must use some other method to manipulate the amount of sagebrush and change the associated vegetation. The management alternatives involving sagebrush density include doing nothing, reducing shrub density, increasing shrub density, and removing shrubs completely. Reasons most commonly given for reducing or eliminating sagebrush include: 1) it is relatively unpalatable, 2) it uses moisture and nutrients that could produce forage, 3) if too thick, it hampers movement of livestock, especially sheep, 4 it snags wool from fleeces, 5) it may cause lambs and calves to stray (Pechanec *et al.* 1965).

Fire is the main ecological factor that controlled sagebrush density before settlement by European man. To use fire as a management tool, the effects of different seasons of burning on the sagebursh and on the abundance and composition of other species must be evaluated. Other considerations are: legal constraints, smoke, danger of escape, susceptibility of of the soil to wind or water erosion after burning, and presence of undesirable species that may increase after burning. Fire is a useful management tool and more needs to be known about its use. One generally overlooked area in the field of burning is the opportunistic use of natural fires. This requires a good fire management plan that will allow an accidental fire to burn within an area where sagebrush control is desired. This has some risks, of course, and can only be used where relatively good firebreaks are present to stop the fire where it should be stopped.

With the introduction of growth-regulating chemicals after World War II, herbicides became the standard tool for sagebrush control. Environmental considerations have since curtailed the use of many herbicides. However, the most effective herbicide for sagebrush still is 2,4-D which is relatively nonpersistent and environmentally acceptable. In spite of this, only small amounts of sagebrush is currently being sprayed on federal rangelands.

Important factors in determining the success of a spraying operation are the form of the chemical, the season of spraying, the time of day, the method of application, and the rate of spraying. The effect of the herbicide on associated species should be carefully considered, especially on sheep or big-game range where forbs are important. However, careful timing of herbicide application can minimize effects on desirable forbs. On the Sawtooth National Forest in Idaho, the number of forb species present was lower on sprayed than on unsprayed areas for 4 years following spraying. However, there generally were more forb species on sprayed areas in the period 5 to 19 years following spraying (personal communication, Tom Phillips, U.S. Forest Service, Intermountain Region, Ogden, Utah).

Mechanical eradication has been widely used for removing sagebrush but it is probably one of the more expensive methods. Mechanical methods include railing, chaining, rotobeating, and discing or plowing. Time of the control operations is important. If railing, chaining or other mechanical methods are used after the seed of sagebrush has been set in the fall, it may insure a good crop of sagebrush seedlings the next year. On good sites with deep nonrocky soils, mechanical eradication, seedbed preparation, and drilling may be the best way to proceed.

Biological control of sagebrush occurs naturally in some instances but has not been used as a management tool. Frischkencht (1972) and Mueggler (1967) have shown that voles (*Microtus* spp.) often girdle and kill sagebrush during peaks in their population cycle. The Aroga moth has destroyed fairly large stands of sagebrush in some areas (Gates 1964). Whether these or other biological controls, such as other insects and diseases, can be used to reduce sagebrush under controlled conditions is not known.

Treatment after Sagebrush Reduction or Control

The major decision to be made after sagebrush reduction or controls whether seeding is required. This will depend on the variety and amount of herbaceous species present and the planned use of the land. If abundant palatable grasses and other desirable forage species are present, it probably is not necessary to seed unless spring forage is needed earlier than the native species can provide. Shown *et al.* (1969) found that the most successful conversions of big sagebrush to crested wheatgrass (*Agropyron desertorum*) have occurred where annual precipitation exceeds 25 cm (10 in) on soils having good moisture-holding capacities, and where big sagebrush vigor was relatively high.

If seeding is determined to be advantageous, the following must be considered:

1) Species: Species chosen must fit the site, the climate, and the potential use. Things to consider include:

   a) Native versus introduced. This decision will depend on the availability of seed; ease of establishment; price; production potential; longevity, palatability, and grazing resistance of the species involved; and the season of growth. Native species, even cultivated varieties, often do not start growth as early in the spring as do some introduced species.

   b) Single species or mixture: Monocultures of some wheatgrasses and other species have led to problems with insects (black grass bug), poor stands if improper species are chosen, and in some cases, a poor "public image" especially from some environmental groups. However, species mixtures can also have problems because of differential palatability. This can lead to elimination of all but one or a few species after a few years and the extra cost and the advantages of a mixture are lost. Other things to consider are whether there should be shrubs in the mixture for livestock, wildlife, or aesthetics. Sagebrush often is planted because it was in the original community before disturbance. However, improper choice of subspecies or density of planting can cause problems later, either because of competition or because of digestibility problems caused when livestock or game eat a pure diet of sagebrush. Even on wildlife ranges, other shrubs may be more desirable to plant than sagebrush because of the potential for sagebrush to dominate the site and to cause digestive problems for ruminants. Forbs, especially legumes, may be included in the mixture for variety in species composition and possibly for nitrogen fixation. There have been suggestions that "wildflowers" be put in some mixtures for increased aesthetics in areas that are highly visible to the public. In any case, the choice of a mixture or a single species is not an easy one.

2) Methods of seeding: It is generally agreed that seeds must be covered in order to get a good stand of seeded grass. Broadcasting in ashes of a burn sometimes has achieved good results. Seed can be broadcast ahead of a railing or chaining operation and the mechanical disturbance covers the seed. If any other method of sagebrush control is used, it is generally desirable to prepare a seedbed and drill the seed rather than broadcast.

3) Time of seeding: This will vary in different areas, depending on climate, snow cover, spring weather, etc. If much of the moisture is gone from a site before equipment can be used on it in the spring, fall seeding probably is best.

4) Other factors: Rate, depth, and row spacing will depend upon the species being planted and the area.

5) Control of undesirable fauna: Rabbits, pocket gophers, prairie dogs, insects, and other pests can destroy a seeding if not controlled. Environmental considerations have put many constraints on control methods but ways are still available to control these animals.

6) Follow-up control: This sometimes is necessary to reduce other undesirable species or to prevent sagebrush from becoming too thick again. The methods used for follow-up control might be different than those used initially. For example, if an area is plowed and seeded and sagebrush reinvades, a light fire through the area can get rid of the small sagebrush plants.

7) Fertilizer: Fertilizer can increase production in some instances but the economics must be carefully considered. One aspect of fertilizer that has received little study is the use of fertilizer to delay sagebrush reinvasion.

8) Size of seeded area: The area seeded must be a manageable unit, but excessively large seeded areas can be detrimental to wildlife and other values.

9) Grazing management: Proper management immediately following sagebrush control and seeding is essential to allow the seeded stand to become established. Application of proper grazing management systems for your area can also be effectively used to prevent or at least slow down reinvasion of sagebrush. However, a grazing management system that might work quite well before sagebrush seedlings become reestablished might not be the best system to use after they are established. With cattle, any rest-rotation or similar system that puts heavy pressure on herbaceous plants, even one year out of three or four, will tend to favor the sagebrush because the cattle do not eat the sagebrush, even with heavy pressure. A combination of cattle and sheep or occasional heavy grazing by sheep in the fall or winter can be used to keep sagebrush density and vigor low.

Watershed Considerations

Because much of the sagebrush ecosystem occurs in a fairly low rainfall zone, the effect of sagebrush management strategies on run-off and erosion are usually considered but the effects on water yield often are ignored. The hazard of run-off and erosion that might occur with any disturbance will depend on slope, soil texture, plant and litter cover, probability of high intensity summer storms, and other factors. If run-off is occurring before treatment,

the decision must be made as to whether the treatment chosen will improve the situation or accelerate the run-off and erosion.

Snow is a major supplier of moisture in the sagebrush type and treatment may affect snow distribution and melt. The amount and timing of snowfall, the wind direction and speed in winter, and the drifting potential for increased water if patterns of sagebrush are left must be considered. The effect of live and dead shrubs on snow accumulation and melt patterns may also be important. In some locations, large areas with no shrubs may be scoured clean of snow and actually reduce the water on site for plant growth. A paper reviewing the status of knowledge on hydrologic relationships on undisturbed and converted big sagebrush lands was recently published by Sturges (1975).

Other practices to increase water held on site, such as pitting and furrowing, have not been widely used in the sagebrush type but certainly must be considered.

Economic Implications

For any sagebrush control management strategy, the major economic implication is the length of control and the value of that control versus the cost. Alternative methods must be examined, such as grazing management rather than costly mechanical or chemical treatments. The probability of need for follow-up also is a major consideration.

The main value of sagebrush control usually is increased forage production which is converted to increased animal production. In Wyoming, Kearl and Brannan (1967) reported up to 10-fold increases in grass production (1316 kg/ha versus 124 kg/ha on untreated) on plowed and seeded sagebrush land. The amount of increase depends on the site, precipitation, and other factors. However, you must also consider other uses that are difficult to assign a dollar value to--such as watershed, aesthetics, nongame wildlife, game wildlife species, and open space. Any available cost sharing practices should be taken into account by the landowner before deciding on the economics of any particular management strategy.

Other Considerations

Some other factors with management implications are:

1) The allelopathic characteristics of sagebrush. Sagebrush leaf litter has been shown to inhibit the germination and growth of some other species. The allelopathic effects may come from water-soluble substances or volatile substances.

2) Nutrient cycling. The effect of sagebrush control on cycling of various nutrients is not well understood. However, the possibility of changes in nutrient cycling should be considered before any decision about sagebrush control is made.

3. Secondary products. The woody stems of sagebrush contain considerable amounts of wood fiber. This fiber is not marketable now but utilization may be possible in the future. Sagebrush leaves contain considerable amounts of volatile oils and other compounds for which there is no present use. In the future, these compounds might also have a market in medicine or elsewhere and the combination of wood fiber and chemical compounds could make it economically feasible to remove sagebrush over large areas and increase production of either native or seeded understory forage species.

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ECONOMICS AND THE SAGEBRUSH ECOSYSTEM

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Introduction

Managers of western rangelands must meet the challenge of correlating present and future needs of our society and the rangeland environment.

The range livestock industry uses rangelands in producing food and fiber. Despite low rainfall, thin soils, and often rough terrain, most of this multiple-use resource also has potentials for recreation, watershed, wildlife habitat, urban and rural expansion, and aesthetics. Each of these possible users of the land is increasingly vociferous in demanding consideration for his needs in future land-use planning.

Judicious range improvement by means of brush control is an efficient way to increase red meat production without seriously harming man, animals, and the environment. Nevertheless, there appears to be considerable reluctance by some range managers and ranchers to put this range improvement into practice.

There are several alternative methods of controlling sagebrush on rangelands. These include chemical spraying, planned burning, plowing and seeding, rotobeating, and chaining. On many sites more than one method may be used with a high probability of success. However, on other sites alternative methods of treatment may be limited by topography, understory of perennial grasses, and size and density of sagebrush, to mention a few limiting factors. Removal of sagebrush by selective grazing or biological control, although feasible in some cases, will not be evaluated with an economic analysis in this report.

In Utah, 20.2 percent (2,453,000 acres) of state and private rangelands are dominated by big sagebrush (*Artemisia tridentata*) and merit improvement [Environmental Protection Agency (EPA) 1972]. Of this estimated total, 1,830,000 acres are recommended for improvement by the use of chemical herbicides, namely 2,4-D. The remaining 623,000 acres could best be improved by other methods.

Alternative methods of controlling big sagebrush (other than spraying) were largely evaluated in terms of the expected response of the total plant community to treatment. These data, together with comparable data from spraying, were used to determine the economic feasibility of big sagebrush control.

If one could limit the herbaceous matter eaten by either insects or voles to big sagebrush and other species designated as undesirable, biological plant control could possibly see a future in range management. As it is, their nonselective eating habits could leave a range in a worse-than-before posttreatment condition.

Economic Analysis of Data

Sagebrush control costs vary depending on type of equipment, difficulty of job, whether the equipment is owned by the rancher (or an agency), or if the job is contracted. If the rancher owns the equipment and uses it for other ranch projects, fixed costs charged against range improvement are relatively low. When the job is done completely on a custom basis, all costs are variable (Kearl and Brannan 1967). When a manager constructs new fences and/or reservoirs in conjunction with sagebrush control, his variable costs will increase considerably, but again this depends on size of the area being treated, type and extent of fencing, and size, type, and number of reservoirs.

The main concern of a rancher is to recover the costs of range improvement. Total costs incurred for sagebrush control can be recovered by one, a combination, or all of the following ways: 1) revenue received from increased red meat production; 2) increased sale or leasing value of rangeland by improving the watershed and increasing the forage production; and 3) revenue from selling recreational privileges.

Benefits from range improvement in terms of additional animal-unit-months (AUMs) available for grazing vary depending on management decisions of the rancher. One ranch manager may adopt a conservative attitude in rangeland stocking, even though his range is more than capable of providing an increase in carrying capacity. Another may increase the size of his operation and realize an economy of size. There is also the manager who is now able to maintain his present operation size, whereas a size reduction would have been necessary without range improvement (Kearl and Brannan 1967).

It would be impossible to account for all the variations and combinations of variables that are involved in range improvements. However, if certain variables are held constant, then it can be determined if future range improvements are economically feasible.

Determinants of Economic Success of Sagebrush Control Methods

Several important factors must be considered when making an economic analysis of a range development project. First, there are the usually benefit-cost items discussed below. In addition, one must make assumptions about the pattern of benefits (the expected forage production) over the life of the project. Are the benefits constant over the life of the improvement? Do they start at high levels in the early years and decrease over the life of the

project? Usually the benefit stream is assumed constant. This assumption might not be entirely realistic, but when one analyzes the deviations from other assumed benefit streams, the differences are not usually significant when discounted for the useful life of the project. However, the nonuse requirement during the initial year of a brush control project and for 1 or 2 years following treatment can be a significant factor in the economic evaluation. Nonuse will be given special emphasis in the following discussion and in Appendix A.

Two distinct problems are encountered when dealing with rangeland deferment (nonuse). First, there is the biological problem of whether deferment is really needed to get the best response from brush removal. Most land management agencies recommend or require one or more years of deferment from grazing to aid attainment of maximum forage production (Pechanec et al. 1965). This requirement may place a hardship on the ranching operation because herds must be reduced or additional range must be acquired to offset the temporary loss of forage.

Smith (1969) found that deferment from grazing was not always necessary following chemical control of big sagebrush. Four experimental areas were evaluated in his study--Buck Creek, Grouse Creek, Antelope Butte, and Soldier Creek, all of which were located in the Big Horn National Forest, Wyoming. All sites had a relatively dense understory of grasses and forbs before spraying. Crown cover and density of sagebrush was reduced by about 98 percent following aerial spraying with 2,4-D.

Each of the experimental areas was divided into 4 sections to compare the effects of 0, 1, 2, and 3 years of deferment on forage production and reinvasion of sagebrush.

At Buck Creek and Grouse Creek, length of deferment had no effect upon production of all grasses and forbs. In the Antelope Butte area, total production of grasses and forbs was not affected by length of deferment except that the yield of Idaho fescue was greatest under no deferment.

At Soldier Creek, 1 and 2 years' deferment had the same effect as 3 years of deferment. The nondeferred areas, however, produced 547 pounds more air-dry forage per acre than did the deferred areas.

Smith also established that sagebrush reinvasion was similar in all cases. No year-to-year increase in sagebrush density was noted regardless of length of deferment. Utilization of the forage in posttreatment years was less than 43 percent.

Special consideration should be given to not requiring any deferment, especially at elevations where annual precipitation exceeds 15 inches and the grass understory is abundant (see Appendix A).

If it is determined that grazing should be deferred following brush control, should complete nonuse be imposed for 2 years or can the rangeland be grazed late in the season for the first 2 years. Once a determination about the deferment required has been made from a biological basis, the proper economic analysis must be completed.

Unrealistic assumptions have often been made about nonuse in analyzing the economics of brush control because these assumptions made the computation of the internal rate of return easier. For example, if 2 years of nonuse were required biologically, the value of grazing foregone for the 2 years would be added to the initial cost of spraying. Full benefits were then assumed to occur in year 1 and continue through year n. This type of analysis presents two problems. First, only 1 year's nonuse occurs the year of spraying, (year 0) the second year's nonuse occurs in year 1 and should be discounted. Second, if a full 2 years' nonuse is taken, there are no benefits in year 1. Thus, the benefit stream does not start until year 2. Other variations of nonuse may be appropriate for a given brush control project. If so, one should reflect nonuse costs in the year they occur and start the net benefit stream in the year it actually begins. Examples of different ways of handling nonuse, that have been used, will be shown in this report. Because nonuse is important in the results of an economic analysis, range managers should be sure that suggested nonuse requirements are based on sound biological and ecological principles.

Factors that influence the economic success of sagebrush control are: 1) cost of control method; 2) original forage production; 3) increase in forage production; 4) value of increased forage production per AUM; 5) effective life of control; 6) market interest rate or opportunity cost of money; and 7) whether or not the rancher practices nonuse. All these factors are considered when the economic feasibility of sagebrush control is determined using the internal rate of return technique.

Cost of control method. The cost of sagebrush control varies depending on the method used and on the size and condition of area being treated. Other costs vary in relation to total activity and management decisions, examples of which include seeding, nonuse, construction of fences and reservoirs, and miscellaneous annual costs.

Original forage production. The original forage production on a given range must be known in order to calculate the cost of nonuse, and only 50 percent of the forage produced can be considered in an economic evaluation. For example, if the range forage production is 400 pounds per acre air-dry, one would assume 50 percent (200 pounds) available for animal consumption and 50 percent (200 pounds) remaining on the ground. Grazing at an intensity to consume 200 pounds will allow the plants and soil to stay in a condition which will allow for a sustained yield at the estimated carrying capacity.

Nonuse cost = yield before treatment in AUMs x value per AUM or the cost of replacing this number of AUMs.

Increase in forage production. The same principle applies for an increase in forage production in that only 50 percent of the increase should be used in our economic evaluation. If forage production increased by 900 pounds per acre air-dry, only 450 pounds per acre air-dry are considered as available in the economic analysis. It is further assumed one can estimate an average increase in

forage production that is constant for the life of the project.

Value of increased forage production per AUM. Determination of the value of an AUM of forage is somewhat confusing and difficult. The calculated value depends upon the technique employed. For example, one could take residual ranch income after payment of all costs other than forage and compute the average value of all AUMs required during the year by capitalizing the net income to forage. Another way of handling the problem would be to assume that the rancher plans to increase the size of his business by increasing the carrying capacity of the land and increasing the size of the ranch. Value of these AUMs would be based on the net added returns and (in Utah) one would usually expect them to be higher than the value of an AUM for the entire ranch given the present size and organization of most Utah ranches. Another value of an AUM that must be considered is the market value, usually expressed as a monthly lease rate.

Each analysis of a sagebrush control project may have some unique characteristics that would influence the appropriate AUM value. The AUMs developed from sagebrush control programs initiated to relieve seasonal grazing shortages may have values several times higher than the "market value" if they provide a way of using all other ranch resources more efficiently.

Since one does not always know the unique characteristics of each situation, a reasonable value to use is the market value or lease rate. If the return to AUMs on the ranch is less than the "market value", the rancher would still have the opportunity of leasing these AUMs to another stockman. In this analysis, the average market value of an AUM is assumed to be $3.98 (USFS 1973). The annual economic returns of 450 pounds forage in terms of an AUM is calculated as follows:

900 pounds (total forage increase per acre) x 0.50 percent = 450 pounds;
450 pounds/800 pounds (forage required for an AUM) = 0.56 AUMs per acre;
By multiplying 0.56 AUMs per acre increase x $3.98, the calculated annual economic return from usable forage is $2.23 per acre.

Effective life control. The effective life of sagebrush control depends on method used, management practices, and percent kill of sagebrush. Enhanced forage production usually declines at some point in time. The rate and time of decline depend on the factors listed above. For practical purposes, once reinvading sagebrush reaches a certain density, the productive life of a treatment is essentially over. Retreatment then becomes another economic decision one should consider.

Market interest rate or opportunity cost of money. This is the rate at which a rancher can borrow money or what his best alternative use of capital will return. The market rate of interest for range improvement is assumed to be 8 percent.

Internal rate of return. The internal rate of return is the discount rate which forces the discounted returns to equal the cost of obtaining the income stream (Nielsen 1967). For a project to be economically feasible, the internal rate of return must be greater than the market rate of interest (cost of obtaining income stream).

Various methods can be used to determine internal rates of return on a given investment depending on the nature of the income stream. If one assumes the income stream begins in year 1 and remains constant over the life of the project, the following formula can be used (Nielsen 1967):

$$I = R \left[\frac{1 - (1 + i)^{-n}}{i} \right]$$

where: I = initial investment per acre
R = net additional annual return per acre
n = effective life of improvement (years).

In this equation, we are solving for i, which is the internal rate of return.

In the above discounting method, the formula assumes a constant income stream throughout the effective life of the project, beginning in year 1 (year following treatment) and extending to year n. Also, all nonuse costs (the value of the forage foregone by not grazing) are assumed to be incurred in year 0 (year of treatment), regardless of the year in which the nonuse cost actually occurred.

Although this method is a relatively easy way to calculate the internal rate of return, it is not as accurate as one may desire. For example, a sprayed range may be deferred from grazing for 2 years. The first year of deferred grazing occurs the year the land is sprayed (year 0). This nonuse is added to the cost of spraying. Also, the net income in year 1 (if any use is made this year) would be less than in the following years (year 2 through n), because the nonuse cost in year 1 would be subtracted from the annual income stream of year 1. If no use was made in year 1, the nonuse cost would appear as a negative entry in year 1.

Each year's net income is discounted separately and summed to arrive at the present value of the net income stream. Thus, one is able to properly account for the nonuse costs in years 0 and 1 which results in a smaller internal rate of return than if all nonuse costs are assumed to occur in year 0.

The following assumption will hold for all control methods unless otherwise indicated:

1) Fences and stockwater facilities are sufficient for proper range management following treatment;

2) Seeding is not necessary except when plowing is done; and

3) All treatments are done on contract.

Spraying

Results of sagebrush spraying projects were gathered from sources representing Utah and various surrounding states. Following treatment, forage production increased one- to threefold, and AUMs per acre increased from 0.1 to 0.9. These data have been summarized in Table 1.

The average annual AUMs per acre before treatment and the average annual increase in AUMs per acre after treatment were 0.2444 and 0.4185, respectively. These results are consistent with studies conducted by Kearl and Brannan (1967), in which AUMs per acre on pretreated and treated range were 0.2 and 0.5, respectively. The USFS (1973) estimated from 17 five-to-seven-year-old projects in the intermountain region, that forage gained as a result of chemical treatment was 0.37 AUMs per acre with a utilization rate of only 40 percent. At a utilization rate of 50 percent, forage gained would have been approximately 0.47 AUMs per acre. Thus, the increase in forage production used in this study (0.4185 AUMs) is considered to be a conservative estimate.

It is rather difficult to determine the effective life of spraying rangeland. Kearl and Brannan (1967) projected a longevity of 15 years and the USFS (1973) estimated an average of more than 20 years. From data available in the literature, it seems that 12-15 years is a realistic estimate.

In most cases some nonuse is imposed following a spray project. However, since nonuse has a significant impact on the magnitude of the internal rate of return, serious attention should be given by range managers to determine if it is really necessary to obtain projected yield increases resulting from brush control (see Appendix B). Two years of nonuse is assumed in the following analysis.

Each year's net income will be discounted separately and summed over the life of the project. This method of computation will be used for each type of brush control project considered in this report. For a detailed summary of how different assumptions about nonuse affect the internal rate of return, see Appendix B.

Calculating the internal rate of return where nonuse costs are accounted for in the years where they occur is a rather involved process of trial and error. The methodology can best be understood if it is set out in algebraic form. The data used are the same as used below from Table 1.

I = \$5.82, cost of chemical treatment per acre (USFS 1973), + \$.97, cost per acre for nonuse during year 0, = \$6.79.

R = \$1.67, value of AUM in annual returns per acre in year 2 through year 13.*

R = -\$.97 during year 1 (nonuse cost).

(Assume 2 full years nonuse.)

Since the income stream is not constant over the 13 years, each year's income must be discounted separately (Table 2).

Using 15 percent, the sum of the discounted annual returns (\$7.03) is greater than the cost incurred in year 0 (\$6.79), therefore, the internal rate of return has been underestimated (Table 2). A higher rate is selected, for example, 16 percent, which results in the internal rate of return being overestimated, because the sum of the discounted annual returns (\$6.65) is less than I (\$6.79).

This iterative process is continued until the sum of the discounted returns converges on the costs incurred in year 0. By this process and using interpolation, the internal rate of return (i) is about 15.62 percent. Therefore, at a discount rate of 15.62 percent, I (\$6.79) is equal to the sum of the annual discounted returns (\$6.79).

Planned Burning

Planned burning was once used extensively to

Table 1. Sources of data, annual yields, and AUMs of forage before spraying, annual increase in yields and AUMs of forage after spraying, and number of years range improvement was observed

	Annual Yield Before Improvement (Pounds)	Annual AUMs per Acre Before Improvement (50% Utilization)	Annual Increase in Yield After Improvements (Pounds)	Annual Increase in AUMs per Acre After Improvement (50% Utilization)	Number Of Years Observed
Allen & Bohmont (1958)	526	0.3287	1549	0.9681	5
Cook (1966)	430	0.2687	370	0.2312	3
Cook (1966)	800	0.50	700	0.4375	3
Hyatt (1966)	343	0.2143	800	0.50	6
Sneva (1972)	227	0.1418	454	0.2837	17
Peterson (1973)	221	0.1381	621	0.3881	3
Brady (1973)	191	0.1193	193	0.1206	3
	391.14	0.2444	669.57	0.4185	5.7

Table 2. Nonuse costs and annual returns per acre, discounting factors, discounted costs and returns per year when sprayed range is deferred from grazing for 2 full grazing seasons

Year (n)	Nonuse Costs and Annual Returns per Acre (Dollars)	Discounting Factors (Percent) 15	16	Discounted Annual Costs and Returns (Dollars) (Percent) 15	16
1	-0.97	0.869565	0.862068	-0.8434	-0.8362
2	1.67	0.756143	0.743162	1.2627	1.2410
3	1.67	0.657516	0.640567	1.0980	1.0698
4	1.67	0.571753	0.552291	0.9548	0.9223
5	1.67	0.497176	0.476113	0.8302	0.7951
6	1.67	0.432437	0.410442	0.7219	0.6854
7	1.67	0.375937	0.353829	0.6278	0.5908
8	1.67	0.326901	0.305025	0.5459	0.5093
9	1.67	0.284262	0.262952	0.4747	0.4391
10	1.67	0.247184	0.226683	0.4127	0.3785
11	1.67	0.214943	0.195416	0.3589	0.3263
12	1.67	0.186907	0.168462	0.3121	0.2813
13*	1.67	0.162529	0.145226	0.2714	0.2425
I = $6.79			Total	7.0277	6.6452

*Discounting is carried into year 13 because 2 full years of grazing was lost to nonuse.

control big sagebrush, but in recent years its use as a management tool has been limited. It can be an excellent method of big sagebrush control, assuming a sufficient understory to carry the fire, and if proper follow-up management is used.

The USFS (1973) estimated forage production gained by planned burning the same as for chemical spraying, 0.37 AUMs per acre. Of course, the estimate would be somewhat higher than 0.37 if 50 percent utilization of increased forage was used.

Estimates of increased AUMs attributed to planned burning seem to differ. Pechanec et al. (1954, revised) show an increase in AUMs of 0.225; (740 pounds on postburn, minus 380 pounds on preburn = 360 pounds 0.50 forage utilization = 180 pounds/800 pounds per AUM = 0.225). This is considerably less than the USFS estimate. However, Pechanec's estimate is the result of work in one region, whereas the USFS based their estimate on studies throughout the Intermountain States.

In determining the internal rate of return for planned burning, we used the data in Table 1. This seemed justifiable because of: 1) insufficient availability of forage yield data for planned burning; and 2) comparable forage yield estimates made by the USFS.

The effective life of a planned burn has been reported to have lasted for at least 15 years (Pechanec et al. 1954, revised). Whiteworth (1963), a rancher in Beaverhead County, Montana, reported 12 years of increased capacity following planned burning.

An effective life of 12 years will be used in the following economic evaluations. This expected longevity correlates with the forage data used from big sagebrush control using 2,4-D. It must be remembered a major determinant of big sagebrush reinvasion is the number of plants surviving treatment (Johnson and Payne 1968). It is assumed the same percentage of big sagebrush plants killed by 2,4-D will be killed by planned burning. Treated range will be deferred from grazing in year 0 and will not be grazed until the fall of year 1, but will be only one fourth of the potential stocking rate (Pechanec et al. 1954, revised).

Economic analysis.

$4.00 = cost of planned burning per acre (USFS 1973);
$3.98 = market value per AUM;
0.2444 = annual AUMs per acre prior to treatment;
0.4185 = annual increase in AUMs per acre after treatment;
$0.97 = cost per acre for each year of nonuse;
$1.67 = value of AUM in annual returns per acre.

I = $4.00, cost of burning per acre (USFS 1973), + $.97, cost per acre for nonuse during year 0 = $4.97.

R = $1.67, value of AUM in annual returns per acre in year 2 through year 13.

R = -$.31, in year 1 (-$.73, nonuse cost for three fourths of year 1 minus $.42, value of an AUM for one-fourth year in year 1).

n = 13 years (year 13 is added to help compensate for one and three-fourths years lost in grazing in year 0 and 1).

The internal rate of return (i) is 23.85 percent.

Plowing and Seeding

From data collected in our study, forage production increased by four- to sixfold following plowing and seeding. The average annual AUMs per

acre before treatment and the average annual increase in AUMs per acre after treatment were, respectively, 0.1216 and 0.5399 (Table 3).

The longevity of most exotic grasses after plowing and seeding is at least 20 years (Cook 1966 and Hull and Klomp 1966). Kearl and Brannan (1967) in their economic analysis projected a useful life exceeding 20 years. In this study, the longevity of various exotic grasses when plowing is followed by their seeding is estimated at 25 years, which is believed to be rather conservative.

Treated rangeland will be deferred from grazing for 2 full years. This nonuse period will enable young seedlings to become established and lessen the hazard of wind and water erosion.

Economic analysis.

$21.00 = cost of plowing and seeding per acre (USFS 1973);
$ 3.98 = market value per AUM;
0.1218 = annual AUMs per acre prior to treatment;
0.5399 = annual increase in AUMs per acre after treatment;
$ 0.49 = cost per acre for each year of nonuse (0.1218 x $3.98);
$ 2.15 = value of AUM in annual returns (0.5399 x $3.98).

I = $21.00, cost of treatment per acre (USFS 1973), + $.49, cost per acre for nonuse during year 0 = $21.49.

R = $2.15, value of AUM in annual returns per acre in year 2 through year 26.

R = -$.49, in year 1 (nonuse cost).

n = 26 years (year 26 was added to help compensate for 2 full years lost in grazing in year 0 and 1).

The internal rate of return is 7.5 percent, which is less than the assumed market rate of interest. However, it is not lower than the long-term average rate of interest for such investments. One might want to review the analysis to be sure the data were accurate before accepting or rejecting a seeding project.

If a range manager believed such factors as yields and/or longevities could be increased, plowing and seeding might be a worthwhile investment. Also, many ranchers may be able to decrease the $21 per acre cost considerably if they used their own equipment and labor.

Rotobeating

The use of rotobeaters to control big sagebrush is very limited. Therefore, data on yields before and after treatment are scarce. Data from 3 sources are listed in Table 4. Average pretreatment AUMs (0.1447) and the posttreatment increase in AUMs (0.1653) are relatively low. This low productivity may be partially due to the short effective life of rotobeating (Cook 1966 and Hedrick et al. 1966). Kearl and Brannan (1967) projected a 12-year effective life for rotobeating. Other data (Table 4) show that the longevity of rotobeating effects is less than that of chemical treatment. Therefore, an effective life of 10 years was used in our economic evaluation.

Grazing is assumed to be deferred for 1 full year to facilitate seeding vigor. If a sufficient understory of grasses and forbs are present, deferment might not be necessary.

The cost of rotobeating is highly variable. Vallentine (1971) believes it can vary from $5 to $50 per acre, depending on the density and age of sagebrush. Kearl and Brannan (1967) reported an average cost of $4.76 per acre, which would be considerably higher in 1974. For plowing and seeding, the USFS (1973) quoted a cost of $21 per acre, while Kearl and Brannan had quoted a cost of $13.61 per acre in 1967. The 1973 cost is approximately 55 percent higher than the 1967 cost. Assuming the cost of rotobeating rose proportionally to that for plowing and seeding, the approximate cost in 1973 would have been $7.37 per acre.

Economic analysis.

$7.37 = cost of rotobeating per acre;
$3.98 = market value per AUM;
0.1447 = annual AUMs per acre prior to treatment;
0.1653 = annual increase in AUMs per acre after treatment;

Table 3. Sources of data, annual yields, and AUMs before plowing, annual increase in yields and AUMs after plowing and seeding, and number of years range improvement was observed

Source	Annual Yield Before Improvement (Pounds)	Annual AUMs per Acre Before Improvement (50% Utilization)	Annual Increases in Yield After Improvement (Pounds)	Annual Increase in AUMs per Acre After Improvement (50% Utilization)	Number of Years Observed
Cook (1966)	190	0.1187	668	0.4175	9
Cook (1966)	199	0.1243	868	0.5425	9
Hull and Klomp (1966)	195*	0.1218	775	0.4843	14
Hull and Klomp (1966)	195*	0.1218	932	0.5825	14
Hull and Klomp (1966)	195*	0.1218	1077	0.6731	10
Average	195	0.1216	864	0.5399	11.2

*Yields before treatment were not available for Hull and Klomp; therefore, Cook's yields before treatment were averaged to arrive at 195 pounds per acre air-dry.

Table 4. Sources of data, annual yields and AUMs before rotobeating, annual increase in yields and AUMs after rotobeating, and number of years range improvement was observed

Source	Annual Yield Before Improvement (lbs/ac)	Annual AUMs per Acre Before Improvement (50% Utilization)	Annual Increase in Yield After Improvement (lbs/ac)	Annual Increase in AUMs per Acre After Improvement (50% Utilization)	Number of Years Observed
Mueggler and Blaisdell (1958)	293	0.1831	347	0.2168	8
Hedrick et al. (1966)	200	0.1250	178	0.1112	8
Kearl and Brannan (1967)	202	0.1262	269	0.1681	-
Average	231.6	0.1447	246.6	0.1653	8

$0.58 = nonuse cost for 1 year (0.1447 x $3.98);
$0.66 = value of AUM in annual returns (0.1653 x $3.98).

I = $7.37, cost of rotobeating per acre, + $.58, cost per acre for nonuse during year 0 = $7.95.

R = $.66, value of AUM in annual returns in year 1.

n = 12 years.

The internal rate of return is less than 0, thus, rotobeating is not an economically feasible way to control big sagebrush. High costs, short longevity, and limited increases in forage undoubtedly contribute to the lack of interest in rotobeating.

Chaining

Data available on chaining big sagebrush are very limited. Increases in forage production after chaining are estimated by the USFS (1973) to be 0.30 AUMs per acre, assuming a 40 percent forage utilization rate. With a 50 percent forage utilization rate, the increase in forage production would be 0.3750 AUMs per acre. Cost of chaining per acre is listed at $8.50 (USFS 1973).

Chaining is believed to have a shorter effective life than spraying because fewer sagebrush plants are killed. It is assumed the longevity of chaining would be very similar to rotobeating, therefore, an effective life of 10 years will be used.

Deferred grazing is not recommended following chaining unless seeding is employed (USFS 1973). Thus, in the following economic analysis no deferment will be used.

Economic analysis.

$8.50 = cost of chaining per acre (USFS 1973);
$3.98 = market value per AUM;
0.3750 = annual increase in AUMs per acre after chaining;
$1.49 = value of AUM in annual returns ($3.98 x 0.3750).

I = $8.50, cost of chaining per acre (USFS 1973).

R = $1.49, value of AUM in annual returns per acre in year 1 through year 12.

n = 10 years.

The internal rate of return (i) is 11.83 percent. Chaining is an economically feasible way to control big sagebrush, although the returns are considerably lower than would accrue to either burning or spraying.

The internal rates of return for the different big sagebrush control methods are summarized in Table 5.

Table 5. Internal rate of return for different big sagebrush control methods and types for nonuse

Control Method and Types of Nonuse	Internal Rates of Return
	%
Chemical spraying	
Nonuse--2 years	15.62
Nonuse--half-year for 2 years*	20.00
Nonuse--none*	27.05
Planned burning	
Nonuse--1 and 3/4 years	23.85
Plowing and seeding	
Nonuse--2 years	7.50
Rotobeating	
Nonuse--1 year	0
Chaining	
Nonuse--none	11.83

*See Appendix B.

Summary and Conclusions

Economic feasibility of the various big sagebrush control methods was evaluated in terms of: 1) cost of the control method; 2) original forage production; 3) increase in forage production; 4) value of increased forage production per AUM; 5) effective life of control; 6) market or opportunity interest rate; and 7) nonuse requirements.

The highest internal rate of return was obtained with planned burning. Treated range, when grazing was deferred for 21 months, realized an internal rate of return of 23.85 percent.

The returns to chemical spraying with the various grazing deferments (0, 1, and 2 years) were 27.05 percent, 20.0 percent, and 15.62 percent, respectively.

Plowed and seeded range, when deferred for 2 years, yielded an internal rate of return of 7.5 percent. This does not compare favorably with the current market rate of interest on capital borrowed for range improvement of 8 percent.

The rate of return to rotobeating with 1 year of deferment was negative. Chaining with no deferment brought an 11.83 percent return. Although this return is considerably lower than that realized by either burning or spraying, it does indicate that chaining is an economically feasible method of controlling big sagebrush if no deferment is biologically acceptable.

The most important factors influencing economic success are the site vigor index and the amount of forage present before treatment. The site vigor index is mainly dependent upon soil nutrients and precipitation. Pretreatment forage yields and posttreatment yields are directly related. A larger pretreatment forage yield will give a larger internal rate of return, assuming the vigor index is sufficiently high.

If rangelands infested with big sagebrush are not improved by spraying or other control methods, considerable economic benefits, called opportunity costs, will be foregone. Spraying all rangeland in Utah that can be sprayed could be expected to yield an annual opportunity cost of $3,048,102.

Appendix A

Further Consideration of Deferment

The greatest divergence in economic success among sagebrush treatments lies in the method of control and the type of deferment. A rancher usually chooses the method that best meets his economic commitments and hopefully will be consistent with environment quality. The same type of decision would be expected for deferment, except that deferment sometimes does not appear to be feasible to the ranch manager, and it is questionable as to whether deferment is environmentally necessary following spraying. Deferment is obviously needed on plowed-seeded and burned ranges.

The Utah Agricultural Stabilization and Conservation Service (ASC) has required ranchers who participate in the service's cost-share program, to defer grazing their ranges following sagebrush control. Such deferment at times places a temporary hardship on the rancher who had to compensate for the loss of forage by reducing herds or finding additional range. Also, deferment often required additional fencing, which greatly increased the cost of the spraying program.

Recommendations for deferred grazing appear to be based on the general range management principles that deferment is necessary for seedling establishment and aids overall vegetation growth (Pechanec et al. 1954, p. 34). They stated that, "where the natural increase of native grasses is being relied upon, it is advisable to delay grazing for at least a full year." When that statement was written (1954), however, little was known about spraying sagebrush. Also, Pechanec et al. failed to reference any experimental data to substantiate their statements (Kearl 1966).

Hyder, also in in 1954, said:

> You will not need to prevent grazing on the sprayed field, but you should graze lightly while the grass is green for two or three years. Because of the greater amount of forage produced, continuation of the prespraying rate of stocking will often result in light grazing after spraying (Hyder 1954, pp. 11-12).

Hyder went on to recommend that the sprayed range be grazed moderately during spring and early summer to help prevent sagebrush reinvasion. Again, however, no experimental evidence is cited and it appears that Hyder's judgment is based upon range management experience.

The only experimental data on the subject are in Smith (1969) and Kearl (1966). Smith's work was discussed previously on page 4. Briefly, the experiments covered a range of elevations from 7,500 to 9,500 feet. The treatments were deferment for 0, 1, 2, and 3 years. After 6 years of study, Smith did not detect any significant vegetative production differences between treatments.

Kearl (1966) cited some unpublished experimental work done by W. Johnson of the Rocky Mountain Forest and Range Experiment Station, Laramie, Wyoming. The area investigated is away from the mountains in the Beaver Rim area near Lander. It is at an elevation of approximately 6,000 feet and the annual precipitation is 12 inches or less. Although the experiment was primarily intended to determine the best time and rates for 2,4-D spraying, some of the plots were fenced to exclude grazing and others were left open to grazing. Years later, no significant diferences existed between fenced and unfenced areas in extent of brush reinvasion, plant species composition, or forage production.

The need for deferment following spraying was researched by Kearl (1973) using mail and personal interview surveys. Information was obtained from 78 percent of the ranch operators who had sprayed 200,000 acres of sagebrush in Wyoming prior to 1963. Of the respondents, 61 percent applied no deferment. Moderate stocking or deferment of 1 to 3 months was the rule in 13 percent of the cases while an additional 13 percent of the cases deferred for 4 to 6 months. Deferment of from 7 to 12 months occurred in 8 percent of the cases with deferments of 13 to 14 months in 5 percent. Through 1966, between 553,000 and 617,000 acres of private land was sprayed without any subsequent deferments. Much of this sagebrush, which was sprayed in the early years of Federal cost-sharing programs, did not need respraying in the years 1967 and 1968. The ranch operators involved did not anticipate a need for respraying in the immediate future.

Much of the spraying in Wyoming was done at elevations from 4,000 to 9,100 feet with precipitation ranging from 10 to 20 inches. Under these conditions, there is a question about whether deferment is needed. If it is not needed, it could mean as much as 11.43 percent (27.05 percent minus 15.62 percent, Table 5) greater internal rate of return.

One might be led to conclude that nonuse is not required to obtain the expected increases in yield after spraying. The reader will have to arrive at his own conclusion about nonuse. The 1966 Wyoming data do seem to indicate that nonuse may not be necessary in all situations. Further study needs to be undertaken and data-based guidelines made available to range managers. If nonuse is not required, the rate of return is significantly enhanced and ranchers could avoid one of the most difficult problems they face when contemplating a range spray project--What will I do with my livestock during the nonuse period?

Other Factors Affecting the Economic Success

Obviously, the duration of any deferment required alters the magnitude of the internal rate of return on a given big sagebrush control project are the vigor index and pretreatment forage production.

The vigor index of a range site is determined by such factors as soil and air temperature, light, soil nutrients, and annual precipitation; the latter 2 being the most important. Each of these factors must be in sufficient abundance or forage will not respond significantly to sagebrush control. The vigor index is often called the sagebrush vigor index because, where big sagebrush grows vigorously,

so should grasses and other desirable forage. Of course, as with any rule of thumb, there are exceptions.

Secondly, pretreatment and posttreatment forage yields are directly related. If a range site is only producing 150 pounds of air-dry forage per acre prior to treatment, even with a threefold increase, post-treatment forage yields would only be 450 pounds per acre air-dry. In contrast, a pretreatment yield of 300 pounds per acre air-dry when increased threefold to 900 pounds per acre air-dry. Although both increased threefold, the second will realize a higher internal rate of return. So treat the best areas first!

Appendix B

To demonstrate how different assumptions about nonuse costs affect the internal rate of return, 6 different examples are analyzed.

The first analysis will utilize the formula

$$I = R\left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

with deferred grazing (type of nonuse) being the only variable. Data used are found in Table 1 of the text.

Case 1-A

The sprayed rangeland is deferred for 2 full grazing seasons, and the nonuse cost is added as if it all occurred in year 0.

$5.82 = cost of chemical treatment per acre (USFS 1973);
$3.98 = market value per AUM;
0.2444 = annual AUMs per acre prior to treatment;
0.4185 = annual increase in AUMs per acre after treatment;
$.195 = cost per acre for 2 years of nonuse (0.2444 x $3.98 = $.97, value of nonuse per acre x 2 years);
$1.67 = value of AUM increase (0.4185 x $3.98).

$$I = R\left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

I = $5.82, cost of chemical treatment per acre (USFS 1973), + $1.95, cost per acre for nonuse during year 0 = $7.77.

R = $1.67, value of AUM in annual returns per acre in year 1 through year 12.

n = 12 years.

$$7.77 = 1.67\left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

$$\frac{7.77}{1.67} = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

$$4.67 = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

By using present value tables, the internal rate of return is between 18 and 19 percent.

Case 2-A

The sprayed rangeland is not grazed for half the grazing season each of the next 2 years and the nonuse costs are added as if they all occurred in year 0. It is grazed after grass seeds are set, but at only half the potential stocking rate. Thereby, new seedlings can become established and nonuse costs are half those of full deferment.

I = $5.82, cost of chemical treatment per acre (USFS 1973) + $.97*, cost per acre for 2 years nonuse, = $6.79.

R = $1.67, value of AUM in annual returns per acre in year 1 through year 12.

n = 12 years.

$$\frac{6.79}{1.67} = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

$$4.07 = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

The internal rate of return is between 22 and 23 percent.

Case 3-A

No deferment is used following spraying.

I = $5.82, cost of chemical treatment per acre (USFS 1973).

R = $1.67, value of annual grazing increases per acre in year 1 through year 12.

n = 12 years.

$$\frac{5.82}{1.67} = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

$$3.49 = \left[\frac{1 - (1 + i)^{-n}}{i}\right]$$

The internal rate of return is between 27 and 28 percent.

Calculating the internal rate of return when nonuse costs are accounted for in the years in which they occur is an involved trial and error process. The methodology can best be understood if it is set out in algebraic form. The data used are the same as used above from Table 1 (text).

Case 1-B

Given the same assumptions about nonuse as in Case 1-A:

I = $5.82, cost of chemical treatment per acre (USFS 1973), + $.97, cost per acre for nonuse during year 0, = $6.79.

R = $1.67, value of AUM in annual returns per acre in year 2 through year 13.*

n = -$.97 during year 1 (nonuse cost).

Since the income stream is not constant over the 13 years, each year's income must be discounted separately (Appendix Table 1).

It is known that the internal rate of return will be lower than 18 percent (Case 1-A). Using 15 percent, the sum of the discounted annual returns ($7.03) is greater than the cost incurred in year 0 ($6.79), therefore, the internal rate of return has been underestimated (Appendix Table 1). A higher rate is selected, for example 16 percent, which results in the internal rate of return being overestimated, because the sum of the discounted annual

*See footnote at bottom of Appendix Table 2.

*See footnote at bottom of Appendix Table 1.

returns ($6.65) is less than I ($6.79).

This iterative process is continued until the sum of the discounted returns converges on the costs incurred in year 0. By this process and using interpolation, the internal rate of return (i) is about 15.62 percent. Therefore, at a discount rate of 15.62 percent, I ($6.79) is equal to the sum of the annual discounted returns ($6.79).

Case 2-B

Given the same assumptions about nonuse as in Case 2-A:

I = $5.82, cost of chemical treatment per acre (USFS 1973), + $.59, cost per acre for nonuse during year 0, = $6.31.

R = $1.67, value of AUM in annual returns per acre in year 2 through year 12.

R = $.35 during year 1.*

n = 12 years.

The same iterative process is repeated as in Case 1-B. The internal rate of return is 20 percent (Appendix Table 2).

Case 3-B

Since no nonuse is assumed, Cases 3-A and 3-B are identical. The results of these comparisons are summarized in Appendix Table 3.

Although the examples shown in 1-B and 2-B are more difficult to compute, they provide the most accurate estimates of the internal rates of return.

When nonuse costs and benefits are properly handled in the discounting process, they produce lower internal rates of return which may be important in the decision-making process.

*See footnote at bottom of Appendix Table 2.

Appendix Table 1. Nonuse costs and annual return per acre, discounting factors, discounted costs and returns per year when sprayed range is deferred from grazing for 2 full grazing seasons

Year (n)	Nonuse Costs and Annual Returns per Acre (Dollars)	Discounting Factors (Percent) 15	Discounting Factors (Percent) 16	Discounted Annual Costs and Returns (Dollars) (Percent) 15	Discounted Annual Costs and Returns (Dollars) (Percent) 16
1	-0.97	0.869565	0.862068	-0.8434	-0.8362
2	1.67	0.756143	0.743162	1.2627	1.2410
3	1.67	0.657516	0.640567	1.0980	1.0698
4	1.67	0.571753	0.552291	0.9548	0.9223
5	1.67	0.497176	0.476113	0.8302	0.7951
6	1.67	0.432437	0.410442	0.7219	0.6854
7	1.67	0.375937	0.353829	0.6278	0.5908
8	1.67	0.326901	0.305025	0.5459	0.5093
9	1.67	0.284262	0.262952	0.4747	0.4391
10	1.67	0.247184	0.226683	0.4127	0.3785
11	1.67	0.214943	0.195416	0.3589	0.3263
12	1.67	0.186907	0.168462	0.3121	0.2813
13*	1.67	0.162529	0.145226	0.2714	0.2425
I = $6.79			Total	7.0277	6.6452

*Discounting is carried into year 13 because 2 full years of grazing was lost to nonuse.

Appendix Table 2. Nonuse costs and returns per acre, discounting factors, discounted costs and returns per year when sprayed range is deferred from grazing for half of the grazing season for 2 years

Year (n)	Nonuse Costs and Annual Returns per Acre (Dollars)	Discounting Factors 20 %	Discounted Costs and Returns (Dollars) 20 %
1	0.35*	0.833333	0.2917
2	1.67	0.694444	1.1596
3	1.67	0.578704	0.9664
4	1.67	0.482253	0.8053
5	1.67	0.401878	0.6710
6	1.67	0.334898	0.5591
7	1.67	0.279082	0.4659
8	1.67	0.232568	0.3883
9	1.67	0.193807	0.3236
10	1.67	0.161506	0.2697
11	1.67	0.134588	0.2246
12	1.67	0.112167	0.1872
I = $6.31		Total	6.3124

*Income stream for year 1 ($.84 value of AUM for half of year 1 minus $.49 nonuse cost for half of year 1).

Appendix Table 3. Type of nonuse, internal rates of return using 2 calculating methods when controlling big sagebrush with 2,4-D

Type of Nonuse	A	B
	%	%
Case 1--2 years	18.80	15.62
Case 2--half a year for 2 years	22.35	20.00
Case 3--none	27.05	27.05

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