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Conversion Pinyon-Junifer Woodland to Grassland

Richard S. Aro

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CONVERSION OF PINYON - JUNIPER WOODLAND TO GRASSLAND

BY RICHARD S. ARO

WATER RESOURCES DIVISION
GEOLOGICAL SURVEY
DENVER, COLORADO
CONVERSION OF PINYON-JUNIPER

WOODLAND TO GRASSLAND

by

Richard S. Aro
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CONVERSION OF PINYON-JUNIPER WOODLAND TO GRASSLAND

by Richard S. Aro

INTRODUCTION

People have been looking at pinyon-juniper woodlands for a long time, seeing in them different values and wondering what to do with them. Land managers, wildlife conservationists, economists, hydrologists, ranchers, and others have sought answers to pinyon-juniper management problems and each retains an important stake in finding solutions.

Any land resource which has the potential for producing a variety of products will naturally receive the attention of varied interested parties. When that resource is also public, the plot thickens and the roles played by the principals merge inextricably. Such is the case with much of the pinyon-juniper woodland type in the United States. Several public resource management agencies, both federal and state, are obliged to maximize the social good from this widespread vegetation type. In some cases, management goals differ sufficiently among agencies to create troublesome conflicts that impede efficient resource utilization. Sometimes the practices or beliefs of an agency may even be in serious, if unnecessary, conflict with its own needs. Not all, by any means, of the aims, attitudes, or actions of any agency are at odds with the realities of pinyon-juniper management. However, sufficient uncertainty exists with regard to optimum land use allocation and treatment practices in this vegetation type to warrant an examination of the physical problem and the management alternatives.
Fisher (1963) as president of Resources for the Future, observed that, "Certain changes and new emphases raise the disturbing thought in the minds of many that serious inconsistencies exist within the conservation programs now being pursued in this country and that serious mistakes are being made. These apprehensions should not be repressed but should be opened to full view through the approaches of research and analysis so that they may be understood and corrected."

The present study is the result of a joint desire of operations and research leadership in the Department of the Interior to evaluate one aspect of pinyon-juniper management—the conversion of woodlands to grasslands. It is part of a comprehensive examination of land treatment practices on public lands of the western states which is being conducted cooperatively by the Bureau of Land Management and the Geological Survey. The present investigation has included two phases (1) an examination of ecologic criteria for conversion of pinyon-juniper woodlands to grasslands, and (2) an evaluation of actual conversion practices. This report includes some material from phase 1, but puts major emphasis on the ecologic and economic implications of pinyon-juniper treatments.
The author gratefully acknowledges the help of all those with whom he worked during the investigation, in particular, Allen LeBaron, Center for Social Science Research on Natural Resource Problems of Utah State University, the men of the Bureau of Land Management district offices, and Farrel A. Branson, Lynn M. Shown and Charles C. Hammill, U.S. Geological Survey, Denver, Colorado.
ECOLOGY OF PINYON-JUNIPER WOODLANDS

General Description

The pinyon-juniper woodland has also been called the pigmy conifer community, the pigmy forest, the juniper-pinyon forest, the cedar-pinyon woodland, the western xeric evergreen forest, and by several other names, some of which probably were prompted more by economic evaluation than by semantic precision. Whatever its value, the pinyon-juniper zone is large. Moessner (1962) estimated its area at 51 million acres in Arizona, Colorado, Nevada, New Mexico and Utah, or roughly two and one half times the total acreage of commercial forest land in those states. A federal report listed the total area of the pinyon-juniper range type as 74 million acres (U.S. Congress, 1936). An earlier estimate by Dayton (1931), based on Shantz and Zon's natural vegetation map of the United States, gave the area of pinyon-juniper in the West as approximately 83 million acres.

Most of the pinyon-juniper woodland lies between 5,000 and 7,000 feet in altitude and receives precipitation of 10 to 14 inches annually. Pinyon-juniper woodlands occur on a wide variety of lithology including sandstone, limestone, basalt, and the soils derived from them. The woodland usually grows in "scattered stands between the desert or grassland below and the true forest of the yellow pine belt above" (Sampson, 1925). According to Woodbury (1947), the upper limits of the zone in Utah and northeastern Arizona vary from 6,500 feet on north-facing slopes on the Kaibab
Plateau to about 8,400 feet on south-facing slopes of the Book Cliffs in east-central Utah. He gave 5,200 feet as the typical lower limit for pinyon-juniper in the Great Basin and Colorado Basin, with a possible extreme low for the type in that region at 3,200 feet near St. George, Utah. Johnsen (1962) reported that one-seed juniper "may be found growing from about 3,000 feet in the upper parts of the deserts to above 7,500 feet in the ponderosa pine forests."
The author has observed outliers of one-seed juniper down to 3,000 feet along the southeastern limits of the coniferous woodland in Texas.

Flora and Fauna

Plant species are few in the typical pinyon-juniper woodland. Colorado pinyon (*Pinus edulis*) and either Utah juniper (*Juniperus osteosperma*) and one-seed juniper (*J. monosperma*) are the only important tree species in the community through most of its range. Utah juniper is the usual codominant with pinyon in Nevada, Utah, western Colorado and northwestern Arizona. One-seed juniper normally occurs with pinyon from north-central Arizona through New Mexico and into Texas and parts of southern Colorado. However, since Utah juniper and one-seed juniper are so similar, both taxonomically and ecologically, the academic distinctions between them will be ignored, and hereinafter "juniper" will refer to either or both of these species. In Nevada, and at some localities in western Utah and northwestern Arizona, single-leaf pinyon (*P. monophylla*) is the codominant with one of the junipers, and also frequently occurs in nearly pure stands. Rocky Mountain juniper (*J. scopulorum*) is found
over most of the range of pinyon-juniper woodlands, usually at the upper altitudinal levels, if present, but seldom as a dominant in the mixed community.

Shrubs and half-shrubs which are commonly present with pinyon-juniper stands include:

- Mountain-mahogany (Cercocarpus sp.)
- Antelope-brush (Purshia tridentata)
- Service-berry (Amelanchier sp.)
- Cliff-rose (Cowania mexicana)
- Apache-plume (Fallugia paradoxa)
- Big sagebrush (Artemisia tridentata)
- Black sagebrush (A. nova)
- Rabbit-brush (Chrysothamnus sp.)
- Joint-fir (Ephedra sp.)
- Oak (Quercus sp.)
- Yucca (Yucca sp.)
- Prickly-pear (Opuntia sp.)
- Snakeweed (Gutierrezia sarothrae)
- Wild-buckwheat (Eriogonum sp.)
Grasses have been severely depleted by grazing and tree competition in much of the pinyon-juniper type, but species that are still encountered frequently are:

Indian ricegrass
Needle-and-thread
Squirreltail
Junegrass
Galleta
Western wheatgrass
Bluebunch wheatgrass
Slender wheatgrass
Blue grama
Side-oats grama
Ringgrass
Downy chess
Three-awn

Oryzopsis hymenoides
Stipa comata
Sitanion hystrix
Koeleria cristata
Hilaria jamesii
Agropyron smithii
A. spicatum
A. trachycaulum
Bouteloua gracilis
B. curtipendula
Muhlenbergia torreyi
Bromus tectorum
Aristida sp.

Pinyon-juniper woodlands provide food and cover for a variety of animal life, most notably the mule deer (*Odocoileus hemionus*). Populations of coyotes (*Canis latrans*), porcupines (*Erethizon dorsatum*), rabbits (*Lepus* sp.), mountain quail (*Oreortyx pictus*), mourning doves (*Zenaidura macroura*) and lesser numbers of elk (*Cervus canadensis*), mountain lions (*Felis concolor*), bobcats (*Lynx rufus*), golden eagles (*Aquila chrysaetos*) and wild turkeys (*Meleagris gallopavo*) spend time in these habitats, along with various other creatures, including man and his livestock.
Invasion and Occupation of Grasslands by Pinyon-Juniper

One of the big concerns of range users and managers has been the extent of pinyon-juniper invasion of adjacent grasslands. A variation of the same phenomenon is the thickening of tree stands that changes open savannahs into closed woodlands. These conditions raise the obvious question, "What causes the expansion of the pinyon-juniper woodland type, to the detriment of the associated grassland communities?" Many answers have been advanced, some supported by solid research evidence, others with convincing, if less scientific, arguments. Of course, the ecologic issue of changes in the spatial relationships between pinyon-juniper woodlands and grasslands is very pertinent to the practical matter of woodland-grassland conversion. So-called invasion sites not only provide a certain amount of political and economic impetus to remedial action, but they also may indicate, without further interpretation, where conversion efforts will succeed.

Causes of Invasion

Although it was not a purpose of this investigation to find causes of pinyon-juniper expansion, it may be useful to review what others have reported on the subject. Referring to the vegetation types of Arizona, Nichol (1943) said unequivocally, "Every evidence points to the fact that many acres that were at one time mainly grassland, with a scattering of juniper and pinon trees, now have rather dense stands of juniper reproduction brought about by the grazing influences of domestic stock." Humphrey (1950), in a description of the pinyon-
juniper type in Yavapai County, Arizona, said, "Much of the area where juniper grows today as pure stands was once open grassland."

He suggested that the grasslands invaded by juniper could be told from those that originally supported pinyon and juniper by the general absence of the pines and by the age of the junipers. He said of the invasion stands, "Few or none of the trees are old and gnarled and the oldest all appear to be about the same age." The same could be held generally for much of the pinyon-juniper type in Arizona and New Mexico, though not so comfortably north of the 37th parallel.

Heavy grazing was suggested by Mason (1963) as the cause of increases in big sagebrush and invasion of juniper on a former blue-bunch wheatgrass site in northern Utah. Woodbury (1947) tied pinyon-juniper expansion to the destruction of grass in southwestern Utah, saying that the woodland boundary has extended into the lower sagebrush and grasslands during the historic period. He felt that there was a tendency for pinyons to follow the junipers in the invasion of new area, based on the observation of pure juniper stands at the periphery of invasion and mixtures with pinyon farther back from the edge. Arnold (1959) pointed out a decline in forage production due to "invasions of grasslands by juniper, pinyon, and associated woody plants and the thickening up of established stands." He also made measurements of vegetation within plots that had been fenced for 13 years and on adjacent grazed ranges and reported that, "Contrary to popular opinion results indicate that grazing slows up the growth and spread of juniper and pinyon." Arnold's data showed that perennial grasses and weeds decreased one-third in ground cover between 1940 and 1953 within the fenced plots, where tree and shrub canopy
increased three times. On the open range during the same period there was a 20 percent loss in cover of perennial grasses and weeds, while the canopy of juniper, pinyon and shrubs doubled. Miller (1921) felt that grazing animals may have reduced juniper seedling survival on grama grassland areas in northern Arizona. In any case, there is good evidence now that reduction or elimination of livestock grazing and subsequent recovery of grasses to heavy production are not always enough, by themselves, to prevent the expansion of pinyon-juniper woodland. Jameson (1962) documented one example of this problem on a galleta-black grama grassland about 25 miles north of Flagstaff, Arizona. In 1907 much of the area was severely overgrazed grassland with only a few scattered one-seed juniper trees. After a half-century of management, which featured grazing reduction and fire protection, the grasses had regained a pristine-like condition and the juniper stand had increased to about 60 trees per acre. Some factor or factors, other than grazing, must be involved in the maintenance of treeless grassland areas and open savannahs in the pinyon-juniper zone. Pearson (1931) offered what may be, to many, a reasonable explanation, namely, that one-seed juniper, Utah juniper and pinyon are very sensitive to fire and "large areas of woodland have been completely wiped out by this agency, probably in conjunction with bark beetles," He said, "Such areas may become grasslands, or, where overgrazing has followed fire, they may grow up to brush. . . . If fires are kept out of woodland burns, the trees come back in time, especially within the range of Utah juniper, which is particularly
aggressive as an invader of new territory." Arnold and Schroeder (1955) felt that "Before (white) settlement, the spread of juniper was probably repressed by repeated wildfires."

The most satisfactory hypothesis for the cause of pinyon-juniper invasion of grassland seems to rest on two critical factors, the removal of herbaceous ground cover and the reduction in grass fires in the woodland zone. As Johnsen (1962) summarized in his excellent treatment of the problem, "It appears that much of what is called juniper invasion is occurring in former juniper savannahs and grass-land inclusions within the pinyon-juniper woodlands. These areas were probably maintained as open stands or grasslands in the past by competition and frequent grass fires."

There is little doubt that invasion of adjacent plant communities by pinyon-juniper woodlands has taken place in many parts of the Southwest; also, that the phenomenon is more general, and more widely discussed, in Arizona and New Mexico than elsewhere. (Perhaps a north-south gradient of climatic factors is associated with the apparent increase in pinyon-juniper invasion from central Utah to northern Arizona.) But more pertinent to the present discussion than "how," "whether," or even "where" pinyon-juniper may be occurring is the question, "Which sites should receive conversion treatments?"
Relations of woodlands to grasslands and soil factors

In addition to various socio-economic considerations, some of which will be discussed later, the problem of site selection raises several closely related ecologic questions. First, what is a "true" pinyon-juniper site as compared to a "true" grassland site? Identification of invasion and expansion types may help answer this, but will provide only a partial solution. From the standpoint of treatment action it may matter little whether the trees to be eliminated have invaded the place or have deep ancestral roots in the site. Many pinyon-juniper woodlands that would be considered as climax communities for their sites occupy land that has high potential for conversion to grassland. The need in this context is to define a grassland site, because, essentially, its characteristics should be the same as those of the best treatment (conversion) sites.

Careful delineation of treatment sites for pinyon-juniper conversion projects depends on how well the critical environmental factors are defined for each plant community involved. This is not to suggest that society really wants (or knows that it wants) a grass cover on all of the pinyon-juniper acreage that is suited to such conversion; but land managers must know where to produce the grassland benefits that society requests. In terms of land economics, there may be no real significance in locating former grassland now occupied by pinyon-juniper woodland. Greater good would come from deciding how much of each available vegetation type is needed by society, then determining where and how to obtain it or to maintain it. It is largely academic
whether or not a particular pinyon-juniper woodland is a "true climax" community for the site unless it is determined, on intelligent grounds, that pinyon-juniper vegetation is unwanted at that location, or that a replacement type, be it wheatgrass or watermelon, is valued higher. Thus, the problem is more basically one of land classification than of vegetation conversion; but assuming that the need is clear for a change from pinyon-juniper to grassland, the general, yet practical, question of the land manager is, "What are the best ecologic criteria for planning the conversion?"

Soil moisture

Soil moisture availability is the major factor controlling plant community patterns in the pinyon-juniper zone. Availability of moisture to plants under semiarid conditions involves a complex interaction among a number of soil and climatic parameters. Greatest in importance of these are: amount of precipitation, temporal distribution of precipitation and physical properties of soils. These combine to influence the amount of water stored per unit of time, per unit of precipitation, and per unit of soil depth. But the amount of soil water stored is only part of the moisture availability picture. The stress with which water is held by the soil is also an important ecologic variable. Total soil moisture stress opposing water withdrawal is made up of two components—a matrix suction caused by pressure phenomena that occur between soil water and soil particles, and a solute suction which is often referred to as the osmotic pressure of the soil solution (Marshall, 1959).
The relationship between soil moisture tension and percentage of moisture in soil varied characteristically with soil texture. Fine-textured soils retain a greater percentage of moisture, by weight, between field capacity and the upper tension of moisture availability to plants; but a higher percentage of the available-water capacity of coarse-textured soils is held at low tension levels. Accordingly, if plants were to extract water at the same rate from various soils, the matrix suction would increase more abruptly on approaching the upper tension of availability in the coarse-textured soils than in the fine-textured soils. In other words, the length of time during which plants would be subjected to conditions of high soil moisture stress short of the availability limit would be less on coarse-textured than on fine-textured soils (Black, 1957).

Under given conditions of climate and geologic parent material, soil texture and rockiness determine the presence and distribution of woodland and grassland communities in the pinyon-juniper zone. Trees prevail on the coarser, rockier sites, whereas herbaceous vegetation characterizes the finer textured soils. This is only one example of the much more general nature of plant community patterns in dry regions, i.e., under the same conditions of climate, coarse soils support plants with a higher moisture requirement than do fine-textured soils. (The reverse may be true in areas that receive more than 30 to 35 inches of precipitation annually, where soil moisture may be stored to great depths even in fine-textured soils, or where leaching of essential elements from coarse soils may result in dominance by
species that have high tolerance for nutrient deficiencies.) Coarse, rocky soils generally have higher infiltration and percolation rates and lower total porosity than do fine-textured soils, and therefore store more precipitation per unit of time and to greater depths per unit of precipitation, though less moisture per unit of depth.

Trees and shrubs, which usually have extensive root systems, can thrive on coarse, rocky sites where there is little runoff and most of the precipitation can penetrate the loose soil mantle to considerable depth. Grasses, with fibrous, compact and generally shallower root systems may also grow on such sites, but are much better adapted than are most woody species to fine-textured soils. Unless runoff is ponded on a fine-textured site or shrinkage cracks allow rapid infiltration even during high intensity storms, the amount of atmospheric moisture that becomes available for plants on a sandy or rocky site will probably be much greater than the moisture which is stored and released to vegetation on an adjacent fine-textured soil.

The view in figure 1 shows a pinyon-juniper woodland, in the foreground, growing on a hill of interbedded limestone and shale, and, in the background, a mixed ponderosa pine-pinyon-juniper woodland on sandstone which outcrops along a canyon. The grama grassland between the two woodland types is growing on a fine-textured, mixed alluvium. Figure 2 illustrates the same general relationship, with ponderosa pine on granite outcrops surrounded by mixed prairie on fine-textured soil.
Figure 1.--Woodlands on stony sites near Las Vegas, New Mexico.

Juniper-pinyon woodland in the foreground is growing on a dome-shaped hill composed of interbedded limestone and shale. In the background, ponderosa pine and a scattering of pinyon and juniper are restricted to a narrow zone of sandstone outcrops and shallow sandy soil along the canyon of the Gallinas River. Grama grassland occupies the finer-textured alluvial soil between the woodland communities.
Figure 2.--Ponderosa pine on granite ridges near Virginia Dale, Colorado.

Sharp contrasts between the woodland on stony soils and the grassland on adjacent fine-textured alluvium emphasize the dominance of soil moisture properties in controlling distribution of plant communities in this area.
Conditions such as these are obvious and widespread in most areas that receive less than 35 inches of precipitation annually, yet few reports describe or explain the relationships of woodland-grassland ecotones to soil texture and development. In his investigations of the ponderosa pine zone, which included many references to pinyon-juniper, Pearson (1931) found that in areas with similar geology the growth of trees was usually best in the more sandy or gravelly soils. He observed that, "This relation is so general in the Southwest that texture appears to be more important than chemical composition, particularly in the growth of seedlings." Merkle (1952), describing a pinyon-juniper community at Grand Canyon, Arizona, said, "The soils are shallow and mechanical analysis indicated that this and the ponderosa pine community are found on the same soil types, generally high in sand and clay." The observations of Harper (1941) from western Oklahoma, though outside the pinyon-juniper region, are consistent with the relationships described above. He found that the surface soil must have less than 20 percent clay "in order that a sufficient amount of moisture will be absorbed to maintain a satisfactory growth of trees." Harper reported that the severe drought of the mid 1930's had killed up to 50 percent of the large trees in many areas of woodland where xerophytic species occurred on shallow soils or mesophytic types grew on soils containing a high percentage of clay. He also remarked, "A decrease in total rainfall reduces the depth of penetration and the quantity of available moisture in fine-textured soils and favors the development of grass as a climax type of vegetation."
Sharp breaks between woodlands and other communities are often related to abrupt changes in lithology, which are especially common on active or bedrock surfaces. Figure 3, shows juniper occurring only on the sandstone caprock and talus, whereas a more desert-like Nuttall saltbush community clings to the adjacent, fine-textured, shale-derived material.

One of the most significant contributions toward an understanding of soil-plant relations was made by Lincoln Ellison in his study of subalpine vegetation of the Wasatch Plateau in central Utah (1954). He was perhaps the first to point out, with solid supporting evidence, that, "herbland communities, because they are associated with gentler slopes and deeper, more rock-free soils, are more advanced successional than either shrubland or forest communities," i.e., "succession has proceeded from conifer and shrub communities to a herbland community, and not the other way around." Ellison rattled another bone in the skeleton of the traditional concept of primary succession by stating that the "influence of lichens and mosses in disintegration of limestone appears to be slight, as compared with direct atmospheric weathering." Though much of the area in which Ellison made his measurements and interpretations receives twice the average precipitation of the pinyon-juniper type, his description of primary succession on talus slopes of warm, dry exposures would bear a valid resemblance to the lower woodland zones. He said that, "spruce and fir invade deep crevices as pioneers . . . . A few tall shrubs and some forbs and grasses also occur in such crevices, but spruce and fir are more conspicuous . . . . As the rocks disintegrate
Figure 3.--Juniper on sandstone caprock and talus near Grand Junction, Colorado. The coarse-textured sandstone provides a favorable soil moisture environment for tree growth but underlying shale-derived soil holds moisture with such high stress that it supports only a xerophytic Nuttall saltbush community.
and spaces between them become filled with soil, trees and shrubs
become denser, with an understory of tall forbs and grasses
characteristic of the herbaceous climax. Eventually, with more
complete disintegration of the rock, deepening of the soil, and
occupance of the soil mass by the fine roots of herbaceous species,
woody plants fail to be replaced, and a mixed forb-grass climax
results. The transition may be directly from mixed trees and shrubs
to herbland or by way of an intermediate stage in which few trees are
present and shrubs are dominant."

A description of similar relationships in the pinyon-juniper
zone was furnished by Woodbury (1947). He noted that, "discon-
tinuities within the forest occur mainly in valleys, canyons, mesas
or shallow washes where the pigmy trees occupy the rough rocky or
coarse soil areas and the finer soils of the bottoms bear other
types of vegetation." Woodbury illustrated an example of two kinds
of cover (pinyon-juniper and big sagebrush) "on two types of soil
lying side by side where there could be no significant differences
in either precipitation, insolation, air pressure, wind, relative
humidity, evaporation or air temperatures." He suggested that the
most satisfactory explanation for this zonation of plant cover rested
with the moisture supplying conditions of the two soils, that the
coarse types provided "more available water to the trees." Woodbury
felt that the conifer woodland was spreading from restricted centers
on rocky hills to surrounding portions of the same type and to coarse
soils of the flats, but in general was not invading the finer soils.
Similarly, in Arizona, Miller (1921) remarked that parklike areas having dense compact soil and covered by a grama grass sod were always deficient in juniper reproduction. Johnsen (1962) commented on the numerous stands of one-seed juniper with microclimatic and soil variations which result in habitats that are more moist than surrounding grassland. He said that the junipers maintain themselves on these generally rockier sites but are not invading the adjacent grasslands.

However, pinyon and juniper, especially the latter, do grow on non-rocky soils, even if these are less suitable sites for them. Mason (1963) offered this perspective, "Numerous historical records indicate that pinyon pine and juniper were the climax vegetation on stony, shallow sites. Today, they are classed as increasers on these sites. The deep soils and those relatively free of stones had a dense cover of grass, forbs, and shrubs in which juniper and pinyon pine could not compete until after man's grazing herds removed a large part of this cover. On these sites pinyon and juniper are classed as invaders." Historical records (Simpson, 1859; Mason, 1963) indicate that an abundant grass understory was common in pinyon-juniper woodlands prior to livestock grazing. Stoddart and Smith (1955) disagreed, saying, "Except where juniper has invaded grasslands it is doubtful whether much of this region ever produced an abundance of forage, though it was the source of valuable early-spring feed."
Woodbury mentioned another example of the influence of soil texture on effective precipitation and plant distribution. On a site at an altitude of 3,200 feet in southwestern Utah pigmy conifers occur on sand about 500 feet below the presumed 10 inch precipitation line. He said that, "In contrast with adjacent clay soils, the sand would absorb more of the precipitation without runoff, would permit the water to percolate to a greater depth much faster, would lose much less water from the surface by evaporation, and would hold a much smaller proportion of the water adsorbed to the sand particles below the wilting coefficient level. The extra moisture yield of the sand would thus seem to be approximately equivalent to the extra precipitation yielded by adiabatic effects in 500 feet of altitude."

The same effect was noted in the present investigation and can be seen within the pinyon-juniper woodland in an area north of the Mogollon Rim in east-central Arizona. Pinyon-juniper woodlands there cover the limestone ridges at about 6,200 feet in a 12 inch precipitation zone. Ponderosa pine occurs just below the ridges on sand dunes which apparently increase the effectiveness of the precipitation by at least one-third.

Emerson (1932) made some interesting observations on the rooting habits of pinyon and juniper trees relative to grasses in a study of woodland-grassland associations in northeastern New Mexico. He found that grass roots usually penetrated downward 30 to 40 centimeters, or about the depth to which non-rocky soils were wetted by precipitation. Pinyon and juniper, with more generalized root systems, were
well adapted to rocky sites. They had both lateral roots, growing in a horizontal zone 15 to 40 centimeters below the soil surface, and vertical roots penetrating to the bedrock and along rock surfaces where water accumulated. Thus, pinyon and juniper trees can compete directly with grasses for soil moisture in the upper 30-40 centimeters, yet have practically no competition for water in the deeper layers of soil.

Johnsen (1962) described essentially the same kind of root distribution in one-seed juniper. He found that, "The taproots of mature trees ranged from 18 in. to more than 12 ft. in length," and "The lateral roots were usually widespread, commonly being 2.5 to 3 times as long as the tree was tall... usually in the surface 3 ft. of soil, occasionally growing deeper but most concentrated below the surface 6 in." Referring to competition between trees and grass, Johnsen observed that, "... site domination by one-seed juniper is very noticeable with trees 2 or 3 ft. tall on sandy soils, but may not be apparent until the trees reach 6 ft. on clay soils." He attributed this to greater root development and moisture penetration on the coarse-textured soils, on which sites the tree with deeper roots would be favored. The shallower rooted grasses were in a more favorable competitive situation on the fine-textured soils.
Criteria for site classification

A study of woodland-grassland ecology was begun by the writer in 1962 to define ecologic criteria for the conversion of pinyon-juniper woodlands to grasslands. First, an extensive reconnaissance was made of the pinyon-juniper type and associated grasslands in Arizona and New Mexico. One site in New Mexico and two sites in Arizona were selected in 1963 for more intensive examination of vegetation and soils. The sites, between 6,200 and 6,400 feet in altitude, are within the latitudinal belt from 34°30' N. to 35°30' N. at the following longitudes: 105°15' W., 110°30' W., and 112°15' W. The average annual precipitation for all sites is approximately 14 inches.

Each site had a mixed pinyon-juniper woodland on a rocky limestone hill above a grama grassland on finer textured locally-derived materials. A sampling panel was laid out on each site perpendicular to the general contour of the southwest slope from the top of the hill down onto the grassland at the foot. The panels were 20 meters wide, with dividing lines extending from side to side each 10 meters, which provided contiguous 10- by 20-meter sampling plots. In each of these plots the number, species and basal diameters of trees in each of four height classes were determined. Relative amounts of bare soil, surface stones, mulch and basal cover of herbaceous vegetation were measured with a point frame. Pins were lowered vertically to make one contact per pin on the various surface features at 5 cm
intervals along transects provided by the sides of the sampling panels. A hit on stone was recorded for contact with any rock fragment that was large enough to be readily discernible from surrounding materials and on which the point frame pin would rest when the pin was not being steadied by the operator. The resulting effective minimum diameter for stones was about 2-5 mm. Soil samples were taken in each plot or vegetation type. Infiltration rates were measured at the two Arizona sites.

Pinyon trees were larger and more abundant toward the tops of the hills, but in all cases at least a few young pinyons were found at the lower edges of the woodlands. Figure 4 is a general view of the northeast-facing slope of the New Mexico sampling site, showing the "true" pinyon-juniper woodland crowning the hill and the young junipers invading the grama grassland below. Junipers, present throughout the stands, were more numerous than pinyons on the middle and lower slope segments, which properly should be called juniper-pinyon communities. Shrubs were scattered at all levels in the woodlands. Junipers were the only woody species that had made significant advances onto the surrounding grasslands. The smaller sizes of these invading trees, relative to trees on the stonier sites, was in itself a key factor in determining the grassland-woodland break. The lower limit on the slopes of pinyon also served as supporting evidence of the original woodland boundaries. Examples of the pinyon-juniper woodland, juniper-pinyon woodland, and juniper-invaded
Figure 4.--Sampling site near Las Vegas, New Mexico

A. Pinyon-juniper woodland on limestone which caps hill.

B. Juniper-pinyon woodland on mixture of limestone and underlying shale at mid-slope.

C. Juniper-invaded grama grassland on fine-textured alluvium at base of hill.
grassland "types" on one sampling panel of the New Mexico site are shown in a series of photographs in figure 5. Cotner (1963b) observed that pinyon does not invade grasslands as readily as do one-seed and Utah juniper, which he referred to as, "the principal invaders of open grassland at the lower elevations." On sandy soils or under higher precipitation, the presence of young pinyons neither confirms the site as original woodland habitat nor precludes the case for woodland invasion of an adjoining type. But the apparent higher moisture requirement of pinyon compared with juniper provides a useful, and sometimes very sensitive, ecologic tool for delineating dynamic woodland vegetation patterns. By keeping in mind the multiple effects that site lithology and soil development have on effective precipitation, it is obvious that the systematic arrangement of species and communities is an integrated expression of edaphic, climatic and genetic characteristics. At a given locality juniper can survive and reproduce on sites that are less stony and less "climate-modifying" than those to which pinyon is adapted. Except as noted above, pinyon seldom invades grasslands, even where juniper may be an aggressive invader. The differential response of these species to soil moisture conditions can aid the observant land manager in distinguishing invasion sites from original pinyon-juniper habitats.

Slope profiles gave expected agreement with vegetation-soils relations. Narrow ecotones between woodlands and grasslands were recorded at the topographic breaks from stony upper slopes to non-
Figure 5.—Woodland on limestone hill near Las Vegas, New Mexico. Pinyon is the dominant tree on the stonier soils at the top of the hill. Juniper is more abundant than is pinyon on the lower part of the slope and is invading the grama grassland in the foreground.
stony, gently-sloping lower transect segments, which characterized each sampling panel. The slope on woodland portions of transects averaged 25 percent. Ends of sampling panels on the grasslands had an average slope of about 15 percent, which was steeper than would have been recorded had the transects been extended farther out into this type. But again this raises the question of how the break between a grassland and a woodland can be determined other than a subjective basis. The answer is that such a line cannot otherwise be drawn, because the very concepts, "grassland" and "woodland," are subjective and arbitrary. Nonetheless, reasonably valid ecologic criteria can be set for defining pinyon-juniper woodlands and adjacent grasslands that may serve the practical need to classify and manage both types of site, though they may be jointly obscured in an area by a mixed cover of original and invasion woodland.

The most consistent indicator of an original pinyon-juniper site is the stoniness or coarseness of the soil. Such sites range from limestone ledges, with fine-textured soil contained in scattered fractures to deep, uniform, sand dune deposits; but the ecologic effects of geologic materials such as these may be essentially the same. Rapid infiltration, deep penetration and low soil moisture tension at these sites favor dominance of woodland over grassland. The data supported these and earlier observations on the association between soil stoniness and growth of woody plants, as well as the inverse pattern with regard to grass cover. Figures 6, 7, 8 and 9 provide a visual comparison of the vegetation and soil characteristics on
Figure 6.--Woodland on limestone ridge near Heber, Arizona. This view of a sampling site shows the compatibility between tree growth and stony, immature soils in an arid climate. It is reasonable to assume that this site was never grassland.
Figure 7.--Soil pit on site shown in figure 6. Fractured limestone bedrock is covered by layer of stony soil about 40 centimeters deep that contains a wide range of particle sizes. The effect on soil moisture relations is favorable to growth of woodland.
Figure 8.--Woodland-grassland contact near Heber, Arizona. Vegetation break is related to soil differences (see figures 7 and 9) that control the amounts, location and resistance to withdrawal of the moisture actually available for plant growth in each community. Moisture availability may differ greatly, though sites are side by side in the same macro-climate.
Figure 9.--Soil pit on site shown in figure 8. Fine-textured alluvium is rather uniform to a depth of at least 50 centimeters. Root indicates ability of trees to obtain moisture from this soil, even though tree seedlings have difficulty becoming established on a grassland site such as this one.
the woodland type and the sharply contrasting grassland type at one of the Arizona sampling sites.

Moisture-holding properties that soil particles themselves contribute to a stony site are not as important in controlling distribution of plant communities as are the integrated ecologic attributes of fractured rock and its innate mortar of weathered materials. This is borne out by comparisons on both sides of the woodland-grassland boundary. For example, limestone ridge sites, on which the upper 50 to 100 centimeters of substrate may contain over 75 percent rock and the remainder as finely weathered soil material, support the same kind of vegetation for a given climate as a mound of uniformly coarse sand; likewise, the moisture retention characteristics of the fines within the stony soil, as indicated by saturation percentage measurements, were not substantially different from these qualities in the fine-textured, non-rocky, grassland soils obtained downslope. The mixture of rock and soil provides the suitable hydrologic environment for pinyon-juniper woodland. In fact, the presence of a relatively impermeable zone of weathered shale 20 centimeters below a broken limestone pavement apparently aided the vigorous growth of pinyon at the crest of one study site.

Figure 10 summarizes the relationship between vegetation and the stoniness of sites as measured in this study. The tree production index used in the graph was computed by multiplying estimates of basal diameters and heights of all trees included in the sampling plots. Magnitude of the resulting values should be a valid indication of woodland production potential, as well as a guide to the woodland-grassland breaks.
Figure 10.--Relation of trees and grass to stoniness of site near Las Vegas, New Mexico. Hits per 100 pins on rock and grass indicate relative amounts of ground covered by these features. Tree production index is a function of trunk diameters and heights of trees. Sampling plots are numbered consecutively, from number 1 in woodland at the tops of the slopes to number 15 on grassland at the lower ends. Data are averages from slopes on opposite sides of same hill. Trees were pinyon and juniper. Grass cover was mainly blue grama and ringgrass.
The dominant role of texture in determining woodland-grassland boundaries in a semi-arid climate is plainly evident at the sites shown in figures 11 and 12. They are adjacent to each other on a nearly level plain in central New Mexico at an altitude of 6,300 feet and receive the same annual precipitation of about 13 inches. Yet one community is juniper woodland, with a scattered understory of true prairie grasses, such as sand bluestem (*Andropogon halli*), big blue-stem (*A. gerardi*) and little bluestem (*A. scoparius*), and the other community is a typical grama grassland for that latitude. Soil samples were taken from pits at both sites at 10 centimeter vertical increments down to 80 centimeters. The woodland is growing on sand that has a centrifuge moisture equivalent (CME)$^{1}$ of only 2.5 percent, whereas the grassland soil is a silt loam with a CME of 19.1 percent. Almost no rock fragments are present in either soil. The differences between these sites in terms of soil moisture properties offer the most rational explanation for the presence under the same atmospheric environment of two distinctly different natural plant communities having a common, narrow and stable ecotone.

The key to tree growth in the pinyon-juniper zone involves a combination of soil-water factors, (1) efficient infiltration of scarce, and frequently intense, storms; (2) low evaporative losses, because of capillary barriers near the soil surface and/or deep

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$^{1}$Water content of soil at equilibrium in an evaporation-cooled, humidified centrifuge at 1,000 times the force of gravity, expressed as the percentage of the oven dry ($110^\circ$C) weight of the soil sample.
Figure 11.---Juniper woodland on sand near Cedarvale, New Mexico. High infiltration rate, deep percolation and low soil moisture stress apparently combine to make more precipitation available for plant growth on this site than on the adjacent type, shown in figure 12.
Figure 12.--Grama grassland on silt loam near Cedarvale, New Mexico.

Under an average annual precipitation of 13 inches, fine-textured soil in foreground stores only enough moisture to sustain a short grass community, but with same climate the sandy site in background supports a juniper woodland and the tall grasses, sand bluestem and big bluestem.
moisture storage; and (3) low-tension availability of soil water, either due to the inherent moisture characteristics of coarse-textured materials, or as the result of higher levels of soil moisture content caused by impeded percolation. Moisture is what matters, and the interplay of rainfall and rock set how much, how deep, and how tightly held the soil water will be.

Planning conversion of pinyon-juniper woodlands to grasslands involves more than the ecology of these types. Treatment alternatives and other economic considerations enter into the analysis, and, in many cases, govern the action. Allowing for modification by such variables, these emerge as the best ecologic criteria for site classification and conversion planning in the pinyon-juniper type:

1. **Stoniness.**--The relative area covered by stones or bedrock at the soil surface is the simplest and best site factor to use in judging the suitability of a pinyon-juniper woodland for conversion to grassland. A satisfactory rule would be to reject sites which have 15 percent or more ground cover of stones or bedrock.

2. **Slope.**--The steepness of the land surface is a practical feature on which to judge a conversion site. Rejecting slopes greater than 15 percent will minimize the post-treatment erosion problem, and will seldom conflict with the rule for stoniness or exclude significant acreages of invaded or potential grassland.
3. **Species.**—Presence of pinyon may aid in identifying non-conversion sites, but the physical criteria, above, are more basic constraints.
ECONOMICS OF PINYON-JUNIPER RESOURCES

Background

Economics is primarily a study of the way in which we try to produce the things that will satisfy the maximum number of a society's wants (Worcester, 1953). One of the most important branches of our economic life is production. It is the transformation of things less esteemed into more highly valued goods and services; in other words, an act is productive whenever it increases the satisfaction of human wants (Worcester, 1953). Production in our society has many limbs, and out on one of them is the pinyon-juniper problem. Doing something productive with pinyon-juniper woodlands may or may not involve a transformation of them. That depends on what values society attaches to past, present and potential goods and services from these lands. Human evaluation is essential to production (Worcester, 1953).

To properly evaluate these resources, or the methods for modifying them, the various elements of the problem should be kept in true relative perspective. Production is a process of applying human effort, knowledge, and capital to natural resources in order to produce a useful output (Baumol and Chandler, 1954). In other words, the factors of production are land, labor, management and capital goods. Land may be thought of as natural resources. Labor and management are actually two aspects of human resources—the first identified with the expenditure of human energy and the latter tied to the decision-making functions, sometimes called enterprise. Enterprisers determine what will be produced, how it will be done, where
it will be distributed, and in general, take responsibility for determining the manner in which production is carried on (Worcester, 1953). Capital goods are simply produced resources or those natural resources that have been modified by human resources. Specifically, then, pinyon-juniper woodlands constitute a natural resource to which certain produced resources, in the form of capital goods, and human resources, as labor, may be applied by another human resource, the land manager. Capital, labor and managerial expenditures will be treated later. The natural resources of pinyon-juniper woodlands should be mentioned at this point for the sake of "policy perspective." There is a need for decision-makers to see the pinyon-juniper "problem" as something more than just, "How do we replace the trees with grass?" In fact, it is only by seeing and understanding the many facets of the pinyon-juniper resource that managers can write policies and plans that will lead to acceptable solutions. The assumed, though unsubstantial, conflicts among interested parties can best be laid to rest by clear, candid and complete discussion of the goals, desires and needs that each interest is attempting to satisfy. If straight, hard thinking is put to work on developing an integrated approach to pinyon-juniper management, the seemingly irreconcilable conflicts can be largely eliminated.

Resources

What are the natural resources of pinyon-juniper woodlands? From a practical standpoint, the goods and services of these lands may be categorized as follows:
Tree Products

Pinyon-juniper woodlands yield a variety of tree products, including fence posts, firewood, Christmas trees, resins, and nuts.

The actual dollar value of juniper fence posts cut each year would be difficult to estimate, but the material value to land users in the West is substantial. Even with the trend toward their replacement by steel posts, juniper posts still meet a definite need in fence construction and retain a widespread, if lessened, demand. Some public land managers report sizeable annual income from post sales and apparently have no intentions of suspending this phase of their operations.

Firewood obtained from these woodlands falls in two categories, that collected by individuals for their own use in heating and cooking and that cut by commercial operators for resale, especially as fire-place wood. The latter business can attract capital where large metropolitan markets, such as Denver or Salt Lake City, are not too distant.

In recent years the interest in pinyon Christmas trees has brought both individual families and commercial cutters to the conifer woodlands for this traditional forest product. The magnitude and monetary value of these activities is, like firewood production, related to proximity of the source to population centers, and, additionally, to the availability of the particular sizes and shapes of young pinyons desired for yuletide use. Arnold, Jameson and Reid (1964) stated that
pinyon Christmas trees were the most valuable tree product in pinyon-juniper woodlands. These authors also mentioned that, "Charcoal can be produced from pinyon and juniper trees, but it has not been developed commercially" and "The possibility of producing wood molasses, paper, or particle board have not attracted industry because of the high harvesting costs in pinyon-juniper stands."

The value of naval stores produced from southern pines is well known. Two species of pine found in California yield a distinctive resin that contains heptane, which at one time was used as a standard in testing the antiknock properties of gasoline (Champion, 1961). A study was conducted in Arizona to determine whether similar products of commercial value could be obtained from pinyon resin (Deaver and Haskell, 1955). The investigators concluded that unless a valuable chemical component of the pinyon resin could be found, these resins could not be harvested at a low enough cost and in sufficient quantities to compete with resins from other pines or with synthetics. Although these results discourage placing any potential market value on pinyon resin, the chance remains that this raw material may someday satisfy a special need.

According to Champion (1961), pinyon pines yield the only nuts produced by an American coniferous tree that have ever had any importance as an article of food or commerce. He noted that this nut has held an important place in the diet of Indians and Spanish Americans in the Southwest, though those who used the pinyon nut regularly in their diet have become less dependent on it. Champion reported that as much as
6 million pounds of pinyon nuts per year has been marketed, though current crops are estimated at about one-half million pounds. Prices to gatherers have ranged from 50 cents to one dollar per pound, enabling a family group to make as much as 50 dollars for a day's gathering. The value of a current annual crop could go as high as one and one-half million dollars, based on a top retail price of three dollars per pound for shelled and roasted nuts.

Deaver and Haskell (1955) mentioned, in addition to pinyon resin and firewood, the potential for other products, such as charcoal, lumber, paper, and pressed wood that could be harvested from a pinyon-juniper vegetation type. Howell (1941) had made a strong plea for management of pinyon-juniper woodlands to "secure firewood, fence posts, and other valuable woodland products."

Any suggestion to manage pinyon-juniper woodland for what it first of all is, woodland, may be colored by a timber management bias on the part of foresters; but all such notions should not be summarily dismissed even on these grounds. It might be equally just to claim a forage production bias among some range-oriented conservationists as a major cause of the present monolithic approach to pinyon-juniper management on the public domain lands. A discriminating, but balanced, appreciation for all of the important natural resources of pinyon-juniper woodlands is needed.
Livestock grazing

One use of pinyon-juniper woodlands that needs no introduction and little explanation is livestock grazing. However, a great deal of explaining by public land managers may be necessary if present pinyon-juniper management does not meet with greater success in the field and in the eyes of certain unsympathetic observers. There is a critical need for improvement of spring-fall ranges, a use that is widely made of the pinyon-juniper zone. Encroachment of pinyon-juniper into grasslands has become a severe economic problem for range livestock producers (Cotner, 1963a). Proper treatment of these woodlands can produce economic goods of great value. Benefits and costs of such conversions will be discussed in a later section.

Wildlife habitat

An increasingly important value of the pinyon-juniper type is the wildlife habitat it provides. Human population growth is felt more and more in the area of outdoor recreation, of which deer hunting is a major activity. Pinyon-juniper woodlands are one of the most important habitats for deer in the West. Maintenance of adequate tree cover and improvement of browse production should be an essential part of any large-scale pinyon-juniper management program. Reynolds (1964), in a preliminary report from a study which promises to be an important contribution to pinyon-juniper management, remarked that, "As our human population increases, we demand more usable products from pinyon-juniper. This woodland can be improved, both as game habitat and as livestock range."
Soil and water

Yields of water and sediment from pinyon-juniper woodlands are not well known. An increase in runoff is generally desired, so long as erosion does not increase. Conversion of woodland to grassland could decrease water and sediment yields, while increasing the efficiency of on-site water utilization through the production of forage rather than trees. Ackerman and Lof (1959) felt that, "insofar as water conserving practices divert to productive use soil moisture which would otherwise disappear through evaporation or transpiration by unproductive vegetation, they add to the available water supply. Where they alter the timing or runoff or the site of moisture use, as in the mountainous basins of the West, the benefits are to be found in other ways than in total water yield." The hydrologic interpretation requires more knowledge of these systems than is presently available; the economic evaluation needs a judgement as to which of the products is valued highest—the off-site water, the forage, the trees, or some combination of these. It can probably be assumed that erosion control, or soil stabilization, has a preeminent long-range economic value and should therefore always be one goal of pinyon-juniper management.
Space

A somewhat abstract, yet obvious, feature of the pinyon-juniper resource is that it occupies area. It takes up space, or is space, depending on the point of view. As mentioned, the pinyon-juniper type is, according to estimates, somewhere between 51 and 83 million acres in extent. More importantly, these acres are rather strategically, or unfortunately, located, again depending on the viewpoint. Situated between the higher mountains and the plains or desert valleys, these undernourished forests seem to be everybody's and everybody's animals', stomping ground. The pinyon-juniper woodland is the "door mat" of the Intermountain region and the Southwest. It seems as though every cow, sheep, horse, man, and mouse within range must at one time or another wipe his feet on the pinyon-juniper type while going to or from the mountains and the plains below. The traffic is heavy and the wear and tear shows in the scant or lacking nap of grass cover and the eroding tears in the underlying soil fabric. But even a door mat gets noticed, if only in disrepair, and attention has led to corrective action.

To date, the demand for the space occupied by pinyon-juniper woodland, independent of its products, such as grass or wood, has hardly raised a ripple of thought ahead of the wave of population growth. Indeed, it would be unrealistic to anticipate a significant pinyon-juniper land rush in the foreseeable future, but it would be equally naive to ignore the facts of life. The population of the
United States is growing at an alarming rate, and space, even (or later ... "especially?") pinyon-juniper space will be in greater and greater demand. Space for living and space for playing will be sought in woodlands that are now scheduled for conversion to grassland. Perhaps it will not matter what kind of vegetation occupies the land when the time comes to fill this seemingly remote need, but perhaps the original tree cover would be preferred. Planning for such future possibilities may not seem feasible; but not planning may, in some instances, be inexcusable.

In summary, the natural resources of pinyon-juniper woodlands include tree products, livestock grazing, wildlife habitat, soil, water, and space. How all of these relate to one another and how they can be utilized for the maximum social good is, or should be, the concern of land managers. Conversion of pinyon-juniper woodlands to grasslands is usually aimed at increasing the products from livestock grazing, with subordinate interest in wildlife habitat, water yields, and erosion control. An evaluation of conversion practices should proceed within the context of economic, as well as ecologic, factors.
EVALUATION OF PINYON-JUNIPER CONVERSION PRACTICES

Background

Countless acres of pinyon-juniper woodland are not alone what catch the eye and ire of conservationists. Thoughts of water wasted where enough is seldom seen or put to fullest use are sterner stimuli for switching to a grassland. Need for increased spring-fall grazing capacity throughout the pinyon-juniper zone makes the change to water utilization by forage plants especially attractive to land manager and livestock man alike. The added appeal of soil erosion control has a hallowed, though sometimes hollow, ring. A chance for greater good from water, a need for feed, a sincere wish to save the soil and, perhaps, man's natural bent for controlling his environment have motivated massive attempts to convert pinyon-juniper woodland to grassland.

The language of the pinyon-juniper "problem," if not its magnitude, is enough to set the tenor of these treatment times. Such words as, "invasion," "control," and "eradicate," suggest solutions to an ecologic evil that somehow has gotten out of hand. How pressing the need for action may be is not for this report to settle. But it is appropriate to ask how the public, through its agents, comes to wonder, then to worry, about what to do with all the pinyon-juniper woodland that it owns. Apparently, the very scale of the "problem" creates incentive. The idea of something as unwanted as pinyon-juniper woodland taking over large chunks of real estate does pose a real enough threat to many. Whatever may provide the impetus to implement
corrective measures, the fact is that every year land managers respond with budgets and bulldozers. Fortunately, legitimate desires and designs mark the actions of most of those involved in pinyon-juniper conversion programs. Occasionally such efforts are not fully appreciated by citizens who view the result.

A Study of Pinyon-Juniper Conversion Attempts

To help improve future treatments, the U.S. Geological Survey engaged in an evaluation of pinyon-juniper conversion practices on the public domain. The investigation was cooperative with the Bureau of Land Management, whose personnel have the job of managing more than 30 million acres of pinyon-juniper type on public lands of the western states (Bureau of Land Management, 1964).

The evaluation was aimed at the two main objectives of most pinyon-juniper treatments, kill of trees and production of forage grass, which together constitute so-called, "conversion." No attempt was made in the present study to speculate about any changes in runoff or sedimentation which may result from such vegetation modification. Watershed management investigators in Arizona reported that treatment of a major part of the two million acres of pinyon-juniper woodland in the Salt River drainage might increase water yield by as much as 75,000 acre-feet annually (Arizona Watershed Program, 1956). They added that, "In the process of modification, grass would be substituted for much of the non-useful tree growth and erosion would be reduced." Spense (1937) observed that the erosion problem on the Boise River
watershed in Idaho was largely the result of the replacement of fibrous-rooted plants by those belonging to the taproot and semi-taproot classes, and that rehabilitation could be attained by a reestablishment of the original species or similar fibrous-rooted plants. When considering possible effects of pinyon-juniper conversions on soil erosion, it may be useful to note the climatic relationship between the pinyon-juniper type and the following statement by Langbein and Schumm (1958): "Sediment yield is a maximum at about 10 to 14 inches of precipitation, decreasing sharply on both sides of this maximum, in one case owing to a deficiency of runoff and in the other to increased density of vegetation."

Techniques for killing pinyon-juniper trees fit under three general headings: mechanical means, chemical means, and fire. Examples of mechanical methods and fire effects were included in the present study. Chemical controls are new in the pinyon-juniper field and were not evaluated.

Mechanical treatments that were studied include single chaining, double chaining, chaining followed by windrowing, and rolling with a Marden brush cutter. Chaining, the most widely used method, involves attaching the ends of a heavy anchor chain to a pair of crawler tractors, which then drag the loop of chain through the trees. Weight of the chain varies from about 45 to 90 pounds per link, and lengths range from about 250 to 600 feet. Double chaining is the same process, repeated in the opposite direction. The purpose of chaining is to knock down or rip out the trees and provide some scratching of the
soil surface for coverage of grass seed. Cabling is similar to chaining, but utilizes a heavy cable instead of an anchor chain. Windrowing is the scraping of downed trees, with some soil, into long ridges, or windrows, which leaves cleared ground over most of the treatment area. This method is normally followed by drilling of adapted grass species. The main feature of the Marden brush cutter is a large cylinder with five sharp, straight blades about eight inches deep which are evenly spaced and run the full length of the cylinder. As the device is rolled over the ground, it knocks down the small trees and chops into the soil and vegetation.

Fire can be placed in two technical roles in pinyon-juniper conversion. First, there are the so-called wild, or accidental fires which are a natural phenomenon of pinyon-juniper woodlands. The other kind of fire has similar effects, but is directly and intentionally caused by man in an effort to eliminate trees. Either type may fizzle in a short time and burn very little or may sweep over a large area. The size depends on a number of factors such as weather, vegetation, fire breaks, and the wishes of watchers.

All of these techniques kill trees. How they differ in application, effectiveness and cost is what interests land managers and provides the framework for this evaluation.
Procedure

Bureau of Land Management district offices in Colorado, Utah, Arizona and New Mexico were asked by the investigator to submit completed land treatment reports for any pinyon-juniper projects that were completed prior to June 1963. The request reminded district managers that, to be of greatest service to them, the evaluation should include the full range of success experienced for given practices and should cover as many kinds of sites as possible, with the added note that successes and failures are equally important sources of data for evaluation of problems and methods. Out of the 113 land treatment reports received, about 50 sites were selected for examination during the summer and fall of 1964. Those selected gave a wide geographical range to the study and were, presumably, representative of the population, i.e., the group of projects reported by the districts. To whatever extent projects that were not reported or sites that were not sampled might better exemplify the methods under scrutiny, this evaluation will be amiss. Time allotted for the study did not permit either verification of the actual population of projects being sampled or an exhaustive search for additional sites. Figure 13 shows the study reference numbers and locations of the sites that were sampled.

Tree species, numbers, and height classes were sampled in one-fifth acre plots on treated and adjacent untreated sites. Surface soil to 30 centimeters was sampled and analyzed for physical and chemical properties that might affect grass production. Yields of forage grasses on treated and untreated areas were estimated on a dry weight basis in pounds per acre.
Figure 13.--Map of treatment evaluation sites. Numbered dots are locations of pinyon-juniper conversion sites which were examined during the present study.
Figure 14.--Graph showing variations in tree kill. Percent change in number of trees per acre due to treatment is the ratio of the number of live trees per acre on a treated site to the number of live trees on an adjacent untreated site. Height and position of bar indicates range and degree of success for control method. Average kill for single chaining was 38 percent and for double chaining 60 percent. Estimates of kill for windrowing and burning ranged from 95 percent to 100 percent. Dashed lines on windrowing and burning bars indicate relative uncertainty that any windrowing project killed 100 percent of the trees treated and that any burn achieved as low as a 95 percent kill. Two of the single chaining sites had more trees per acre on the treated area than on the untreated area, which accounts for the single chaining bar extending below zero kill.
Results

Most of the sampling sites had received single chaining; next in number were double chaining areas; the third group represented the intensive chaining and windrowing technique; one site was treated with the Marden brush cutter and another had been cabled. The study included three sites where fire had removed the tree competition.

Tree density on untreated sites ranged from 85 to 710 individuals per acre for all species, with an average of 340 trees per acre. The number of pinyon trees per acre averaged 180 for the untreated woodlands sampled.

Kill on trees varied from an average of about 40 percent for the single-chaining group to over 95 percent on the windrowed sites and 100 percent on the burns. Double chaining was less than twice as effective in killing trees as was single chaining. The Marden brush cutter was moderately successful in eliminating small trees. The one cabling site had an increase of 18 percent in the number of trees, but was still 10 percent "better" than one of the single-chaining projects. Figure 14 compares the effectiveness of chaining, windrowing, and burning in killing trees.

Forage production was consistently low in untreated woodlands, but varied greatly on treated sites. Some of the single-chaining areas showed little or no change in forage yield, but the average increase for the group was about 100 percent. The actual amounts of forage involved on chaining projects were generally so low that the poor tree kills overshadowed in ecologic importance any gains in grass
production. One notable exception was a single-chaining project in northwestern Colorado, shown in figure 15. The treatment produced a tree kill of about 95 percent and increased forage from about 100 pounds per acre before treatment to 500 pounds per acre after treatment, a combined result for chaining which put this site in a class by itself. Grass production was a problem on only one of the windrowed sites, and reseeding in 1965 has apparently corrected that. In fact, the chaining-windrowing-drilling approach is a form of dryland grass farming, which reduces most of the risks down to those caused by variations in climate. Yields of grass from windrowed sites ranged from 500 to over 1,000 pounds per acre. Figure 16 shows a good example of a successful windrowing project in southwestern Utah.

Recovery of grasses on the burned sites was dramatic. Forage production of desirable native grasses was 1,300 pounds per acre on one wildfire site and only about 100 pounds per acre in the adjacent unburned woodland. At the other two fire sites examined, the pounds of forage per acre increased from an estimated 200 to over 600, at one site, and from a scant 25 to almost 500 pounds per acre at the other. The valuable rangeland shown in figures 17 and 18 was like many other pinyon-juniper sites prior to a beneficial burn and subsequent lush regrowth of grass. Dead trees on the site pictured in figure 18 were chained down to ease the movement of livestock and to improve the appearance of the area, but this added step is not essential for a satisfactory conversion by fire. Single chaining followed aerial seeding of crested wheatgrass at site pictured in figure 18.

Appendix A provides a summary of data and evaluations from sites included in this study.
Figure 15.--Successful single chaining, northwestern Colorado. Chaining killed 95 percent or more of the trees, increased yield of forage grasses and stimulated the growth of valuable browse species. Photograph was taken at the beginning of second growing season after treatment.
Figure 16.—Successful windrowing, southwestern Utah. Clearing of trees and seeding to intermediate wheatgrass have made efficient use of precipitation on this excellent pinyon-juniper conversion project. Photograph was taken several years after treatment was completed.
Figure 17.--Successful burn, northeastern Utah. Wildfire killed 100 percent of the trees and released native forage grasses, including Indian ricegrass and slender wheatgrass. Site was photographed in 1964, 11 years after fire.
Figure 18.--Successful burn, chained after fire, northeastern Utah.

Same wildfire area as shown in figure 17, but this site was given the additional treatments of aerial seeding and a single chaining after fire to facilitate the movement of livestock and to improve its appearance.
Discussion

Conversion of woodland to grassland must accomplish two functions almost simultaneously to be complete and successful. Kill of trees without establishment, or equivalent release, or a substantial grass cover is only a partial success. Conversely, a rise in forage production following a treatment which leaves most of the trees alive may yield substantial, if temporary, grazing returns, but is not conversion by any reasonable definition. Setting arbitrary, quantitative levels for "success" and "failure" of pinyon-juniper conversion treatments is not without risk and error. Vegetation manipulation is still more of an art than a science and evaluation of its results must necessarily be rather subjective. Nonetheless, some standards of accomplishment are needed, at least to clarify the present evaluation and analysis.

A "Successful" kill of trees is defined as 95 percent or greater, and a "successful" yield of forage as 500 pounds per acre or greater. These criteria are realistic in judging pinyon-juniper conversion projects for two reasons. First, satisfactory techniques are available and being used to achieve tree kills above 95 percent. Second, the critical site factors observed in most pinyon-juniper woodlands indicate excellent chances to obtain forage yields of 500 pounds per acre and more, following a successful kill of trees and followed by sound management. Although it probably is unwise to state dogmatically that forage increases of less than 500 pounds per acre constitute conversion failures, it is necessary to set some reasonable standard for successful forage improvement on a pinyon-juniper treatment site.
Chaining

Measured by the above criteria, there was only one successful chaining site among the many sampled, or otherwise examined. One project on a demonstration area in Utah achieved a successful conversion with double chaining augmented by burning. The almost universal failure of chaining, without windrowing, to kill a high enough percentage of trees is the single most discouraging aspect of pinyon-juniper conversion efforts. Areas littered with knocked over trees, some dead, some alive, all visible, are unattractive at best and unwanted by many. For examples, see figures 19, 20 and 21. Such scenery will suffer an awkward status in the President's national beautification campaign and Interior Secretary Udall's "Landscape Management" plans. Even the geographical remoteness of a project may not save it from public concern.

Some may argue that chaining does an effective job of killing trees. True, chaining kills a good percentage of the older, larger trees in a stand—the trees that dominate the woodland before treatment and produce most of the foliage volume. But what of the young trees? Chains and cables slide over many trees without damaging them seriously or preventing them from producing seed and increasing their numbers. The tree shown in figure 22 was still very much alive in spite of the chaining which knocked it flat and pulled most of its roots from the soil. A Bureau of Land Management land treatment report from a double chaining project in Utah stated that chaining did not remove all of the small juniper trees ranging from one foot to five feet in height. At that site all of the trees over five feet in height were either chained down or dozed out to achieve a 100 percent kill of
Figure 19.--Single chaining, northwestern Arizona. Chaining, which included area where man is standing, left many young trees alive and perhaps released others. No improvement in forage production was noted. Photograph was taken in 1964, about four years after treatment.
Figure 20.—Single chaining, northwestern New Mexico. Treatment killed many of the older trees and left remainder of stand bruised, but alive.
Figure 21.—Single chaining, west-central Utah. Few trees were killed but area does look disturbed.
Figure 22.—Live, chained tree, northwestern New Mexico. Though flattened and partly ripped from the ground, tree was still producing berries several years after single chaining treatment. Some of the roots on the side of the tree toward which it was felled are still intact and are now benefiting from shading effect of downed tree.
the larger trees. Cotner (1963b) found cabling to be "particularly
adapted for even-aged stands" of pinyon-juniper, but also noted that,
"in a mixed-age stand, the cable is lifted off the ground while the
larger trees are pulled, thus missing smaller trees which bend and are
passed." He reported that, "cabling pulled 94 percent of the trees in
an even-age stand of trees, 15 to 25 feet in height, on a shallow
limestone site. In contrast, on a clay site, the count of dead trees
was only 43 percent in a mixed-age stand on which originally better
than half of the trees were seedling size to six feet." Arnold et.al.
(1964) concluded that, "Cabling or chaining is probably the best
method for uprooting dense stands of old pinyon-juniper trees," but
observed that "the cable slips over small trees (10 feet high and
smaller) and merely tips over many intermediate-sized trees." They
reported tree kills of 50 to 80 percent with cabling. Chilson (1964)
reported that single cabling of juniper failed to result in good kills,
"principally because the cable tends to ride well above the ground as
it passes over the larger trees." This normally killed the larger
trees and left the smaller ones alive. According to Chilson, the
smaller trees that survived had a post-treatment acceleration in
growth, which meant that he was faced with "much the same problem
of over supply of pinion-juniper that was present before the initial
cabling."

Data collected for the present study tend to agree with these
erlier observations on the relationship between size of trees and
effectiveness of chaining. Among a group of five sampling sites,
where the percentage of trees greater than 10 feet in height made up 50 percent or more of the stand, single chaining killed from 46 to 84 percent of all trees. The kill averaged 61 percent in these older stands, or approximately the degree of control obtained with double chaining. By comparison, single chaining killed an average of only 30 percent of all trees on projects where over one half of the trees on the untreated sites were less than 10 feet in height. Correlation coefficients were computed to measure the relationship between percentage of kill and the proportion of large trees in the stand. At single chaining sites the value of \( r \) for the combined pinyon-juniper kill percentage vs. ratio of trees greater than 20 feet in height was 0.81. The same \( r \) value was obtained for single chaining kill on pinyon alone vs. the percentage of pinyon trees taller than 10 feet on adjacent untreated sites. Analysis gave an \( r \) value of 0.70 for single chaining kill on pinyon-juniper combined vs. percentage of all trees taller than 10 feet. All three of the above correlation coefficients were significant at the 0.01 level, based on a test of the hypothesis that \( \rho = 0 \), using the \( t \) distribution: 

\[
t = \frac{r \sqrt{n-2}}{\sqrt{1-r^2}} \quad \text{with} \quad n-2 \quad \text{d.f.}
\]

When single chaining and double chaining data were pooled for comparison with greater-than-10-foot and greater-than-20-foot size class ratios, the correlation coefficients dropped to 0.27 and 0.05, respectively. These data and analyses, supported by results of earlier studies and by uncomplicated observation, suggest that the probability of successful pinyon-juniper kills from chaining will increase in direct relationship to the percentage of trees 10 feet tall and taller that are present in the untreated woodland.
According to personnel in one Bureau of Land Management district, chaining may work better in mid-winter when the soil is frozen. Under these conditions a good kill was obtained on a mixed age stand in northeastern Utah.

Certain woodland areas, for obvious aesthetic reasons, should be left alone. Figures 23, 24 and 25 are views of an Accelerated Public Works project in Colorado that has, by offending the public eye, brought out the stop signs on projects that ignore the occasional wisdom of treatment inaction. Figure 26 displays a scenic spot on a resource conservation area in Utah that was littered with ugly debris when chaining of nearby land was extended too far.

Many chained areas enjoy a flush of increased grass production soon after treatment, but regrowth and release of young trees cancels out the early forage gains. Small trees that are missed by cabling or chaining "grow two to three times as fast after release from the dominance of larger overstory trees" (Arnold, et. al., 1964). The young trees present a formidable challenge to follow-up control, since as yet no chemical sprays are available to kill them, and even if prescribed burning were allowed, the nature of some post-treatment stands precludes anything else but additional mechanical treatment. Inexpensive chaining, which may kill a relatively high percentage of old trees while leaving most of the young ones and releasing seedlings, can create an ecologic situation that is harder and more expensive to treat than the original woodland. Trees that remain could be cut down individually by hand or perhaps even burned, one
Figure 23.--Untreated pinyon woodland near Alamosa, Colorado. Relatively open, mature stands of pinyon, such as this one growing on the stony outwash of Mt. Blanca, though not rare, probably have more aesthetic value as part of the general landscape than do any other woodlands in the pinyon-juniper zone.
Figure 24.--Chained pinyon woodland near Alamosa, Colorado. Chaining of this stony site, which is adjacent to the untreated stand shown in figure 23, followed seeding of forage grasses and sweet clover. Treatment killed less than 10 percent of the trees and produced little or no increase in forage yield. The most significant effect of the project has been the drastic change in the appearance of the area, whether viewed close-up, or from a distance, as in figure 25.
Figure 25.--West slope of Mt. Blanca, southern Colorado. Distant view
of same sites shown close-up in figures 23 and 24 illustrates
effect chaining or other treatment practices can have on the
appearance of certain landscapes. Location and topography, as
seen here, can have much to do with the overall "success" that
a pinyon-juniper conversion project may achieve in the eyes of
the general public.
Figure 26.--Chained juniper on scenic area, northeastern Utah. Chaining of juniper on nearby land to increase forage yields was inadvertently extended to include this unproductive sandstone site, which would have had more value in its original condition. Careful selection of conversion sites and better supervision of treatment operations can avert such misfortunes.
by one. But these methods might be prohibitive in cost, depending on the degree of original conversion success and the forage potential for the site. Figures 27 and 28 illustrate the problem of reestablishment of trees on a chained area. The average cost for hand chopping, sawing, and grubbing for 102 projects in Arizona, 1950-56, was $5.91 per acre (Arnold, et. al., 1964). The prospect of waiting several hundred years until the trees get big enough to be chained effectively is even less attractive. A major weakness of the chaining approach seems to lie with a misplaced emphasis on saving money, rather than producing benefits. The object of a pinyon-juniper conversion is, by definition, to get rid of trees in a given area and replace them with grass. Any practice which does not accomplish these aims with ecologic and economic efficiency is a failure as pinyon-juniper conversion, no matter how "cheap" it may be. If different primary objectives for pinyon-juniper control are adopted, such as "wildlife habitat improvement" or "watershed protection," then the above criteria for "success" and "failure" may not apply. In any case, it is unreasonable to assign broader meanings to these conversion standards than those intended in the present context.

One result of chaining that has not received adequate attention is the matter of the trash left on the ground. Certain advantages, such as snow entrapment and erosion control, are claimed for the tangled masses of tree parts left in the wake of the chains. Skau (1961) felt that pits and debris left by juniper cabling reduced
Figure 27.--Untreated woodland, south-central Colorado. View shows stony site and a mixed juniper-pinyon woodland that contained about 350 trees per acre, of which number about 60 percent were juniper. Eighty percent of all trees were less than 10 feet in height.
Figure 28.--Chained woodland, south-central Colorado. Six years after chaining, the above site, which is adjacent to the one shown in figure 27, had 180 live trees per acre, a survival or recovery of 52 percent. About 55 percent of the live trees on the treated site were juniper. All of the live trees sampled were less than five feet in height, not taking into account the original heights of taller trees which were knocked down, but were still alive when sampling was done.
the amount of surface flow on a watershed in northern Arizona. Some wildlife specialists believe that the trash on a chained area improves a site as game habitat. Arnold, et. al. (1964) warned that, "Unlike light slash, heavy slash shades out grass, may absorb considerable moisture, interferes with the handling of livestock, and increases the difficulty of subsequent mechanical treatment." Examination of these effects was not emphasized in the present study, but estimates were made of the percent of ground covered by trash at a number of chaining projects. Amounts of trash cover ranged from 10 percent to over 50 percent, with a reasonable average about 25 percent. Figures 29 and 30 show adjacent untreated and treated sites respectively on a project in Utah. The single chaining increased forage to about 500 pounds per acre of treated land, killed most of the older trees for an overall mortality of 46 percent, and covered more than 25 percent of the acreage with heavy trash. Much of the trash left by chaining at sites like this remains in dense piles that are impenetrable by livestock, so that forage plants growing in these protected patches usually produce more seed than feed. Probably more important than all these items is the obvious fact that the trash takes up space. To the extent that any feed within it is unavailable to animals, the area of trash cover must be subtracted from the total area treated to arrive at the true net acreage "converted". Chaining can, for example, reduce a thousand acres of pinyon-juniper woodland to 750 acres of variably disturbed and temporarily productive rangeland (which, of course, is one way to diminish the pinyon-juniper "problem"), but in this case whatever rate of forage yield applies to the accessible
Figure 29.--Untreated pinyon-juniper woodland, southeastern Utah. Stand shown here contained 270 trees per acre, two-thirds of which were pinyon. Fifty percent of the pinyons and 90 percent of the junipers were 10 feet in height or taller. Forage production was negligible.
Figure 30.--Chained pinyon-juniper woodland, southeastern Utah. View of treated site adjacent to woodland shown in figure 29 typifies problem of heavy chaining trash and low percentage of kill which often result from this practice. Kill was effective on older trees at this site, but averaged only 46 percent. All of the live trees sampled on the treated area were less than 10 feet in height, though many which were nearly horizontal, but alive, would have measured more than 10 feet along their trunks. Forage yield was increased to about 500 pounds per acre of treated land. Photograph was taken in October of 1964, four years after treatment.
areas, applies to only 75 percent as much land as the original woodland covered. Economic analysis can reveal what this means in terms of the actual dollars-and-cents net effectiveness of chaining.

Windrowing

Compared to chaining operations, the intensive chaining-windrowing-drilling technique, though more costly, is a far better mechanical means of replacing trees with grass. Clearing the ground completely, which is necessary for drilling, not only provides a clean kill of trees and a control on shrubs, but the resulting stands of grass surrounded by untreated woodland probably have as much aesthetic value to residents and travelers as does the typical pinyon-juniper scenery. Few can object to seeing public funds employed to produce lush grasslands, where needed, as shown in figure 31. The method is also ecologically sound. Grass establishment is more dependable and tree reinvasion is less of a problem where clean scraping and drilling are practiced. The Bureau of Land Management districts that are headquartered at Fillmore and Cedar City in Utah have achieved, through the good fortunes of enlightened management, adequate budgets and timely precipitation, an enviable record of conversion results with windrowing projects. Having the know-how and the courage of their convictions to gamble on a good method has paid off in sound and salable conservation. The windrowing site shown in figures 32 and 33 typifies the outstanding work being done by the men in these districts.
Figure 31.--Windrowing project, western Utah. View shows outstanding success of a large conversion project in the Fillmore District of the Bureau of Land Management. Narrow site in center of picture was too steep and rocky to be included in a windrowing treatment. Photograph was taken in August of the first year in which crested wheatgrass became established.
Figure 32.--Untreated juniper-pinyon woodland, southwestern Utah. Site shown here had 315 trees per acre, of which number about 90 percent were juniper. Sixty percent of the junipers sampled were less than 10 feet in height. Understory shrubs were big sagebrush, snakeweed and rabbitbrush. Forage production was negligible. The noncalcic, silt loam soil had a saturation percentage of 25 and a pH of 7.2. Site is 6,400 feet above sea level and has an estimated average annual precipitation of 12 inches.
Figure 33.--Windrowing site, southwestern Utah. Success of this treatment effort, adjacent to site shown in figure 32, was typical of windrowing conversions examined in this investigation. Treatment killed 95 percent or more of the trees, reduced shrub cover and increased annual forage production to over 500 pounds per acre. Photograph was taken on June 3, 1964.
There is an interesting and important connection between windrowing conversions and wildlife habitat. First, in order to use the windrowing technique intelligently and successfully, the land manager must make a thorough survey of site conditions in the proposed treatment locality. Selection of sites to treat should recognize certain basic ecologic criteria such as slope and stoniness of soil, as discussed earlier. By careful delineation of treatment areas, leaving out those woodlands that are too steep or too rocky to be included in a grass farm, the manager will, in effect, be classifying the land resources into "natural" and "modified" areas. The untreated woodland sites will continue to provide the kind of habitat conditions that wildlife conservationists desire, whereas the adjacent converted areas will produce needed forage, primarily for livestock, but not entirely avoided by deer. Reynolds (1962) noted that game abundance is favored by diversity and interspersion of vegetation types.

An added benefit of the windrowing technique is the creation of a greater length of edge between woodland and clearings, a valuable feature for wildlife habitat. Gabrielson (1941) wrote that "Forest animals are generally those described as edge-inhabiting species. They congregate about the borders of forests and in woodland openings, for there they find a greater variety and abundance of the plants that furnish both shelter and sustenance." The U.S. Forest Service (1959) noted that "clear-cutting timber in small blocks leaves wooded patches and openings close together, making an excellent
wildlife habitat." Antelope and elk were observed to frequent pinyon-juniper control areas, especially near their edges (Arnold, et. al., 1964). Kerr and Hofman (1964) in describing the benefits of pinyon-juniper chaining in southwestern Colorado said, "The long irregular perimeter between down and standing trees provides the much preferred 'edge effect' which accompanies increased game numbers." Hubbard and Hiehle (1965) pointed out that fuel-breaks, which are open grassland strips in woodlands, though constructed primarily for fire hazard reduction, also benefit deer by creating edge and variation in the type of vegetation. Increase in border between treated and untreated areas can be accomplished with any technique, but will often be a natural outcome of a selective windrowing treatment and thus can provide a convenient form of resource compromise between livestock and wildlife interests.

To calm fears that the forage source for Utah's deer population was endangered by widespread pinyon-juniper conversions, Plummer (1958) pointed out that, "The present abundance of juniper trees, together with a very plentiful supply of juniper seeds in the ground, practically guarantees that the number of these trees will likely remain ample to satisfy the demands of game indefinitely." Reynolds (1964) made a preliminary report on habitat uses of a pinyon-juniper area in southern New Mexico by deer and elk. In it he stated that livestock range improvement can be coordinated with deer and elk habitat preservation by confining clearing of pinyon-juniper to slopes of less than 15 percent, and leaving existing cover on northeastern exposures. Reynolds felt that elk and deer habitat might be improved by thinning trees, which overtop shrubs, where they exceed about 150 trees per acre.
Lloyd (1961) sounded a challenging note on the ranching vs. wildlife issue in a speech that was later reprinted by the Idaho Section of the American Society of Range Management. Stressing the general theme that social changes are shifting rangeland uses, Lloyd said, "Increased production of big game will have a more widespread effect on rangeland utilization than any other form of competition to livestock production. Game production as it is presently valued can outcompete livestock production in the market for some private rangeland, and pressure for use of public land for game increases. Even so, the tendency is to emphasize the isolated and spectacular case, thus creating the illusion that all stockmen will immediately be forced off the public lands. This is not the case, but the trend is evident." So long as a proper balance is maintained between clearing woodland and leaving food and cover for game, there should be little conflict among the various parties who are interested in obtaining the most good from pinyon-juniper resources.

A windrowing conversion program is essentially self-classifying, from a land use standpoint, since ecologic criteria restrict the practice to certain sites which will usually produce greater benefits when converted to grassland than if left untreated as, for example, wildlife cover. Stony, wooded ridges and canyon slopes scattered among grass-covered valleys and mesa tops is the sort of vegetation pattern that will normally result from this conversion technique. Soils that are best suited to tree and browse production generally are not included with windrowing and drilling sites. Whenever large
areas selected for windrowing do not contain enough stony, steep, or otherwise naturally unsuitable conversion sites to satisfy a legitimate need for wildlife food and cover, the necessary islands of untreated woodland can easily be left anywhere in the project. It is simply a matter of the land manager being sensitive to the desires for a balanced vegetation modification program and his being willing to refine the planning and execution of the conversion to accommodate a companion resource.

The same reasoning could apply to the coordination of conversion practices with other land values in the pinyon-juniper type, such as camping and picnicking needs, historical and archeological sites, areas of particular scenic or scientific interest, or any other feature of a woodland that should receive special attention.

The approach becomes more one of specialized use, or horizontal segregation of use for each kind of land, rather than multiple use, or vertical integration of land uses. Some vertical integration of land uses will naturally result from intensive "windrowing and withholding" conversion projects, but instead of trying to cover an entire pinyon-juniper area with a seemingly harmless chaining that will do the least damage to any user-interests, the land manager can make definitive plans for each parcel of ground. Future land treatments in pinyon-juniper woodlands may be guided by the idea of "specialized space." Conversion methods can produce the desired special effects in selected space, but land classification must provide the key to planning.
Burning

Fire can be an effective tool in the conversion of pinyon-juniper woodlands to grasslands. Clean kills of trees and certain understory shrub species, notably big sagebrush, can be achieved with fire on a large part of the woodland type. Although only a few burned sites were reported by Bureau of Land Management district offices for inclusion in this study, the rather obvious success of those examined permits some latitude in attributing general usefulness to fire. Burning does not allow the high degree of site selection and treatment control that windrowing does, but may have greater merit for improving combined livestock-wildlife range than would be imagined. For example, Arnold, et. al. (1964) observed from aerial views of pinyon-juniper burns that while tree kill often was "clean on flat to gently rolling terrain... in rough terrain, islands of unburned trees were left on hills and ridges." Preferred deer browse species that resprout after a fire, such as birchleaf mountain-mahogany (Cercocarpus betuloides) and Wright silktassel (Garrya wrightii), may provide additional incentive in some areas to remove tree competition with a controlled burning program (U.S. Forest Service, 1963a). Contrary to some views, serviceberry, also valued as deer browse, can resprout vigorously following a fire, even one that has completely killed the overstory trees.

A program of planned burning on the Hualapai Indian Reservation in northern Arizona has demonstrated the effectiveness of this technique in pinyon-juniper conversion. Schroeder (1964) reported
on a wildfire that burned off 16,000 acres of pinyon-juniper woodland on the reservation in 1953. The burn was seeded to the following mixture in 1954: crested wheatgrass, 1 pound per acre; western wheatgrass, 3 pounds per acre; weeping lovegrass, 1/2 pound per acre; and yellow sweet clover, 1 pound per acre. Grazing was deferred for 3 years following seeding to allow the grasses to become fully established. Cost of the project was $3.60 per acre. Dry weight of forage in adjacent unburned areas averaged about 60 pounds per acre, while production on the seeded burn was 1,660 pounds per acre.

Encouraged by the beneficial results from an accidental fire and followup seeding, and aided by their government advisors and technicians, the Hualapai Indians launched a controlled burning program to convert pinyon-juniper woodland to productive grassland. In the period from 1955 through 1963 they burned and seeded about 17,000 acres of pinyon-juniper type at an average cost of about $4.50 per acre. Forage production was increased an average of approximately 500 lbs. per acre for the 33,000 acres of burned woodland and, according to Schroeder, pinyon and juniper had shown little or no tendency to return on the controlled areas.

The Hualapai Indians and Schroeder were primarily interested in increasing livestock production, a somewhat oldfashioned design by current "standards" of rangeland management, but one that holds considerable appeal among ranchers. To this end, burning of trees
and seeding the land to adapted cool-season grasses have served
them very well. Steers grazed on areas that were burned and reseeded
to these grasses from 1959 through 1962 weighed, on the average,
78 pounds more than steers grazed on adjacent untreated native
grass ranges, and brought their owners an average of $21.75 more
per steer at market time.

Accurate observations and objective interpretations on the
subject of woodland burning practices must replace hand-me-down dogma
and propaganda if land managers are to be fully equipped to plan
intelligent, efficient conversion programs and completely free to
carry them out.

No evidence was found to support a common notion that hot,
tree-killing pinyon-juniper fires "sterilize" the soil, making it
unfit for grass establishment. In fact, soil samples from "spots
covered with ashes where a heavy accumulation of slash and debris
had burned" were tested in a greenhouse and reported to have shown
"some increased fertility due to burning" (Arnold, et. al., 1964).

It is hard to reconcile the claims of soil sterilization from
fires with reports that pinyon-juniper woodlands are hard to burn;
yet both opinions have been offered as partial arguments against
prescribed burning in the pinyon-juniper type.

Those who wish to discourage pinyon-juniper burning, lean
heavily on the argument that they have trouble getting a fire to
carry through a typical woodland. More likely than not they are
referring to a carefully controlled burning program attempted when atmospheric and vegetation moisture conditions are such that escape of the fire to adjacent areas would not readily occur. In other words, when everything is moist. Even those who are experienced and sincere in their efforts to apply fire in pinyon-juniper conversion may have difficulty burning trees when weather conditions are not favorable. For example, Schroeder (1964) reported that a 1955 burn of 700 acres and a 1958 burn of 300 acres, both on the Hualapai Indian Reservation, "were attempts that did not burn the acreage desired. Late wet springs and high moisture content in the shrubs are detrimental to a successful summer burn." Arnold, et. al., (1964) tried broadcast burning of live stands of pinyon-juniper at several locations in Arizona and reported that it was difficult and required "special conditions." They found that, even in stands having over 400 trees per acre, "fire will carry only during the hot, dry, windy weather when any burning is hazardous."

The Arizona Watershed Program report of 1956, Recovering Rainfall, stated that, "Where fire can be used, it is the most effective method of juniper control." The report cautioned that, "Human habitations, intensively used recreational areas, and the like should be rigorously protected." However, it continued, "With these exceptions, in any place where juniper is dense enough to carry a fire, there are no land values that require exclusion of this control agent." The Arizona researchers said, "For burning to be effective it must be done when weather conditions will encourage the spread of fire."
This usually means burning in June when temperatures are high and
humidity is low, and when the risk of escape is greatest. Adequate
precautions must be taken to prevent the escape of planned fires and
to minimize the damages that might result. When this is done, the
calculated risks of a burning program are justified by the potential
benefits." The same investigators estimated that in the Salt River
watershed perhaps less than 10 percent of the pinyon-juniper type could
be effectively burned. This somewhat discouraging note agrees with
several comments heard by the writer during the present study with
regard to the difficulty of burning pinyon-juniper woodlands, but
does not square with observations of typical pinyon-juniper stands
in Utah, Nevada, Colorado and many parts of Arizona and New Mexico.
It is fair, if somewhat idle, to speculate that burning could have
been used successfully on many of the chaining sites that were
examined for the present evaluation. Sites with similar character-
istics have had productive burns. A clean kill on a relatively open
stand of pinyon with an understory of sagebrush and some grass was
examined at the scene of an accidental burn in northwestern Colorado,
shown in figures 34 and 35. Naturally, where trees are closer
together, or where a heavy understory can help carry the fire,
the chances of a successful burn will be better. Figures 36 and
37 show the conditions before and after a wildfire had burned a
dense stand of pinyon and juniper in Utah. No artificial seeding
was applied. Natural recovery of grasses has produced valuable
forage and in so doing has made more efficient use of the available
water resource. One chaining site in Utah provided a vivid contrast
Figure 34.--Pinyon-sagebrush community, northwestern Colorado. Site is adjacent to burn shown in figure 35. In addition to big sagebrush, the understory vegetation included common serviceberry (Amelanchier alnifolia), snakeweed, rabbitbrush, needle-and-thread, western wheatgrass and arrowleaf balsamroot (Balsamorrhiza sagittata). A few juniper trees were present. Altitude of site is 7,200 feet; annual precipitation is about 15 inches.
Figure 35.--Pinyon-sagebrush burn, northwestern Colorado. View of area adjacent to site shown in figure 34 illustrates successful conversion of mixed type by wildfire which killed undesirable trees and shrubs and released native grasses. Serviceberry burned to the ground with other shrubs, but has sprouted back vigorously. Establishment of crested wheatgrass, seeded soon after fire, is weak compared to aggressive recovery of native grasses, particularly needle-and-thread. Burn occurred in August of 1962. Photograph was taken on August 7, 1964.
Figure 36.--Untreated pinyon-juniper woodland, northeastern Utah.

Relatively dense stand of mature trees with a sparse understory of mountain-mahogany (Cercocarpus montanus) is growing on a shallow soil and exposed, fractured limestone. Altitude is 7,400 feet and average annual precipitation is about 14 inches. Fire carried through a similar stand and produced the results shown in figure 37.
Figure 37.—Pinyon-juniper burn, northeastern Utah. In 1953 a wildfire produced a clean kill of trees at this site, which was similar to the woodland shown in figure 36. Recovery of native grasses, mainly Indian ricegrass and slender wheatgrass, with no artificial seeding, has increased annual forage yield to over 1,000 pounds per acre. Photograph was taken in August of 1964.
between the merits of chaining and burning for removing trees and improving range. An accidental fire cleaned the trash off part of the chained area, providing ideal conditions for aerial seeding of grass. This was done, and now a lush stand of crested wheatgrass grows alongside the tangled debris and scant forage on the part of the treatment area that received only double chaining and aerial seeding.

Land administrators will probably give more favorable consideration to conversion of pinyon-juniper woodlands by fire whenever it can be used safely and effectively. These two important aspects of burning are often closely interrelated, and may require new applications of fire that will satisfy both needs. For example, a suggestion has been made that a woodland to be burned could be sprayed with diesel oil prior to burning in order to help carry the fire through the treatment area. The spraying could be done for about $1.50 per acre and might permit an effective burn during weather conditions that would also provide a reasonable measure of safety to adjacent lands. The U.S. Forest Service (1964) found that, "A chemical desiccant, sprayed on the foliage of juniper several days before the trees were burned, greatly facilitated control of individual trees that had invaded grasslands in northern Arizona." Their tests showed that, when the moisture content of leaves and twigs had been lowered to 40 percent by applications of monochloracetic acid, the time required to ignite trees was reduced to 20 seconds, or one-seventh the time needed to ignite unsprayed
trees. Fire as a tool in pinyon-juniper conversion has sufficient ecologic and economic merit to warrant increased use of present burning techniques now, and further study of new methods may allow more general application of burning in the future.
Pinyon-juniper conversion projects should be planned and judged as resource allocation. The resources are land, labor, management and capital, as discussed earlier, and each of these factors of production can be used in a number of ways. Thus, the application of any of them in an effort to convert woodland to grassland should receive economic, as well as ecologic, evaluation.

Assuming that the decision has been made to apply enterprise (management) to a selected pinyon-juniper site (land) for the purpose of producing grass forage (a benefit...?), the question remains, how much human effort (labor) and accumulated capital will the benefits justify? The answer largely depends on definition and valuation of the so-called benefits, which naturally vary with the conversion methods used. The several conversion techniques currently available produce different ecologic results, thus differ in economic merit.

Single and double chaining usually fail to kill a high enough percentage of trees to start a successful conversion and should not occupy much of anyone's time in economic analysis of their effects. Claims of good success from chaining are rather general in land management circles and are alarmingly frequent in actual reports of project results. Data collected for the present study suggest a less favorable view of chaining, though indeed all chained sites exhibit some destruction of trees and most also show an increase in grass production.
However, it is pounds per acre of forage, or other concrete units, that economists must consider in making a cost-benefit analysis of conversion practices. Percentage changes have no meaningful dollar value, even though any increase in forage production in the typical pinyon-juniper woodland may seem a real boon to the land manager or rancher.

Two pinyon-juniper conversion methods that work well enough ecologically to warrant economic attention are burning and windrowing. Both techniques kill trees effectively and are usually followed by successful establishment of high-producing stands of forage grasses. Burning in this sense means application of fire to standing woodland, as distinguished from burning of chaining trash or other treatment debris, a practice which is used in many areas.

The use of fire as a primary tool in pinyon-juniper conversion deserves the attention of ecologists and economists because it is the best technique available for the job. Still, the matter of cost-benefit relationships in a fire conversion program will be of little real concern to anyone until there are significant changes in the attitudes of land management policymakers.

Windrowing poses no ecologic problem in justifying its use. Kill of trees is usually over 95 percent; establishment of grass is relatively routine; and, with good management, longevity of productive grass stands should be 20 years or more. The problem is not one of low benefits, but of high costs. Data from Bureau of Land Management district offices indicate that the complete windrowing operation, including single
chaining, scraping of chained trees, and drilling of grass, costs approximately $15.00 per acre. That makes windrowing about three times as expensive as single chaining with aerial seeding, a fact which has discouraged many land managers from using the method, even though windrowing practitioners generally have enjoyed very impressive results. Reluctance to spend the windrowing price per acre is influenced by several factors: (1) land treatment programs still have a strong bias toward quantity of acres, rather than quality of accomplishment, and more dollars spent per acre would mean less treated acres to report each year; (2) many land managers sincerely believe that chaining is an effective pinyon-juniper conversion treatment, relative to any other methods which they are inclined, or allowed to use, and since chaining is cheap and fast, it is popular; (3) the same land managers who prefer chaining, whether forced to a mechanical method or not, probably have serious doubts about the economic justification for any fifteen dollar per acre treatment on pinyon-juniper land, regardless of the ecologic advantages.

The relationships between benefits and costs of a resource management project can be analyzed in a number of ways. Le Baron (1965) reviewed some of the approaches used in water resource policy literature and suggested preferred methods for different investment situations. The economic considerations implicit in pinyon-juniper conversion are
similar enough to certain water resource projects that benefit-cost criteria and techniques developed for the later have validity in the present analysis.

Most investment analysis methods used in resource economics involve computation of benefit-cost ratios, present values of future benefits, rates of return on invested resources, or some combination of these measures. Ranking of alternative projects on the basis of one or more of these criteria is generally the motive for such evaluation. In the present case, where the windrowing treatment may often be the only acceptable investment alternative, the problem of ranking is less important. Still, the land manager should be familiar with some of the basic tools used in economic analysis of resource allocation. The purpose of this discussion is two fold, (1) to remind the reader of certain economic concepts and procedures that could be useful in making pinyon-juniper management decisions, and (2) to show how the intensive, and expensive windrowing technique for pinyon-juniper conversion can be justified by economic analysis. The latter objective is not intended to suggest that economic computations alone can provide sufficient criteria for pinyon-juniper treatment planning, but rather to prevent the rejection of an ecologically sound method, such as windrowing, on the erroneous supposition that it is not economically feasible.
An agronomically successful windrowing project can be a good investment. Lloyd and Cook (1960) reported that, "Analysis of costs and returns from crested wheatgrass seedings on publicly-owned ranges in western Utah indicates that those which produce a satisfactory stand of grass are profitable even when seeding costs are high and drought reduces grass yields below normal."

Investment was defined by Arrow (1965) as "the allocation of current resources, which have alternative productive uses, to an activity whose benefits will accrue over the future." He observed that, "benefits take the form of production of goods and services" and "the cost of an investment is the benefit that could have been derived by using the resources in some other activity." Arrow contended that, "An investment is justified if the benefits anticipated are greater than the costs," in other words, to make efficient use of resources, the present value of future benefits from a given investment, discounted by the rate of return on alternative investment opportunities, must exceed costs. Cotner (1963a) in a discussion of discount theory as applied to pinyon-juniper control problems, explained that, "Since future benefits are required to pay current treatment costs, discounting is an important phenomenon in economic decisions concerning resource improvements."
Discounting Analysis

To compare costs and returns for sagebrush range treatments, Gardner (1962) used a discounting procedure that also could be applied to evaluation of pinyon-juniper conversion practices. He computed an "internal rate of return," or a rate which would make the discounted present value of the annuity returns stream equal to the initial cost of the practice.

The following formula was used for all computations in Gardner's study:

\[ A = \frac{R}{i} \left[ \frac{1 - (1 + i)^{-m n}}{1 - (1 + i)^{-m}} \right] - S \]

Where:

- \( A \) = present value of the returns stream (original cost of practice)
- \( R \) = the annual value of returns (annual value of the difference between prepractice and postpractice carrying capacity)
- \( i \) = discount rate (internal rate of return)
- \( n \) = number of years during which the increased forage is grazed
- \( m \) = number of years of deferment
- \( S \) = value of postpractice carrying capacity that is "lost" if deferment is practiced

In non-deferment situations, the internal rate of return is given by

\[ A = \frac{R}{i} \left[ \frac{1 - (1 + i)^{-n}}{1 - (1 + i)^{-n}} \right] \]

The cost-benefit ratio above is equal to the present value of an annuity of unit value per period for a term of \( n \) periods at the rate
of interest \( i \) per period. By consulting the "Present Value of Annuity" table in a book of standard mathematical tables (Hodgman, 1959) the approximate internal rate of return can be found above the nearest value to the computed \( A/R \) which corresponds to the given term of \( n \) periods. For example, a project with an original cost of $18.00 per acre, an annual net return of $1.50 per acre, and an expected life span of 25 years, would have an internal rate of return of about 6\( \frac{1}{2} \) percent.

Obviously, to use such tools for an economic evaluation of treatment efficiency, the value of benefits and costs must be determined. Gardner (1962) observed that many problems, both conceptual and empirical, arise that are peculiar to range improvement practices, which, he said, "are particularly perplexing on the returns side." As Gardner pointed out, many benefits from increased forage production are not easily measured and are therefore not amenable to economic valuation.

Lloyd and Cook (1960) also found that, "Extra-market returns are real and have value but are difficult to measure or express by usual methods." Examples given by them were "conservation of soil and water, stabilization of the livestock industry, and increased feed for game"--benefits that could accrue to "the whole society as well as the individual range user." When such values are, of necessity, excluded from economic analysis, the total societal benefits will be understated, grossly so in some instances,
according to Gardner. He emphasized this point by saying that the results of his study were "meaningless as indicators of whether or not investment in range improvement is economically justified from society's vantage point. However, it will be possible to draw inferences regarding the profitability of the various practices for the stockman who bears the investment cost (or some of it) and who reaps the benefits of this one use which is considered."

An "appropriate" value for an AUM (animal-unit-month) was assumed, by Gardner, to be its market value, regardless of whether the grazing was done on private or public ranges. He obtained competitive rents from a large sample of ranchers in northwestern Colorado and computed an arithmetic mean in 1958 of $3.03 per AUM, which he then assumed to be the value of all AUM's of increased grazing resulting from the improvement practices under study. The price spread between $3.03 per AUM and typical public land grazing fees for this item suggests that range improvement as a "money-making" project for public land agencies may be untenable, unless private ranchers bear most of the cost. Ranchers contribute about 30 percent of the cost of range improvement programs on Public Domain lands in Colorado (U.S. Bureau of Land Management, 1963).

The second problem regarding investment returns discussed by Gardner was that of estimating the longevity of increased forage production resulting from the improvement practice. Cotner (1958) felt that the major problem in an economic study of pinyon-juniper
control concerns the expected changes in forage and livestock production. Variables such as quality of grass stand, grazing management, period of deferment, and weather make every treatment effort a special case, but following Gardner's approach, an average annual forage benefit can be estimated, and that amount of increased grazing can be assumed to last the life of the project.

Grazing benefits would be considered as zero during a period of deferment, and at the end of the project term could be assumed to revert to their pretreatment level. Gardner assumed that a stand of crested wheatgrass would last for at least 30 years from the time of seeding, based on examination of experimental work done in Utah and Idaho.

One AUM is roughly equivalent to 600 pounds of good quality forage, and based on Gardner's value for an AUM, crested wheatgrass forage should be worth about one-half cent per pound. Successful pinyon-juniper conversions, such as those generally achieved with the windrowing technique, can be expected to produce between 500 and 1,000 pounds of total forage, dry weight, or from 250 to 500 pounds of usable forage per acre per year.

Figure 38 shows the relation between the present value of the returns streams from a conversion project (initial cost of practice) and variations in production and discount rates, based on forage valued at one-half cent per pound and a project life of 30 years. The graph reflects only direct, on-site costs of making the conversion, i.e., for removing the trees and planting.
Figure 38.--Relation of initial cost to annual return. Graph shows the computed relationship between the present value of the returns stream for a conversion project (initial cost) for a range of interest rates (internal rates of return), based on a value of 50 cents per 100 pounds for usable grass forage (dry weight) and a project returns period of 30 years. It permits estimation of "break even" investment levels for given outputs and interest rates, and, conversely, it indicates the average annual forage yield levels required to justify given costs of project investment. For example, to determine how much a $15.00-per-acre practice must return annually for 30 years in dry weight of usable grass forage in order to earn six percent interest, locate intersection of $15.00 cost line (from vertical scale) with six percent interest line, then, directly below this point read annual return value on horizontal scale.
the grass. A reasonable estimate for these items was $15.00 per acre in 1965 for most of the pinyon-juniper region. Occasionally a surplus of idle equipment or labor will bring costs down, while transportation costs can have the reverse effect in the more remote areas. Variables such as price of seed, size and uniformity of treatment area, topography, rockiness, density and size of trees, number of bidders for the contracts, and experience of the contractors can also influence the cost of a windrowing project. Expense for fencing, maintenance, and management personnel also must be considered.

**Benefit-Cost Analysis**

Another approach to planning resource allocation was presented by Eckstein (1958) in an excellent book, parts of which should be required reading for land resource policy-makers. The benefit-cost analysis that Eckstein suggested for evaluation of water resource developments also could be used to test the economic merits of pinyon-juniper conversion projects.

As indicated earlier, benefit-cost analyses are commonly used to rank alternative investment plans. Further study along these lines could compare the economics of chaining vs. windrowing and might show whether or not the added cost of the higher kill with windrowing is necessary to obtain a financially successful treatment. Cotner (1963b) related "the recurring maintenance problem" in pinyon-juniper conversion to the question of attempting 100
percent control with each treatment operation. He pointed out that "Since small trees offer little competition to range forage at first and some economic efficiencies in control can be obtained if there are more trees per acre, the ideal time interval consistent with maximizing returns may involve several years." Cotner added, "When control methods are used that miss small trees or require considerable additional time to remove the small trees a similar economic question is raised whether the additional treatment should be immediate or at a later date." Ecologic and economic facts hold out little hope that either single or double chaining will prove to be superior to windrowing as a general practice for converting pinyon-juniper woodlands to grasslands on a profitable basis. Additional study will be needed to settle this point.

Rates of depletion of benefits must be determined, especially for the typical chaining treatment, where regrowth of trees can probably be expected to reduce forage yields. Retreatment costs following conversion attempts that achieve poor kill of trees, as can be expected from chaining (Arnold, et. al., 1964), will have to be estimated in order to make valid comparisons among pinyon-juniper control projects.

The reduction of acreage by a chaining treatment that leaves impenetrable debris over the landscape, as discussed earlier, may substantially affect the benefit stream. Costs incurred on the total acreage of such a chaining project will return forage value on only part of the accountable area. Note that this variable is
not covered by depletion estimates, but rather it establishes the plateau, or starting point, from which any depletion will be figured.

Risks of obtaining predicted benefits from different techniques will vary and may require adjustments in any benefit-cost analysis that may be applied. Eckstein described three ways by which risk adjustments can be injected into the benefit-cost framework: "(1) by shortening the period of analysis; (2) by including a risk factor in the interest rate; and (3) by making safety allowances on the cost or on the benefit side." He advocated use of a premium in the interest rate to adjust for risk in project evaluation. An interesting point made by Eckstein with regard to risks is pertinent to the pinyon-juniper treatment problem: "Technological change is probably the biggest source of risk for long-range projects, and, even though it is extremely difficult to forecast the exact nature of technological progress, historical experience seems to indicate that there is a fairly steady rate of advance and that it permeates all industries to a larger or smaller degree. From the moment a project is finished, it can be expected to become more and more obsolete as compared to the current state of technology, and as time passes, it will lag further behind current best practice for achieving the same purpose. And so as the benefits become more remote in time they become more problematical and should be discounted more heavily." This would
seem to impose a greater burden for justification on windrowing projects, which require high initial investment and correspondingly long discounting periods to break even. At any time in the future new treatment tools, such as chemical dendrocides, could make today's 15 dollar per acre mechanical practice appear unwise. Changes in land use patterns and resource demands, though not necessarily technological change or progress, also could cast some doubts, in retrospect, on the heavy commitment of funds to a largely singular purpose, such as converting woodland to grassland. In fact, recent developments and comments in the policy area of rangeland management strongly suggest a decided shift in emphasis from grazing benefits to less mundane manna. More politically palatable yields are sought from grazing lands than just steak or leg of lamb. Conversion of pinyon-juniper woodland to grassland may already be an obsolescent pursuit, unless a cover of crested wheatgrass can be shown to use less water, hold more soil in place, and/or be prettier to look at than are trees. Cows, no longer the objects of political affection as rangeland producers, are being downgraded in favor of deer and other wildlife. Just how carefully these changes in land use policy are being weighed and just how staunchly the convictions of long-time grazing specialists are being held in the face of pressures for other products, are questions that should be pondered by all who are really concerned with the future of our range resources. Meanwhile, windrowing is a solid investment for grass production, with low ecologic risk incurred while achieving successful conversions.
According to Eckstein, the choice of interest rate for the design and evaluation of public projects is one of the most difficult and important problems in this field. Use of a low interest rate, such as 2½ percent, in benefit-cost analysis, favors durable and capital-intensive projects, and can lead to justification of projects of little economic value. On the other hand, Eckstein pointed out, "an interest rate of 5 or 6 percent in benefit-cost analysis would preclude the justification of most projects. The high capital intensity and the very long economic lives of resource-development projects make interest cost a larger part of total cost than in most other fields of investment. Under a high interest rate the federal government would reduce its efforts in the resource field."

The rate of 2½ percent, which approximates the interest rate on long-term government bonds, was recommended in 1950 by a federal subcommittee on economic analysis of river basin projects.

Eckstein proposed the following compromise for a benefit-cost analysis, which was "designed to preserve the long-range perspective of the federal program, yet... assure that only projects are undertaken in which capital yields as great a value as it would in its alternative employments: let the government use a relatively low interest rate for the design and evaluation of projects, but let projects be considered justified only if the benefit-cost ratio is well in excess of 1.0." He further suggested that in order to keep the average rate of return as high as in alternative investments, "a combination of interest rates and minimum benefit-cost ratios..."
should be selected which will correspond to a rate of return of 6 percent for a project of average capital intensity." Windrowing is a relatively high capital intensity practice, since almost all of the treatment costs are incurred at the outset and low maintenance costs are the rule throughout the term of the projects.

Eckstein summarized his discussion as follows: "(1) no particular significance attaches to the government bond rate for project evaluation; (2) the rate of return on the best private investments also in inappropriate; (3) the opportunity cost of capital raised by federal taxation is on the order of 5 or 6 percent, accepting private time preference; (4) there are good reasons for rejecting private time preference and using a lower interest rate for planning resource development; (5) but if a low interest rate is used it must be coupled with a minimum benefit-cost ratio greater than 1.0 in order to assure that capital is not wasted. An interest rate of 3 percent and a benefit cost ratio of 1.3 or an interest rate of 2\frac{1}{2} percent coupled with a ratio of 1.4 are combinations which will produce an average rate of return for the entire federal program of about 6 percent, and therefore are appropriate minimum justification standards."

The computations used to apply Eckstein's criteria involve two steps. First, the benefit-cost ratio is determined by the following formula:

$$\frac{B}{C} = \frac{B}{B + A_{1T}K}$$
Where:

\[\begin{align*}
B &= \text{benefits received annually} \\
C &= \text{costs per year, including the charge on capital} \\
K &= \text{fixed investment} \\
O &= \text{operating, maintenance, and routine costs incurred annually} \\
A_{iT} &= \text{annual capital charge per dollar of fixed investments, representing both interest and amortization. Given } i, \text{ interest rate, and } T, \text{ amortization period, } A_{iT} \text{ can be found under rate } i, \text{ for period } n, \text{ in a table for "Annuity Whose Present Value is 1" (Chemical Rubber Publishing Company, 1959).}
\end{align*}\]

Eckstein defined the rate of return, \( r \), by the equation

\[
K = \frac{B - O}{A_{rT}}
\]

Where:

\[
A_{rT} = \frac{T}{\sum_{t=1}^{T} \frac{1}{(1 + r)^{t}}} - 1
\]

which can be derived from the same table as \( A_{iT} \). Solving for \( A_{rT} \), gave

\[
A_{rT} = A_{iT} \left( \frac{B}{C} \right) + \frac{O}{K} \left( \frac{B}{C} - 1 \right).
\]

Find \( r \) above the value for \( A_{rT} \) in the table, "Annuity Whose Present Value is 1."

Eckstein pointed out that if there are no current costs \((O/K = 0)\) then

\[
A_{rT} = A_{iT} \left( \frac{B}{C} \right).
\]
Windrowing projects will generally require little or no annual maintenance costs that are peculiar to the practice itself. Corollary expenses such as fencing, water development and management supervision, which usually accompany intensive forage improvement work, should not be considered in these benefit-cost calculations.

Cost of removing trees or spraying brush that may invade treated areas are examples of operating expenses that legitimately could be included as "0" items in the above formulas.

The analysis for a typical windrowing project might look something like this:

(1) Given:

\[ B = 250 \text{ lbs. usable forage} = \$1.25 \text{ per acre, annually} \]

\[ O = \$0.15 \text{ per acre, annually} \]

\[ i = 3 \text{ percent interest} \]

\[ T = 30 \text{ years} \]

\[ A_{iT} = 0.051, \text{ from table} \]

\[ K = \$15.00 \text{ per acre} \]

\[
\frac{B}{C} = \frac{B}{0 + A_{iT}K} = \frac{1.25}{0.15 + 0.051 (15.00)} = \frac{1.25}{0.91} = 1.37
\]

(2)

\[
A_{rT} = A_{iT} \left( \frac{B}{C} \right) = 0.051 (1.37) = 0.070.
\]

\[ r = 5.6 \text{ percent} \]

Using an interest rate of 2\(\frac{1}{2}\) percent with the other values the same as before gives a B/C of 1.44 and a rate of return of about 7 percent.
Successful windrowing projects that cost 15 dollars per acre can be justified economically by either of the above methods of analysis, using forage as the sole benefit. In the paradoxical event that forage production ceases to be a good enough political reason to improve grazing land, the agencies that manage this resource will have several choices. They could resist irrational political influence and continue to support the widely held view that livestock products are important benefits from rangelands. They could avoid any mention of livestock grazing and attempt to justify range improvements as watershed conservation, landscape management, wildlife ranching, or something else.
SUMMARY AND RECOMMENDATIONS

Invasion and expansion of pinyon-juniper woodlands and definition of grassland sites are discussed as background for management decisions. The availability of soil moisture to plants is emphasized as the most important ecologic factor controlling distribution patterns of pinyon-juniper woodlands and adjacent grasslands. Classical notions concerning contemporary development of soils and vegetation are dented a bit by ecologic evidence which ties woody plants to coarser, younger soils and herbaceous vegetation to finer, more fully developed soils in arid and semi-arid environments.

The resources of pinyon-juniper woodlands are discussed under the categories of tree products, livestock grazing, wildlife habitat, soil and water, and space.

Chaining, windrowing, and burning practices on public pinyon-juniper lands are evaluated. Single chaining projects have the greatest variation in conversion results and average only about 40 percent kill on trees, lowest for all methods examined. Double chaining is less variable, but also is less than twice as effective in killing trees. Windrowing and burning give consistently high tree kills of 95 percent or better and, of the techniques studied, offer the best chances for pinyon-juniper conversion success.

Windrowing is a relatively expensive treatment, as compared with chaining or burning. Two approaches to benefit-cost analysis are presented for use in judging the economic feasibility of pinyon-
juniper conversion projects, and either one can provide economic justification for the intensive windrowing technique.

The pinyon-juniper "problem" is more political than it is technical; therefore, purely technical solutions to it are always incomplete. Basic economic questions of resource allocation and land use classification must be answered before the matter of conversion technique has any real meaning. Land managers who have decided to convert pinyon-juniper woodland to grassland still may not be certain which of the available methods are suited to their particular situations. The following recommendations are founded on investigation of the basic ecologic relationships in the pinyon-juniper type and on examination of more than 50 public land pinyon-juniper conversion projects scattered among the states of Colorado, Utah, Nevada, Arizona, and New Mexico:

(1) Use burning as the primary conversion tool where vegetation is dense enough to carry an effective fire, but with full regard for protection of property values which approach or exceed the benefits from the treatment. Actively resist irrational political and administrative pressures that tend to distort the role of fire in range management. Develop and maintain a balanced perspective on fire as a natural and beneficial instrument in vegetation change.

(2) Use the windrowing technique where soil and topography allow and where burning is legitimately prohibitive. Test economic merits of each proposed windrowing project with an appropriate benefit-cost analysis before investing resources.
(3) Use single chaining or double chaining for conversion of woodland to grassland only where rockiness of site precludes windrowing and then only if at least 50 percent of the trees to be treated are over 10 feet in height and the anticipated forage increase is critically needed.

(4) Seed adapted forage species where potential for rapid natural recovery of desirable vegetation is lacking.

(5) Consider this:

If there are 30 million acres of pinyon-juniper woodland on the Public Domain and...

If one-fifth of that acreage were eventually to be treated by single chaining at a cost of $5.00 per acre and...

If treatment success averaged 50 percent...

About 15 million dollars would be wasted.
LITERATURE CITED


_____ 1964, Pinon-juniper studies launched by BLM: Our Public Lands 13, p. 21-22.

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