United States
Department
of Agriculture

Forest Service

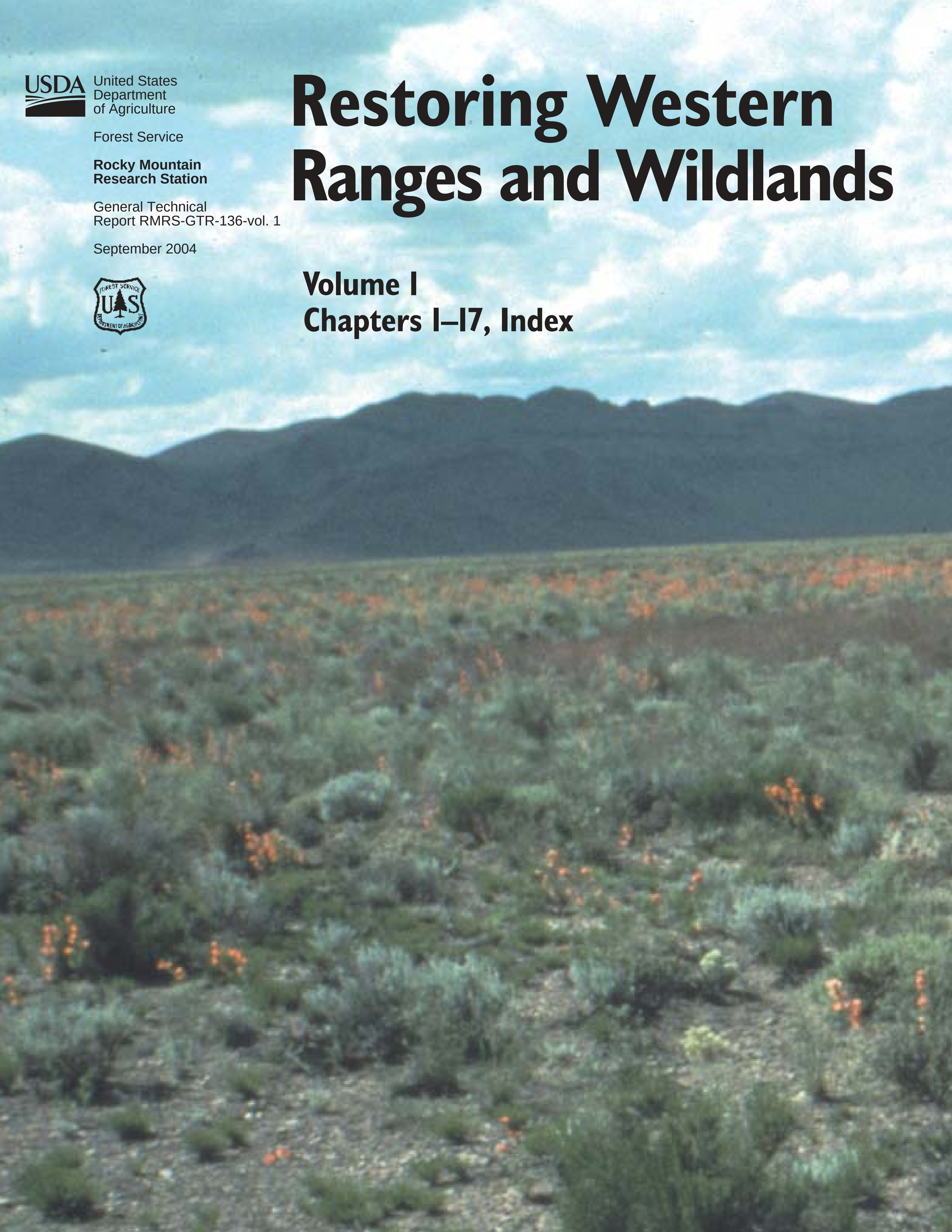
Rocky Mountain
Research Station

General Technical
Report RMRS-GTR-136-vol. 1

September 2004

Restoring Western Ranges and Wildlands

Volume I
Chapters 1–17, Index



Abstract

Monsen, Stephen B.; Stevens, Richard; Shaw, Nancy L., comps. 2004. **Restoring western ranges and wildlands**. Gen. Tech. Rep. RMRS-GTR-136-vol-1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Pages 1-294 plus index.

This work, in three volumes, provides background on philosophy, processes, plant materials selection, site preparation, and seed and seeding equipment for revegetating disturbed rangelands, emphasizing use of native species. The 29 chapters include guidelines for planning, conducting, and managing, and contain a compilation of rangeland revegetation research conducted over the last several decades to aid practitioners in reestablishing healthy communities and curbing the spread of invasive species. Volume 1 contains the first 17 chapters plus the index.

Keywords: rehabilitation, revegetation, plant ecology, seed, plant communities, wildlife habitat, invasive species, equipment, plant materials, native plants

A

B

A—Reseeding on the Boise River watershed, 1937.

B—Rangeland drill.

C—Elk on burned winter range.

D—Sampling soil, north-central Nevada.

E—Aerial seeding.

Front covers on all three volumes: Desert Experimental Range Utah. Photo by John Kinney.

Restoring Western Ranges and Wildlands

Compilers

Stephen B. Monsen
Richard Stevens
Nancy L. Shaw

Volume I
Chapters 1–17, index

C

D

E

The Compilers

Stephen B. Monsen (retired), Botanist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Shrub Sciences Laboratory, Provo, Utah

Richard Stevens, Project Leader (retired), Utah Division of Wildlife Resources, Great Basin Research Center, Ephraim, Utah

Nancy L. Shaw, Research Botanist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Boise, Idaho

The Authors

James N. Davis is Project Leader, Big Game Range Trend Program, Utah Division of Wildlife Resources, Shrub Sciences Laboratory, Provo, Utah.

Sherel K. Goodrich is Ecologist, U.S. Department of Agriculture, Forest Service, Ashley National Forest, Vernal, Utah.

Kent R. Jorgensen was Wildlife Biologist (deceased), Great Basin Research Center, Utah Division of Wildlife Resources, Ephraim, Utah.

Carlos F. Lopez was Soil Scientist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Shrub Sciences Laboratory, Provo, Utah.

E. Durant McArthur is Project Leader and Research Geneticist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Shrub Sciences Laboratory, Provo, Utah.

Stephen B. Monsen was Botanist (retired), U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Shrub Sciences Laboratory, Provo, Utah. He is currently a private natural resources consultant and volunteer worker for the Rocky Mountain Research Station.

David L. Nelson was Plant Pathologist (retired), U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Shrub Sciences Laboratory, Provo, Utah. He continues contractual and volunteer work for the Rocky Mountain Research Station.

Nancy L. Shaw is Research Botanist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Boise, Idaho.

Richard Stevens was Project Leader (retired), Great Basin Research Center, Utah Division of Wildlife Resources, Ephraim, Utah.

Arthur R. Tiedemann was Project Leader and Range Scientist (retired), U.S. Department of Agriculture, Rocky Mountain Research Station, Shrub Sciences Laboratory, Provo, Utah.

John F. Vallentine was Professor (Emeritus), Department of Integrative Biology, Brigham Young University, Provo, Utah.

Gordon A. Van Epps was Associate Professor (retired), Snow Field Station, Utah Agricultural Experiment Station, Utah State University, Ephraim, Utah.

Bruce L. Welch is Plant Physiologist, U.S. Department of Agriculture, Rocky Mountain Research Station, Shrub Sciences Laboratory, Provo, Utah.

Steven G. Whisenant is Professor, Department of Rangeland Ecology and Management, Texas A&M University, College Station, Texas.

G. Richard Wilson was Director (retired), Utah State Seed Laboratory, Utah Department of Agriculture, Salt Lake City, Utah.

Foreword

E. Durant McArthur, Project Leader, Shrubland Biology and Restoration Research Work Unit,
Rocky Mountain Research Station, Shrub Sciences Laboratory, Provo, Utah

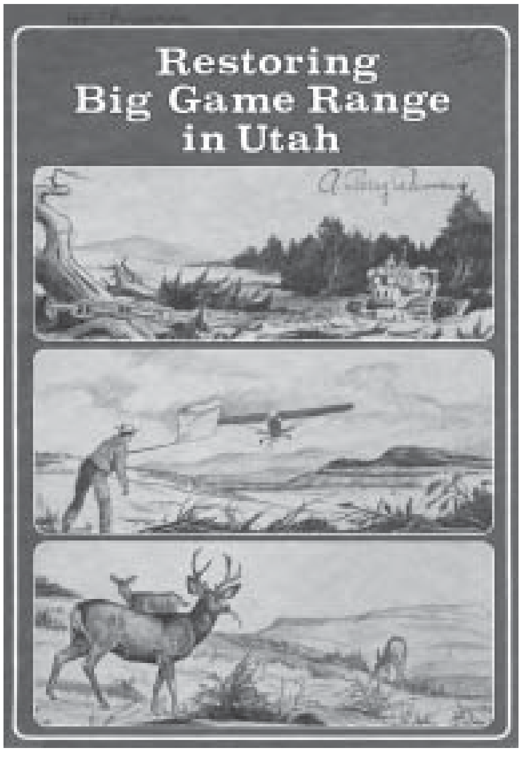
Restoring Western Ranges and Wildlands has had a fairly long gestation period. The final product of three volumes had its beginnings in 1983. At that time research administrators of the Intermountain Forest and Range Experiment Station (now part of the Rocky Mountain Research Station) had obtained funding from the Four Corners Regional Commission (FCRC) to produce a series of research summary syntheses to aid agriculture and natural resource values and management for the Four Corner States (Arizona, Colorado, New Mexico, and Utah) and surrounding areas. The FCRC, now defunct, was formed in 1965 as one of five Federal regional commissions to aid regional development in economically distressed areas. *Restoring Western Ranges and Wildlands* was intended to supplant the successful, out-of-print, *Restoring Big Game Range in Utah* (Plummer and others 1968) with a broader geographic coverage and new knowledge gained during the intervening years. *Restoring Big Game Range in Utah* was published by the Utah Department of Natural Resources, Division of Fish and Game. The authors, in addition to A. Perry Plummer (a Project Leader and Range Scientist for the Intermountain Forest and Range Experiment Station), were Division of Fish and Game Biologists Donald R. Christensen and Stephen B. Monsen. The three were part of an integrated Federal and State workgroup lead by Mr. Plummer and located at the Great Basin Research Center in Ephraim, Utah (for additional details see McArthur 1992). This volume served land managers well. There are many dog-eared copies in offices and libraries in Utah and elsewhere around the West. It has been cited many times in peer-reviewed literature of the *Science Citation Index* during the past several decades (*ISI Web of Science*, *online*).

I sat with a group of administrators and researchers in a 1983 meeting in the conference room of the Shrub Sciences Laboratory in Provo, Utah, as we laid out plans for writing and compiling *Restoring Western Ranges and Wildlands* by subject areas and possible contributors. The lead compilation roles in the effort were assigned to Stephen B. Monsen, by this time a Botanist with the Intermountain Forest and Range Experiment Station, and Richard Stevens, Project Leader of the Habitat Restoration Unit of the Utah Department of Natural Resources, Division of Wildlife Resources. Steve and Richard also took on major writing assignments. But delaying the publishing date were continuing research assignments, other demands on the compilers' time, a shift in revegetation philosophy toward holistic landscape management and emphasis on using native plants, and retirement of both Steve Monsen and Richard Stevens. A third compiler was added to the team—Nancy L. Shaw, a Research Botanist on the Shrubland Biology and Restoration Research Work Unit posted in Boise, Idaho. She worked tirelessly to see the project completed. All three compilers deserve kudos for completion of this massive project.

Many people have helped the authors and compilers complete this work. I extend appreciation to dozens of reviewers of the individual chapters but especially to Robert B. Ferguson, retired Scientist from the Intermountain Forest and Range Experiment Station, and the late Homer D. Stapley, Scientist, from the Utah Division of Wildlife Resources, who each reviewed most of the manuscript. The manuscript was initially prepared on several computer hardware and accompanying software word processing systems. The preparation and integration of the manuscript was facilitated by Pat Ford, Nancy Clark, and Roberta Leslie of the Shrub Sciences Laboratory, and Scott Walker, Nalisa Bradley, and Chris Wade of the Utah Divison of Wildlife Resources, Great Basin Research Center in Ephraim, Utah. Others who contributed to the project include Rocky Mountain Research Station employees who worked on indexing (Jan Gurr), reference compilation (Karl Soerensen and Felicia Martinez), and proofreading and general assistance (James Hall, Jim Spencer, Darren Naillon, Kelly Memmott, Gary Jorgensen, Melissa Scholten, Danielle Scholten, John Kinney, Ann DeBolt, Matthew Fisk, Lynn Kinter, and Nicholas Williams). Also contributing services were the Library staffs of the Rocky Mountain Research Station (Carol Ayer, Mary Foley, Lindsay Bliss, Sally Dunphy, Elizabeth Parts, and Jolie Hogancamp) and Pacific Southwest Research Station (Irene Voit). The Rocky Mountain Research Station Publishing Services lead by Louise Kingsbury, with Nancy Chadwick, Lillie Thomas, Loa Collins, and Suzy Stephens, performed exceedingly well in editing, integration, layout, and design. Many of the line drawings of plant species that are on the chapter introductory pages and illustrate the species in chapters 20 and 21 were prepared by Rocky Mountain Research Technician Annielane J. Yazzie.

This work represents the continuing collaboration of the Rocky Mountain Research Station and the Utah Division of Wildlife Resources. Both organizations contributed materially to publication costs including support from the Federal Pittman Robertson W-82-R Project for wildlife habitat restoration. Other substantial support came from the Forest Service State and Private Forestry National Fire Plan, Bureau of Land Management Great Basin Native Plant Selection and Increase Program, and the Four Corners Regional Commission.

I believe that the materials presented here in a "how to, what with, and why" manner will be timely and relevant for land managers and students in rehabilitation and restoration of degraded Western wildlands for years into the future.



Contents

Volume 1:

Volume 2:

Volume 3:

You may order additional copies of this publication by sending your mailing information in label form through one of the following media. Please specify the publication title and number.

Telephone	(970) 498-1392
FAX	(970) 498-1396
E-mail	rschneider@fs.fed.us
Web site	http://www.fs.fed.us/rm
Mailing Address	Publications Distribution Rocky Mountain Research Station 240 West Prospect Road Fort Collins, CO 80526

Stephen B. Monsen

Chapter 1

History of Range and Wildlife Habitat Restoration in the Intermountain West

Range, wildlife, watershed, and recreation research in the Intermountain region is a relatively young science. Most early research was initiated to rectify problems resulting from overgrazing that resulted in a deterioration of range and watershed resources. Thus, restoration measures were closely aligned to range and watershed disciplines.

Campbell and others (1944) characterized four broad periods of range research: (1) The exploratory period prior to 1905; (2) limited intensive studies, 1905 to 1909; (3) organized experiments undertaken throughout the mountainous West and the Great Plains, 1910 to 1927; and (4) expanded research accompanying aggressive public action on range problems, 1928 to present.

The real growth in range and wildland research began in response to Federal management policy for newly created Forest Reserves (later called the National Forest System). Unfortunately, the development of range research lagged far behind the need, and this lack of information has, in part, contributed to serious problems that still exist in many areas. Although some formal grazing studies were begun by 1910, comprehensive programs did not begin until 1935 (Campbell and others 1944).

The exploratory period described by Campbell and others (1944) consisted of observational and investigative works. The first was the discovery, collection, and description of many native plants (Nuttall 1818; Torrey and Gray 1838-43; Vasey 1889) (fig. 1). This work was aided by the creation of the Division of Botany established in 1868 within the Department of Agriculture. The assemblage of these collections ultimately lead to an understanding of plant distribution, community associations, species abundance, and ecotypic variation. A second area of work involved notations of western pastures and range problems. A third category consisted of exploratory investigations by Department of Agriculture personnel in which rangeland resources within the Forest Reserves were described. These surveys identified research needs.

The range-livestock industry greatly expanded by 1880 and created extremely serious land administrative problems (fig. 2). Development and implementation of realistic husbandry was made possible through the creation of Forest Reserves including the Cascade Range Forest Reserve developed in 1893, which restricted grazing, driving, or herding of livestock within any of the Reserves (Colville 1898). By 1905, an administrative proposal was developed by Potter and Colville (1905) that served as a guide to land use until passage of the Grazing Act of 1934.

Figure 1—Early plant exploration and classification surveys helped to identify plant species and community types.

Figure 2—Livestock grazing seriously altered plant communities, particularly on the high summer ranges of central Utah.

In 1901, the Divisions of Agrostology and Botany were consolidated within the Bureau of Plant Industry. This led to studies relating to reseeding, grazing, and the development of forage plants for rangelands (Burtt-Davy 1902).

In 1905, the Forest Reserves were transferred from the Department of the Interior to the Department of Agriculture and then combined with the Bureau of Forests to form the Forest Service. Grazing problems were so acute that authority was given to control animal numbers, distribution, and grazing duration. Detailed grazing studies were organized. Initial efforts were made to seed mountain rangelands with pasture forages. Work began in Oregon but soon included other areas in the West.

In 1910, the Office of Grazing Studies in the Forest Service was established, and formal range research efforts were developed. Most studies dealt with range surveys, grazing reconnaissance, natural revegetation, and the formulation of grazing practices to improve range and watershed conditions. Some State Agricultural Experiment Stations were established and developed supportive studies during this period (Cotton 1905).

Watershed problems, including flooding and erosion, were critical issues, particularly within the Intermountain States. Consequently, a research facility, initially known as the Utah Experiment Station, was established in central Utah on the Manti National Forest (fig. 3). This center, later renamed the Great Basin Experiment Station, initiated and conducted studies of range management and revegetation.

The Bureau of Plant Industry conducted numerous grazing studies that significantly influenced the selection and use of species for pasture grazing (Shantz 1911, 1924). Range research was transferred from the Bureau of Plant Industry to the Forest Service in 1915. This consolidated and strengthened range research in desert regions when the Santa Rita and Jornada Experimental Ranges, established in 1912, were added to the Forest Service base.

In 1926, the Office of Grazing Studies was transferred from the administrative branch of grazing and established as a division in the branch of research. The subsequent passage of McSweeney-McNary Forest Research Act of 1928 funded and expanded research in timber, range, and watershed at various experiment stations. The Act consolidated all Forest Service range research into regional units and experiment stations. It provided for increased cooperative research with State Agricultural Experiment Stations. It also expanded research activities to include artificial range revegetation, wildlife, and other land values. Artificial revegetation studies included the selection of native species for future improvement and the adaption of native and introduced species for site improvement (Forsling and Dayton 1931; Price 1938; Stewart and others 1939). The studies were primarily located at the Intermountain and Rocky Mountain Forest and Range Experiment Stations.

Figure 3—The establishment of the Great Basin Station in Ephraim Canyon, Utah, facilitated extensive range and watershed research activities.

Establishment of the Great Basin Station quickly generated range and watershed research within the Intermountain region. The station's location in the Great Basin Province was representative of areas including most of the western half of Utah, nearly all of Nevada, California east of the summit of the Sierra Nevada, a large area in southeastern Oregon, portions of southeastern Idaho, and southwestern Wyoming (Keck 1972). Consequently, research efforts were expanded to coordinate with other field locations in Idaho, Nevada, Utah, and Wyoming.

By 1900, livestock grazing had seriously disrupted vegetation in many plant communities within the Great Basin. Extremely critical problems existed on high summer ranges of the Wasatch Mountains and Wasatch plateau. Serious flooding and erosion from high mountain ranges were critical problems. Initial research at the Great Basin Station dealt with assessment of watershed problems and development of measures to correct summer flooding. In 1913, researchers turned their attention to restoring sites by natural reestablishment of native species and direct seeding with natives and exotics. Field adaptability study sites were established in aspen and grass-forb communities, and additional species and field plantings were established in subsequent years. By 1930, considerable information had been accumulated relating to species performance and site adaptability. Many artificial seedings using both native and exotic species were highly successful (Forsling and Dayton 1931).

Beginning in the early 1930s, scientists from the Intermountain Forest and Range Experiment Station united to acquire and field test an extensive array of herbaceous and woody species for use on range and watershed sites in Utah, Nevada, Idaho, and Wyoming (fig. 4). Field testing centers were located at representative sites in the major plant communities in these States. Field plantings and evaluations were carefully maintained at most locations for approximately 20 years. New selections and plant materials were added to the program. Planting sites and environmental conditions were monitored, and plant performance was compared with growth response of adjacent native communities (Frischknecht and Plummer 1955; Pearse and others 1948; Plummer and others 1955).

Figure 4—Three of the early species selection plots established at the Great Basin Station. The plots helped to identify plants for use in revegetation efforts.

Field studies included the assessment of species and the development of planting equipment, methods of seeding, and seedbed preparation (Plummer and others 1943; Stewart 1949). Various equipment and planting practices were developed to treat steep, rough terrain and rangelands (Pechanec and others 1965), but most methods and implements were developed for seeding grasses and broadleaf herbs (fig. 5).

The USDA Natural Resources Conservation Service Plant Materials Centers selected and tested herbaceous plants during this same period. Their efforts resulted in the release and use of many important cultivars (Hafenrichter and others 1949; Hanson 1965). Various State Agricultural Experiment Stations and universities were also conducting species selection and field planting procedures (Cook and others 1967).

In 1954, the testing and development of grasses and broadleaf herbs was transferred from the USDA Forest Service to the newly created USDA Agricultural Research Service. This agency has released numerous introduced, and more recently native cultivars and germplasms.

Problems with big game ranges, particularly winter ranges, became important issues during the 1940s and 1950s. State Game and Fish Departments recognized that game herds and livestock grazing had decimated many important game ranges in nearly all Intermountain States. Scientists and research organizations previously affiliated with range research were solicited for support. Big game habitat and improvement research was begun in Idaho, California, and Utah by Forest Service scientists, but it was funded in part by State agencies in Idaho, Oregon, and Washington. Many herbs previously developed for range purposes proved equally useful for wildlife, but a shift in emphasis from herbs to shrubs took place.

Cooperative shrub research between the Utah Division of Wildlife Resources and Intermountain Research Station began in 1957. This cooperative effort expanded over time, resulting in the establishment of the Forest Services' Shrubland Biology and Restoration Project. The project has contributed to the selection of many useful shrubs and herbs, including development of cultural techniques required to rear and plant these species.

The presence of testing sites, research facilities, and experience with the culture of forage plants developed by earlier researchers at the Great Basin Station aided initial progress in shrub research. In addition, considerable testing and culture of woody plants for conservation plantings (George 1953; Haynes and Garrison 1960; Horton 1949; Mirov and Krabel 1939; Van Dersal 1938) and upland gamebird habitat improvement (Miller and others 1948) provided

Figure 5—A major problem confronting range and wildlife seeding has been the lack of equipment suitable for operating on irregular terrain.

useful species and rearing techniques (Doran 1957) that were adapted to big game habitat improvement (Brown and Martinsen 1959; Plummer and others 1968).

Restoring wildlife habitat by artificial seeding of shrubs and broadleaf herbs has been hindered because of the erratic germination characteristics of various shrubs, the inability of shrub seedlings to compete with herbs, and the lack of equipment capable of operating on steep, mountainous terrain. Yet, considerable progress has been achieved in selecting and developing useful shrub species, ecotypes, and cultivars for game and range seedings. Selections have been advanced primarily through cooperative efforts by the USDA Forest Service, Intermountain Research Station and continue under the present Forest Service structure of the Rocky Mountain Research Station; USDA Soil Conservation Service; and the Utah Division of Wildlife Resources (McArthur and others 1985; Monsen and Davis 1985; Stevens and others 1985c; Stutz and Carlson 1985).

Numerous scientists, agencies, and universities have expanded the scope of shrub research since the 1970s. Although numerous studies have been completed, requirements for establishing many native species that have received little use in past seeding efforts remain largely unknown. Many shrub-dominated communities, particularly in semiarid and arid lands, are difficult to restore using current practices. Consequently, the challenge to enhance rangelands remains formidable.

E. Durant McArthur
Sherel K. Goodrich

Chapter
2

The Intermountain Setting

This book is intended to assist range managers throughout the Intermountain West (fig. 1). The areas of greatest applicability are the Middle and Southern Rocky Mountains, Wyoming Basin, Columbia and Colorado Plateaus, and much of the basin and range physiographic provinces of Fenneman (1981) or about 14° latitude, from the Mohave, Sonoran, and Chihuahuan deserts to the northern Rocky Mountains, and 15° longitude, from the Great Plains to the Sierra Nevada-Cascade Mountain axis. This large area contains diverse landforms and several major vegetational communities. Nevertheless, landform and vegetative type are repeated often enough to consider the multifaceted units. We emphasize the broad vegetation types listed in table 1. Bailey's (1978) attempt at a continental-scale treatment recognized vegetative types, but Küchler (1964), also working on a continental scale, recognized at least 28 vegetative types. Bailey's treatment, for example, doesn't map out the extensive juniper-pinyon woodlands of the Great Basin, whereas Küchler's treatment does. Holmgren (1972) recognized four floristic divisions, divided into 16 floristic sections, in an area coinciding approximately with the southwestern half of figure 1. As

Figure 1—The Interior West locations that are covered in this book, with general vegetative types of Bailey (1978):

- 3120 = Palouse Grasslands Province
- 3130 = Intermountain sagebrush Province
  - 3131 = Sagebrush-wheatgrass section
  - 3132 = Lahontan saltbush-greasewood section
  - 3133 = Great Basin sagebrush section
  - 3134 = Bonneville saltbush-greasewood section
  - 3135 = Ponderosa shrub forest section
- A3140 = Wyoming Basin Province
  - A3141 = Wheatgrass-needlegrass-sagebrush section
  - A3142 = Sagebrush-wheatgrass section
- P3130 = Colorado Plateau Province
  - P3131 = Juniper-pinyon woodland and sagebrush-saltbush mosaic section
  - P3132 = Grama-galleta steppe and juniper-pinyon woodland mosaic section
- M3110 = Rocky Mountain Forest Province
  - M3111 = Grand fir—Douglas-fir forest section
  - M3112 = Douglas-fir forest section
  - M3113 = Ponderosa pine—Douglas-fir forest section
- M3120 = Upper Gila Mountain Forest Province

Table 1—Vegetation types of the Intermountain region.

	Characterization of vegetative types		
Geographic area	**Large**	**Small**	**Disturbed and depauperate**
Valleys and lower mountain slopes			
Big sagebrush	*		*
Shadscale	*		*
Pinyon-juniper	*		*
Black greasewood		*	
Inland saltgrass		*	
Blackbrush		*	
Lowland annual weeds		*	*
Cheatgrass and red brome		*	*
Montane[a]			
Aspen-conifer	*		
Mountain brushlands	*		
Subalpine herblands		*	
Wet and semiwet meadows		*	
Transitional; including both mountain and valley			
Riparian		*	*

[a] Exclusive of alpine habitats.

smaller geographical areas or particular vegetation types are examined more closely, additional vegetation types or subtypes become apparent. Foster (1968) treated 23 major vegetation types in Utah. Passey and others (1982) treated nine major and 27 subservient vegetation types of sagebrush-dominated communities in western Wyoming, southern Idaho, northwestern Utah, and northeastern Nevada.

Our choice (table 1) is to (1) consider plant assemblages together that respond in a similar manner to rehabilitation practices and (2) treat those assemblages that are most in need of restoration (because of disturbance or low productivity) and that have the potential for higher productivity. Some smaller vegetative communities within the area are not considered.

The Intermountain landscape varies widely. This land of considerable topographic relief contains mountains, valleys, and plateaus that create complex patterns (fig. 2, 3, 4). Many mountain-building events occurred in the relatively recent geologic past (Axelrod 1950; Fenneman 1981). Soil types are likewise complex, and soil conditions change rapidly over just a few miles. Soils are often alkaline but may be neutral or more rarely acidic depending on parent material (Shelford 1963). Consequently, the vegetative communities form complex mosaics and islands in the Intermountain area (Fenneman 1981; Passey and others 1982; Tidwell 1972).

The landscape and present climatic patterns are relatively new, and the flora and plant associations, especially in lowland areas, have not been in place for more than 10,000 years. Therefore, plants have been quite active in evolving new forms and establishing equilibria (Axelrod 1950). Plants in many cases have not reached their maximum area of adaptation. The current high mountains trap precipitation and cast rain shadows. Examples of the role of topography and attendant moisture trapping are illustrated in figures 4 and 5. Formerly, the precipitation was more evenly distributed and the tree species of the mountains were continuous over much of the area. The woody *Artemisia* and *Atriplex* shrubs that dominate much of the lowland landscape were either minor fringe components of the vegetation or were substantially displaced from their area of present distribution.

We treat 13 vegetative types in this book (table 1). The more widespread types cover much greater land areas than the restricted types. Some of the listed types are disclimax communities (lowland annual weeds and cheatgrass-red brome grass) brought about by human activities. Others have a substantially different vegetative makeup (for example, the big sagebrush communities) because of human actions such as grazing programs. We have excluded consideration of the creosotebush vegetative type, which occurs on the southwestern periphery of the Intermountain area

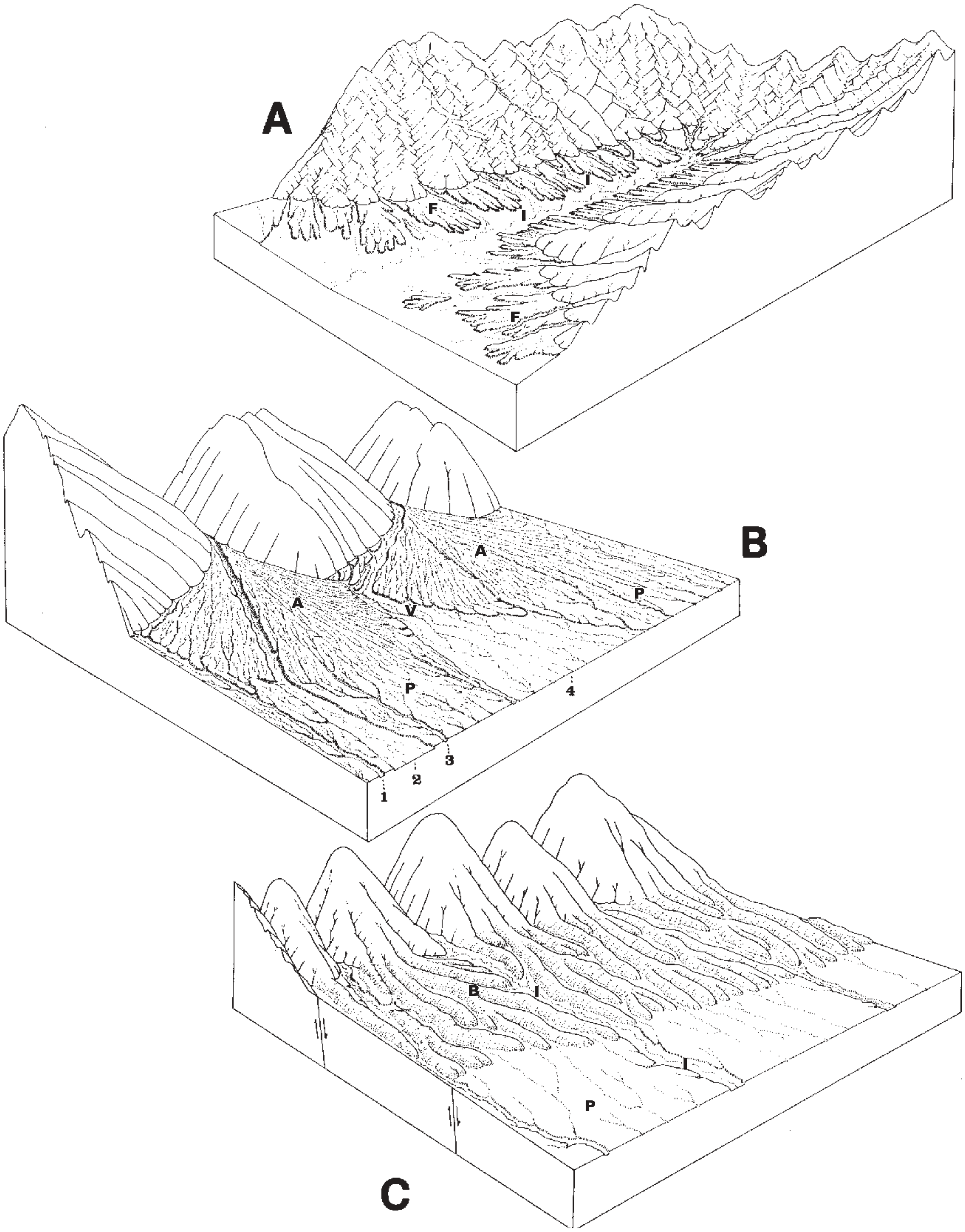


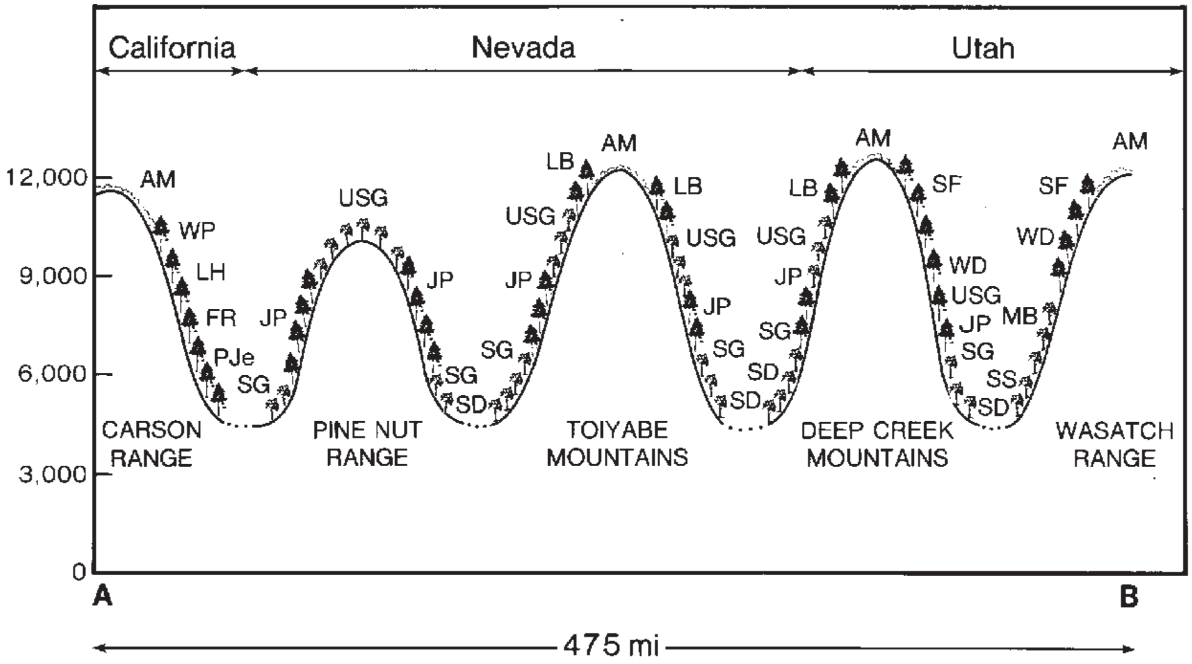
Figure 2—Topographical examples of the Intermountain area from Peterson (1981). (A) Mountain-valley fan with fan remnants [f] and inset fans [I]. (B) Mountain from alluvial fans with alluvial fans [A], interfan valley [V], and fan piedmont [P]. (C) Mountain front topography with ballenas [B], inset fans [I], and fan piedmont [P].

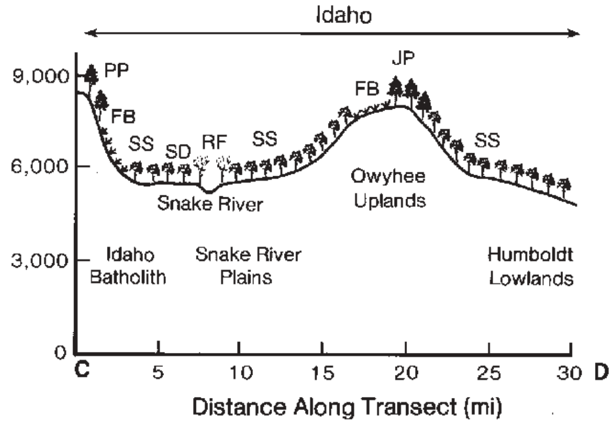
Figure 3—Map locating positions of vegetative types shown in topographic cross section in figure 4.

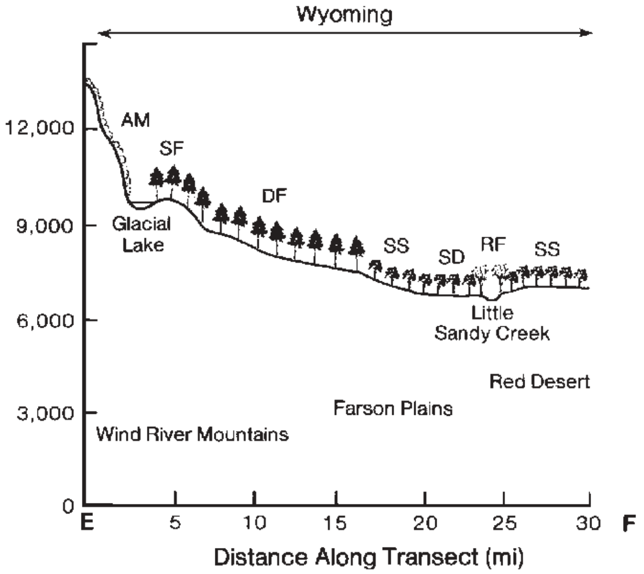
(fig. 1), because that area is essentially warm desert (Holmgren 1972) and that ecosystem behaves radically differently from the cooler areas that are the subject of this book.

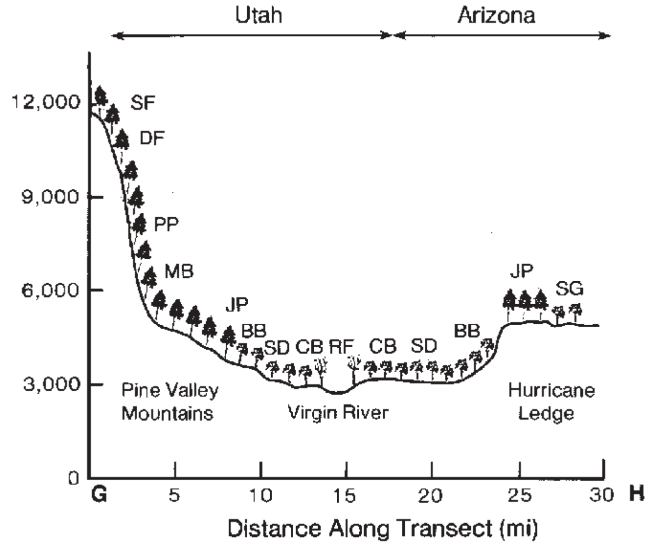
The Intermountain region, with the notable exception of a few metropolitan areas, is sparsely settled. Communities occupy a relatively small portion of the land. Agriculture, other than grazing, is restricted by water availability and rough topography, although there are some notable agricultural tracts in several Intermountain valleys and on the Snake River and Columbia River plains. In Utah, for example, only 1,436,000 acres (581,000 ha) (2.6 percent of the State) is currently irrigated, and only 5,629,000 acres (2,278,000 ha) (10.4 percent of the State) is arable or potentially arable (Wahlquist 1981).

The land provides habitat for many animal species (Shelford 1963). In the sagebrush areas are three important ungulates (elk, mule deer, pronghorn antelope), 13 carnivores (badger, coyote, bobcat, skunks, weasels, foxes, and others), 50 small mammals (chipmunks, grasshopper mice, deer mice, pocket mice, kangaroo mice and rats, woodrats, jackrabbits, cottontail rabbits, pocket gophers, voles, squirrels, prairie dogs, marmot, porcupines, and others), four game birds (grouse, dove, chukar, and quail), and 15 raptors (McArthur 1983a). Numerous songbirds inhabit the region. In a shadscale community in Utah's Uinta Basin, for example, 35 species of birds, many of them songbirds, were observed over a 2-year study (McArthur and others 1978b). Several of these species are managed for hunting and constitute a major


California
Nevada
Utah
12,000
9,000
6,000
3,000
0
AM
WP
LH
FR
PJe
SG
JP
USG
JP
SG
SD
SG
JP
USG
LB
AM
LB
USG
JP
SG
SD
USG
LB
JP
SG
SD
AM
SF
WD
USG
JP
SG
SD
MB
SS
WD
SF
AM
CARSON RANGE
PINE NUT RANGE
TOIYABE MOUNTAINS
DEEP CREEK MOUNTAINS
WASATCH RANGE
A
B
475 mi


Idaho
9,000
6,000
3,000
0
PP
FB
SS
SD
RF
SS
FB
JP
SS
Snake River
Owyhee Uplands
Idaho Batholith
Snake River Plains
Humboldt Lowlands
C
5
10
15
20
25
30
D
Distance Along Transect (mi)


Wyoming
12,000
9,000
6,000
3,000
0
AM
SF
DF
Glacial Lake
SS
SD
RF
SS
Little Sandy Creek
Red Desert
Farson Plains
Wind River Mountains
E
5
10
15
20
25
30
F
Distance Along Transect (mi)


Utah
Arizona
12,000
9,000
6,000
3,000
0
SF
DF
PP
MB
JP
BB
SD
CB
RF
CB
SD
BB
JP
SG
Pine Valley Mountains
Virgin River
Hurricane Ledge
G
5
10
15
20
25
30
H
Distance Along Transect (mi)

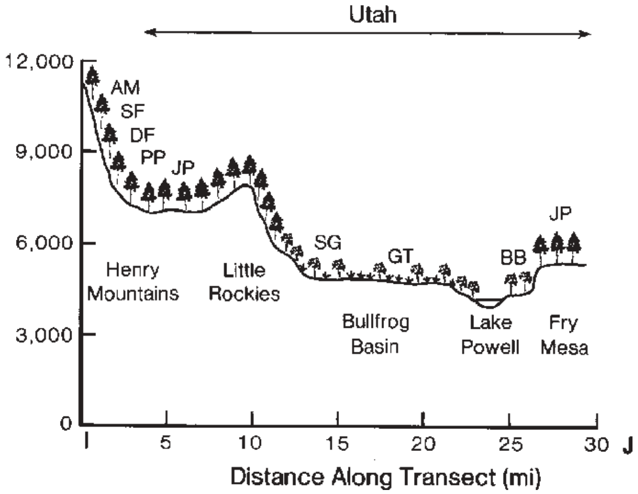

Utah
12,000
9,000
6,000
3,000
0
AM
SF
DF
PP
JP
SG
GT
BB
JP
Henry Mountains
Little Rockies
Bullfrog Basin
Lake Powell
Fry Mesa
I
5
10
15
20
25
30
J
Distance Along Transect (mi)

Figure 4—Cross sections of physiographic provinces showing elevation and topographic positioning of vegetative types located in figure 3. A and B are after Shelford (1963), C through J are after West (1983). Legend:

- AM = Alpine meadow and fellfield
- BB = Blackbrush (*Coleogyne ramosissima*), semidesert
- CB = Creosotebush (*Larrea tridentata*) desert
- DF = Douglas-fir (*Pseudotsuga menziesii*) forest
- FR = Red fir (*Abies magnifica*) forest
- FB = Wheatgrass (*Agropyron*), bluegrass (*Poa*) grassland
- GT = Galleta (*Hilaria jamesii*), threeawn (*Aristida*) shrub steppe
- JP = Juniper (*Juniperus osteosperma* - *J. occidentalis*), pinyon (*Pinus monophylla* - *P. edulis*) woodland
- LB = Limber pine (*Pinus flexilis*), bristlecone pine (*Pinus longaeva*) forest
- LH = Lodgepole pine (*Pinus contorta*), mountain hemlock (*Tsuga mertensiana*) forest
- MB = Mountain brush shrubland
- PJe = Ponderosa pine (*Pinus ponderosa*)-Jeffery pine (*Pinus jeffreyi*) forest
- PP = Ponderosa pine forest
- RF = Riparian forest
- SD = Salt desert shrubland
- SF = Spruce (*Picea engelmannii*)-fir (*Abies concolor*, *A. lasiocarpa*) forest
- SG = Sagebrush (*Artemisia*) semidesert
- SS = Sagebrush steppe
- WD = White fir—Douglas-fir forest
- USG = Upper sagebrush shrubland
- WP = Whitebark pine (*Pinus albicaulis*) forest.

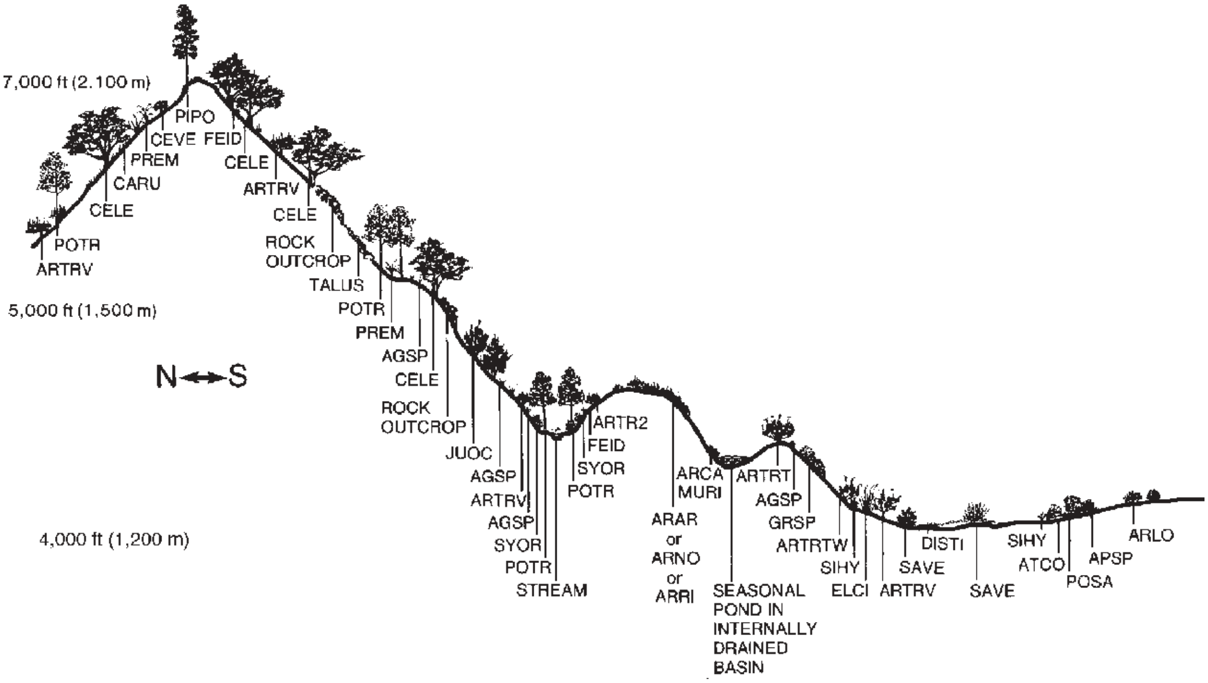


Figure 5—Elevation and site relationships among dominant plant species in the Great Basin of southeastern Oregon. Plant symbols are:

Plant symbol	Scientific name	Plant symbol	Scientific name
AGSP	*Agropyron spicatum*	ARAR	*Artemisia arbuscula*
ARCA	*Artemisia cana*	ARLO	*Artemisia longiloba*
ARNO	*Artemisia nova*	ARRI	*Artemisia rigida*
ARSP	*Artemisia spinescens*	ARTR2	*Artemisia tripartita*
ARTRT	*A. tridentata* ssp. *tridentata*	ARTRV	*A. t.* ssp. *vaseyana*
ATCO	*Atriplex confertifolia*	CARU	*Calamagrostis rubescens*
CELE	*Cercocarpus ledifolius*	CEVE	*Ceanothus velutinus*
DISTI	*Distichlis* spp.	ELCI	*Elymus cinereus*
FEID	*Festuca idahoensis*	GRSP	*Grayia spinosa*
JUOC	*Juniperus occidentalis*	MURI	*Muhlenbergia richardsonis*
PIPO	*Pinus ponderosa*	POSE	*Poa secunda*
POTR	*Populus tremuloides*	PREM	*Prunus emarginata*
SAVE2	*Sarcobatus vermiculatus*	SIHY	*Sitanion hystrix*
SYOR	*Symphoricarpos oreophilus*		

(Diagram from Dealey and others 1981).

recreational resource (Wallmo 1975). Other recreation includes camping, hiking, photography, nature appreciation, and harvesting food such as berries or roots.

Two additional major uses of Intermountain lands are for grazing of domestic livestock and for mining. The livestock industry in the Intermountain area was historically, and is currently, a sustaining source of regional income. Thomas (1973) gave a livestock value of nearly $2 billion for over 16 million head of livestock in Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, and Nevada. The mining industry was important historically, as well as currently. The Interior West is endowed with vast deposits of fuels and minerals. These resources are being exploited at an increasingly rapid rate as the Nation's mineral and energy needs expand. Many of these fuel and mineral resources are amenable to surface mining, which disturbs large land areas. The most prominent resources currently surface-mined or with such potential are coal, oil shale, phosphate, and uranium. Other mineral resources of the area include copper, lead, zinc, molybdenum, gold, nickel, iron, silver, gypsum, clay, vermiculite, pearlite, talc, flagstone, flourspar, sands, and gravel (Copeland and Packer 1972).

Intermountain lands are multiple use lands. Some uses impact on other uses as, for example, mining and livestock grazing on wildlife habitat. Virtually all uses have some impact on the premier value of the land as a stabilized productive watershed. Keeping the land productive, useful, and stable should be a universal goal, and to that end we dedicate the principles, procedures, and information you will discover in this book.

James N. Davis

Chapter 3

Research Background

The rangeland in the Intermountain West urgently required a scientific basis for its management, especially after the great mid-1800's livestock buildup, and then the plant die-off following the severe winters and droughts of the late 1800's (Stoddart and others 1975). After examining the Western ranges, Jared G. Smith (1895), an agrostologist with the U.S. Department of Agriculture, wrote that the perennial species were being overgrazed and were disappearing and were being replaced by weedy annuals. He maintained that no more livestock should be put on an area than could safely be carried through a poor season. Gaining public and livestock owners' acceptance of this concept has been a problem ever since (Stewart 1936).

The Associate Chief of the Forest Service in a Congressional report (Clapp 1936) maintained that severe depletion on ranges was universal and that most Western U.S. range types were in a depleted condition (depleted at least 50 percent from their original condition). These generalized Western range types included short grass, Pacific bunchgrass, semidesert grass, sagebrush-grass, southern desert shrub, salt-desert shrub, pinyon-juniper, and mountainbrush. He also indicated that the depleted conditions had far-reaching negative effects on wildlife and recreation.

Formal range research began about 1910, but a comprehensive range research program did not begin until 1935. Land managers, livestock operations, and the public needed research to be better informed on how to incorporate multiple land use management concepts and to take care of the irreplaceable land resources.

Near the turn of the century, some 1,500 attempts were made to improve the badly depleted Western ranges. These attempts largely failed, resulting in low enthusiasm and optimism for range seeding. The failures were thought to be primarily caused by inadequately adapted seed sources (mostly cultivated varieties) and insufficient site preparation (Stoddart and others 1975).

Establishment of the Great Basin Station (now known as the Great Basin Experimental Range) in 1912 quickly generated a variety of range and watershed research within the Intermountain Region. Early research at the Great Basin Station dealt with watershed management, effects of grazing on vegetative cover, and the relationship of these to erosive flooding from high intensity summer storms (Keck 1972).

Shortly after the project began in 1912, researchers tried revegetation with shrub plantings. Cuttings of many adapted shrubs were placed in the heads of mountain streams with the object of helping revegetate these depleted areas to prevent flooding. A short time later, shrub cuttings were placed in gullies and stream channels. Plantings were also made on depleted intervening ranges.

Research later looked at natural seeding by native species and artificial seeding with native or introduced species. Permanent quadrats were established to study the resulting changes in vegetative cover. Experiments with different species, mostly native (some exotics), were conducted to determine which were adapted to areas needing revegetation.

In the 1930s, and broadening in the 1950s, research was centered on plant species of value to wildlife. Still ongoing, this research has emphasized species adaptation, methods of seedbed preparation and seedling, optimum time for planting, and the effect of already established vegetation on the establishment of seeded species.

Research has stressed the importance of selected woody species, in combination with herbaceous species, for range and watershed in the Great Basin. This was a significant departure from research being conducted on herbaceous species only. Such work was done from the late 1920s through the mid-1930s on a seeding within the oakbrush zone (Keck 1972). This work was initiated because drought and heavy grazing within the oakbrush type had greatly reduced understory production. To make the oakbrush more productive, different species and seeding techniques were tried. The research effort on seeding was expanded across the broad geographic area of the Intermountain region in 1935. The study areas were in all life zones up to the much higher subalpine zone.

Since the late 1940s, State and Federal agencies and Western universities have devoted considerable effort in this area of research. In the latter years, the research has dealt with equipment development from collecting to planting seed. New areas of research include selection of races, strains, and varieties of species with regard to vigor, growth rate, and growth form; nutritional characteristics; drought tolerance; cold tolerance; animal preference; adaption; resistance to heavy repeated use; methods of reducing competition of naturally occurring plants; season to plant and methods of planting; species mixture compatibility; seeding rates and planting depths; and the broad ecological effect of the resulting vegetative changes (Plummer and others 1968).

Problems with big game ranges, particularly winter ranges, became important issues during the 1940s and 1950s. State Game and Fish Departments recognized the unrestricted livestock grazing and wildlife use had devastated many critically important winter game ranges. Scientists and research organizations previously affiliated with range research were solicited for their support. Big game habitat improvement and plant materials research began in earnest in Washington (Brown and Martinsen 1959), Idaho (Holmgren 1954; Holmgren and Basile 1959), California (Horton 1949; Sampson and Jespersen 1963), and Utah (Plummer and others 1968).

A cooperative effort between the Utah State Division of Fish and Game and the Intermountain Forest and Range Experiment Station of the USDA Forest Service began formally in 1955. This enhanced effort focused on pinyon-juniper woodlands and associated sagebrush-grass communities in poor condition, where there were heavy deer losses, especially during the severe winter of 1948 to 1949. The aim stressed the urgency of restoring forage production for both wildlife and livestock and improving soil stability. Species adaptation trial work has been done at more than 70 sites throughout Utah (including plant communities in the salt desert up to subalpine). Since 1955, the project has evaluated 39 genera and 244 species of grasses (2,000 accessions); 207 genera and 527 species of forbs (1,800 accessions); and 90 genera and 270 species of shrubs (2,000 accessions). To date, this project has evaluated more than 6,000 accessions of plants.

As early as 1957, this cooperative project was offering practical solutions to problems of inadequate production and suitable species to help relieve game range problems (Plummer and others 1957). Beginning with the first initial 1957 report, annual reports were published through 1967 (Plummer and others 1966a). The reports were culminated and summarized in a book, *Restoring Big Game Range in Utah*, by Plummer and others (1968). The reports began by identifying site factors that limited the establishment of some of the commonly planted species. Researchers studied species adaptation to help determine desirable forage plants that could be grown on the various vegetative communities (emphasis was on pinyon-juniper sites) throughout Utah. Work has continued on recognizing suitable sites and determining how to identify potential production on sites. Research has also looked at viability of native seeds and the environmental conditions favorable to their germination. Germination requirements were determined for many grasses, forbs, and shrubs, which helped develop better methods and equipment for planting these species. Studies determined “onsite requirements” to prepare for seeding and the basic practical methods for preparing wildland sites and for planting inaccessible areas.

Various equipment development centers and the Range Seeding Equipment Committee helped develop research on more effective equipment for collecting, cleaning, storing, and planting wildland seed. Considerable effort has been put into design, construction, testing, and field demonstrations. The demonstrations include use of some of the following equipment or techniques: cables, anchor chains (light to heavy, smooth, or Ely chains), shrub seeders, seed dribblers, aerial seeding, shrub transplanting, interseeding, diskchaining, Rangeland drills (using a mixture of seeds from shrubs, forbs, and grasses), and pipe harrows (Larson 1982; Roundy and Call 1988; USDA Forest Service 1992b).

Early efforts dealt with problems associated with the depredation of seeds by rodents, rabbits, birds, insects, and other biotic factors. Another major concern was the high population of grazing rabbits consuming mostly succulent forb species (Plummer and others 1968). These biotic factors do not appear to be as much a problem for range revegetation work as they used to be because of the decline in rabbit populations and late fall planting and seeding of larger areas. However, rodent depredation of shrub seeds (primarily bitterbrush) is considered as major a problem today as it was in the 1950s (Brown and Martinsen 1959; Everett and Stevens 1981; Holmgren and Basile 1959). Long-range studies were established using fourway exclosures to help determine compositional development of seeded and native species after chaining juniper-pinyon woodlands and how protection from grazing then affected deer, rabbits, and livestock.

Restoring wildlife habitat by artificial seeding of shrubs and broadleaf herbs has been somewhat hindered because of erratic germination characteristics of various species, the inability of shrub seedlings to compete with herbs, and the lack of equipment capable of operating on steep, mountainous, and undulating terrain. Considerable progress has been made in selecting and developing useful shrub and forb species, ecotypes, and cultivars for wildlife and range seedings (Plummer and others 1968). Official releases or cultivars come primarily through cooperative efforts of the USDA Forest Service, Intermountain Research Station (now called Rocky Mountain Research Station), the Utah Division of Wildlife Resources, and USDA Natural Resources Conservation Service (McArthur and others 1985; Monsen and Davis 1985; Stevens and others 1985c; Stutz and Carlson 1985). Today, seed growers know more about seed production and how to use marginal croplands to produce quality seed from official releases, or how cultivars of these selections could become more widely available in larger quantities and also be less expensive to use in wildland revegetation work.

Shrub research has been expanded significantly since 1960 by numerous scientists, agencies, and universities. But, although we have considerable information, techniques of shrub plantings and long-term performance of shrub-herb seedings still have not been thoroughly investigated. Current research is trying to further refine basic principles and techniques for the conversion and successful establishment of selected species mixtures onto wildlands. Some of these inquiries seek to understand the fundamentals of successional trends for these rehabilitated communities and how management can alter these trends for a longer lasting and productive conversion. Other work looks at species relationships and how compatible the associations of seeded and native species are during succession. Researchers seek alternative methods to enhance critical wildlife habitats without damaging key species or plant associations that are in poor vigor and density because of competition from unrealistically high densities of undesirable species.

This book is a compilation of research and experience acquired since the conception of the Great Basin Station. It reflects decades of cooperative work between the Forest Service’s Intermountain Research Station, the Utah State Division of Wildlife Resources, and many other agencies and universities. The book is our gift of knowledge and our wish for a productive future for our Nation’s rangeland.

Richard Stevens

Chapter 4

Basic Considerations for Range and Wildland Revegetation and Restoration

Plummer and others (1968) proposed 10 principles to follow when planning and implementing rangeland revegetation programs. These principles—or basic considerations for rangeland managers—are applicable to most sites in the Western United States (Jordan 1981; Merkel and Herbal 1973), and many projects in the Intermountain area have been conducted successfully by following them. This chapter provides a discussion of each principle and refers the reader to the other chapters of this book where more information may be found. These should be considered general guidelines and may require modification for local or unusual situations.

Ten Principles of Rangeland Revegetation

Principle 1: The proposed changes to the plant community must be necessary and ecologically attainable

See chapters 5, 6, and 7.

The general goal of most revegetation projects is to change a plant community having undesirable characteristics to one with desirable characteristics. Land managers must determine whether the proposed changes are necessary or desirable and ecologically sustainable (fig. 1). Revegetation normally involves changes in community composition, plant cover and density, and reduction in competition from undesirable species. If the results are to be sustainable, sites targeted for revegetation must have the ecological potential to support the proposed changes and to initiate natural successional processes following treatment. The goal of many wildland revegetation projects is to reestablish native species and restore natural community functions. However, attempts to completely convert one native plant community to another or to a community of introduced species are usually not recommended.

Areas that support a satisfactory number of native species will normally recover with proper management if invasive species are not present. Reduction in competition is best accomplished by selecting the most reliable technique that will have the least impact on existing desirable species. Controlled burning, application of selective herbicides, and various mechanical techniques can be used to remove or reduce competition and permit recovery of understory species.

Figure 1—The maintenance of diverse communities must be a key priority for land management throughout the West. Intact communities should not be altered or disrupted.

Principle 2: The terrain and soil must support the desired changes

See chapters 6 and 7.

The potential productivity of a site must be considered when planning revegetation projects. The USDA Natural Resources Conservation Service has completed soil classification surveys and soil descriptions for most range sites in the Intermountain area. These descriptions provide information that can be used to estimate potential productivity of individual sites and to select appropriate species for seeding them. Stevens and others (1974) defined various site characteristics that significantly affect productivity of semiarid juniper-pinyon and sagebrush/grass sites in Utah. The most important features were:

- Depth of the soil surface and subsurface horizons.
- Soil texture and the amount of salt in surface and subsurface horizons.
- Occurrence and location of hardpans or restrictive layers in the soil profile.

Within these plant communities are areas having coarse, rocky, shallow, alkaline, or saline soils. Restoring native vegetation on these sites may be quite risky and will most likely require considerable investment that may be difficult to justify. Justifications may include controlling erosion, stabilizing disturbances, containing weeds, reducing fire, or providing wildlife habitat. Extremely large disturbances of such environments occur in the Intermountain region, and most continue to degrade, usually through weed invasion. These situations must be addressed, and more reliable practices must be developed to better assure successful restoration (fig. 2).

Figure 2—Low elevation and arid sites commonly occupied by annual weeds are extremely difficult to revegetate. Remedial treatments are required to curtail the spread of weeds.

Species presence, age class distribution, and plant vigor can provide an index of soil types and the productivity and potential of an area to support specific species and communities. For example, sites with a predominance of small, but older pinyon or juniper trees generally have shallow soils. Likewise, relatively low-growing black sagebrush and winterfat occur on specific soil types. The presence or absence of different species may provide indications of specific physical or chemical properties of the soil. The presence of certain chenopods, for example, usually indicates basic and heavy soil textures.

In many cases, terrain and surface conditions determine whether a site can be treated and the techniques and equipment that can be used. Treatment of steep slopes is usually more costly than level areas, but successful chaining has taken place on sites with up to 65 percent slopes. Plowing, disking, harrowing, bulldozing, interseeding, transplanting, and other intensive treatments are usually confined to sites with less than 25 percent slopes.

Principle 3: Precipitation must be adequate to assure establishment and survival of indigenous and planted species

Refer to chapters 6 and 7.

Water is often the most critical factor affecting seedling survival and plant establishment in semiarid and arid regions. Generally, revegetation efforts should not be initiated in areas receiving less than 9 inches (230 mm) of annual precipitation. Before selecting species for a revegetation project, annual precipitation and seasonal distribution of precipitation should be determined (Jordan 1983; Stevens and others 1974). The most critical periods for soil moisture availability are those preceding and during germination (Jordan 1983). Consideration of annual moisture availability on the site must be a major factor in selecting species for planting. Seedling establishment of some species may only be successful during years with unusually high rainfall during the critical periods. Some species may be slow to establish even though they are common or dominant species on low precipitation sites.

Principle 4. Competition must be controlled to ensure that planted species can establish and persist

Refer to chapters 5 and 8.

Young seedlings of most species are usually unable to compete with established vegetation. Undesirable, highly competitive species must be removed or reduced in density to allow seedling establishment of the planted species (fig. 3). Stands of juniper-pinyon, cheatgrass, medusahead, red brome, cluster tarweed, and various perennial weeds are some of the competitive species that must be reduced in density to better assure establishment of seeded species. Methods developed to reduce competition include:

- application of selective herbicides
- anchor chaining or railing
- disking
- undercutting
- plowing and interseeding
- fire

Individual methods usually do not completely eliminate all plants but can sufficiently reduce competition to allow seeds of the planted species to germinate and establish. Treatments can often be difficult to select and implement where retention of existing and desirable species is desired.

Principle 5: Plant and manage site adapted species, subspecies, and varieties

Refer to chapters 12 and 17.

Factors important in determining which plant materials should be selected for seeding are:

- Use of site-adapted species and populations.
- Presence, density and composition of indigenous plants.
- The availability of seed or planting stock.
- Project objectives.

Successful range improvement projects begin with the selection of species that are adapted to the area proposed for treatment. One must make certain that

Figure 3—Reducing competition from weedy annuals is essential to increase the probability that seeded species will establish.

only adapted sources and strains are used. Generally, seed from populations growing under climatic and edaphic conditions that are similar to those of the proposed treatment area are most likely to survive. Materials selected for planting must be able to establish, persist, and reproduce on the site.

Care must be taken to prevent overseeding species that may be aggressive and dominate the site. Rapidly developing species are often included in seed mixtures to provide ground cover and forage and to modify microclimates while slower developing species become established. Management should seek to maximize establishment of all desired species, whether seeded or present in the existing vegetation. Seeding the right combination of plants is critical to the ultimate community diversity that develops over a number of years.

Principle 6: A multispecies seed mixture should be planted

Refer to chapters 12 and 17.

Many early revegetation projects emphasized the use of a limited number of species. For most wildland revegetation projects today, however, there are many reasons to seed mixtures rather than single species:

- Restoration of native plant communities usually requires the reintroduction of a variety of species to provide community structure and function.
- A combination of species is normally required to initiate natural successional processes.
- A variety of species that are adapted to the diverse microsites occurring within major seedings should be seeded.
- Mixtures reverse the loss of plant diversity and enhance natural recovery processes following natural impacts from insects, disease organisms, and adverse climatic events.
- Chances for successful seeding are often improved when mixtures are planted.
- Mixtures can provide improved ground cover and watershed stability.
- Mixtures produce communities that provide greater potential for reducing weed invasion and for providing for a balance in the use of all resources.
- Combinations of species can provide better quality habitat including cover and seasonal forage.
- Total forage production and seasonal succulence can be increased with mixtures.
- Mixtures are generally more aesthetically pleasing and match natural conditions.
- Mixtures provide diverse habitats required to sustain wildlife species.

Seeded mixtures should include the various growth forms, that is: grasses, forbs, shrubs, and trees that existed prior to disturbance. Seeded and indigenous species must be compatible and able to establish and develop together. Successional changes must occur that will result in the ultimate development of a desirable plant community.

A few special situations such as providing immediate ground cover to stabilize erosion may occasionally dictate the seeding of only one or a few species. Because some shrubs establish and grow much slower than many herbs, planting individual woody species with plants having similar establishment and growth characteristics is recommended. Selectively planting different species in separate rows or spots is sometimes required.

Principle 7: Sufficient seed of acceptable purity and viability should be planted

Refer to chapters 12 and 17.

It is important to calculate seeding rates carefully. Planting excessive seed is unnecessarily expensive and increases competition among seedlings and indigenous species. Low seeding rates, on the other hand, may jeopardize stand establishment.

It is essential that seeding rates be determined on a pure live seed (PLS) basis. The number of pure live seed (PLS) per unit of weight varies greatly among species and seed lots (fig. 4). If an equal *number* of live seeds of alfalfa, antelope bitterbrush, slender wheatgrass, and fairway crested wheatgrass were seeded, then average *weight* would be 1.5 lb (0.7 kg) of alfalfa, 20.8 lb (9.5 kg) of antelope bitterbrush, and 3.7 lb (1.7 kg) of slender wheatgrass for each pound (0.5 kg) of fairway crested wheatgrass.

Seed must be tested for purity and germination and properly tagged with the current results to enable the buyer to calculate seeding rates. A certified seed laboratory should analyze all seed, including wildland collections. Seed stored for an extended period should

Figure 4—Selecting and properly planting high quality seed is critical to planting success.

be retested before seeding. Care should be taken to ensure that all species can be seeded at the expected rate with the proposed seeding equipment, and that the equipment can function properly over the entire planting site.

Principle 8: Seed must be planted on a well-prepared seedbed and covered properly

Refer to chapters 12 and 17.

Proper seed coverage is essential for successful germination and seedling establishment. Depth of planting is generally determined by seed size. However, it is also influenced by special requirements of individual species. As a general rule, seeds should not be covered more than three times the thickness of the cleaned seed. Seed of certain species including winterfat, rabbitbrush, sagebrush, and asters are best seeded on a disturbed surface with shallow soil coverage. Indian ricegrass on the other hand, should be seeded 2 to 3 inches (5 to 7.6 cm) deep. Soil type and surface conditions also influence seeding depth. Most species benefit from firm seedbeds, but some do well in loose soils. Heavy soils may crust and prevent emergence. Light textured soils are less likely to crust or become compact; however, they dry rapidly and, thus, deeper planting depths are recommended.

Principle 9: Plant during the season that provides the most favorable conditions for establishment

Refer to chapters 12, 17, and 18.

Late fall and winter seedings have been most successful in the Intermountain West. Advantages of late fall and winter seedings include:

- The inherent seed dormancy of many species is released by overwinter stratification.
- Seeds are in place in early spring when soil moisture is most likely to be available for germination, seedling emergence, and growth. Early emerging seedlings are better able to resist high summer temperatures and drought.
- Seed predation by small mammals and birds is less likely to occur if seeds are planted when these animals are less active.

Seeding too early in fall may result in precocious germination following unseasonably warm periods coupled with autumn rains. Seed losses to mammals and birds also can be high during this period.

Transplanting should be completed in early spring when the soil is wet and before active growth of the transplant stock or the native vegetation has begun. Fall transplanting is generally not recommended unless soils are moist and likely will remain moist until they freeze.

Principle 10: Newly seeded areas must be managed properly

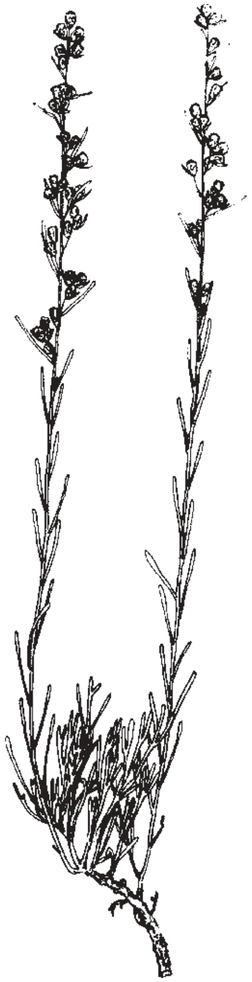
Refer to chapter 16.

As a general rule, newly seeded areas should not be grazed for at least two or three growing seasons following planting. Poor sites and slow-growing species may require a much longer period of nonuse. When grazing does occur, it should be carefully regulated.

Stephen B. Monsen

Chapter 5

Restoration or Rehabilitation Through Management or Artificial Treatments



Introduction

Improvement of vegetative and edaphic conditions on some wildland sites can be achieved through proper management as well as by manipulative plantings (Vallentine 1980). Sites that have been subjected to serious abuse or that lack needed cover, habitat, or forage resources can be improved by various methods (Vallentine 1980). Prior to the development of any site improvement program, land managers must first discern the resource needs and suitability of an area for treatment (Plummer and others 1968). Then appropriate methods and techniques can be developed.

Proper management is the key to the improvement or maintenance of acceptable plant cover and soil stability (fig. 1). Successful revegetation may dramatically change plant and watershed conditions. Yet without appropriate management, improvements can be lost (Vallentine 1980). Following are some factors that influence decisions on whether to improve sites through management schemes, artificial measures, or both. Factors that influence site improvement through management are discussed first. Factors that are of special concern when considering restoration or rehabilitation are presented next. Factors that influence management decisions are also important considerations in developing planting programs.

Management Considerations ______

Status and Condition of Existing Vegetation

Restoration or rehabilitation projects are not usually contemplated unless the native communities have been severely disturbed, resulting in adverse watershed conditions and loss of desirable vegetation. If an adequate composition of desirable species that is capable of recovery and natural spread remains, artificial seeding is unnecessary (fig. 2). If properly managed, plants that have been weakened by excessive grazing and browsing can normally recover and begin producing seed within a few years. Plants growing in arid environments may require longer to recover. Protected areas in the blackbrush and Indian ricegrass communities of southern Utah require many years to recover following heavy grazing. Some disturbed areas within the Wyoming big sagebrush zone in southern Idaho have remained in almost a static condition for more than 50 years with protection from grazing. However, considerable improvement resulted following three unusually wet years. Woody species that exist in mountain brush communities normally have the capacity to recover and spread quickly when managed correctly. Woody species growing at lower elevations are usually usually exposed to more adverse climatic conditions and many are less capable of natural spread. Thus, recovery in salt desert shrublands and low sagebrush foothills is slow.

Figure 2—Natural recovery of native species 5 years following a prescribed fire in a pinyon-juniper community.

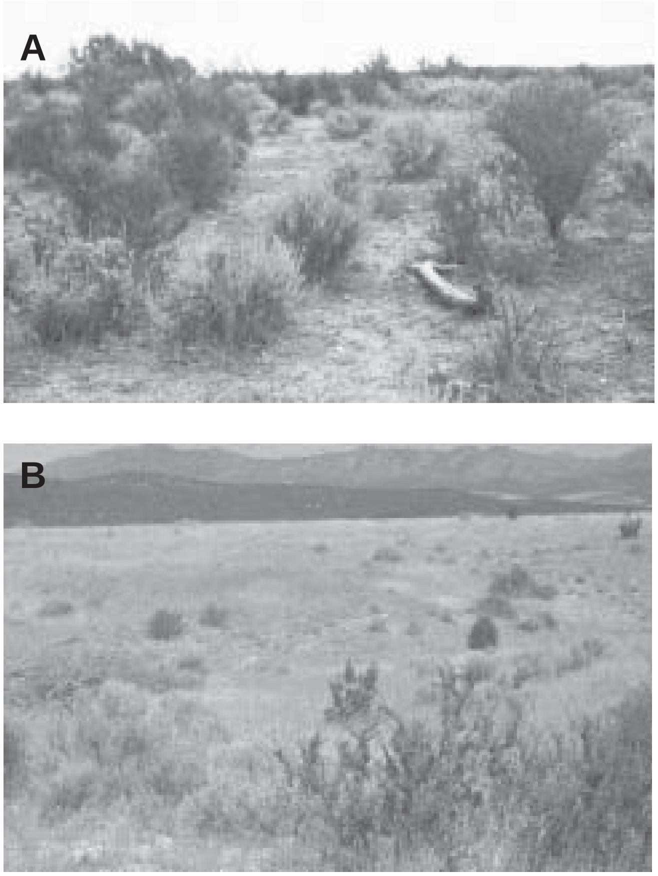


Figure 1—(A) A seeded area that has been properly grazed. (B) A poorly managed site where shrubs are low in vigor and the understory is declining in diversity, density and vigor. Matchbrush and cheatgrass are increasing on this site.

Many native communities are capable of self regeneration by natural seeding or sprouting. However, replacing individuals that die naturally is an entirely different situation than repopulating a broad area where most species have been depleted by grazing.

A disturbed site may still support some species but not others. This is quite common on most overgrazed rangelands. The more desirable forage plants are often lost by selective grazing (fig. 1). Other remaining, but less desirable species may be capable of recovery, but the important forage species may not reappear without some means of artificial seeding. Controlling livestock grazing on important game ranges often results in an increase in total herbage production. However, the recovery of important broadleaf herbs frequently does not occur. Species such as nineleaf lomatium, sticky geranium, and bramble vetch usually occurring on specific microsites may not dominate a community, but they are important as seasonal forage. Unfortunately, these same species are often eliminated by grazing and do not persist in sufficient numbers to recover, even when protected for extended periods. If desirable species are not present, improvement by natural means may be unattainable.

Natural recovery processes must be considered in predicting secondary successional changes. Although some desirable species may not be present on a disturbed site, their reentry may depend on factors other than the adverse effects of grazing. For example, some shade dependent plants are not able to survive if overstory species are not present. The shade tolerant species will not appear until overstory plants have become established, assuming a viable seedbank remains.

The recovery capabilities of individual species must be correctly evaluated to decide on methods of improvement. Plants of big sagebrush, rubber rabbitbrush, and sulfur eriogonum spread well from seed, even under stressful situations. By contrast, few seedlings of Saskatoon serviceberry, skunkbush sumac, and true mountain mahogany (fig. 3) are encountered even though abundant seed crops are produced most years. Some species are site specific, existing as pure stands but intermixed with other communities. Such is the case with curlleaf mountain mahogany. If these stands are eliminated or seriously diminished, natural recovery is extremely slow (fig. 3). Recovery is affected by limited seed sources, low plant density, and poor distribution of parent plants.

Although more time may be required to achieve natural recovery, this may be the most practical approach. However, land managers must understand that during the period of recovery the vegetation may not furnish desired forage and cover. Until a complete recovery of all species is attained, all resource values may not be provided.

Status of the Soil Conditions

Soil and watershed conditions are critical resources that cannot be allowed to deteriorate. If disturbance has progressed to the extent that soil loss is serious, rehabilitation measures must be implemented (fig. 4). If adequate protection of the soil and watershed through management is not realized within a satisfactory period, artificial revegetation measures will be required.

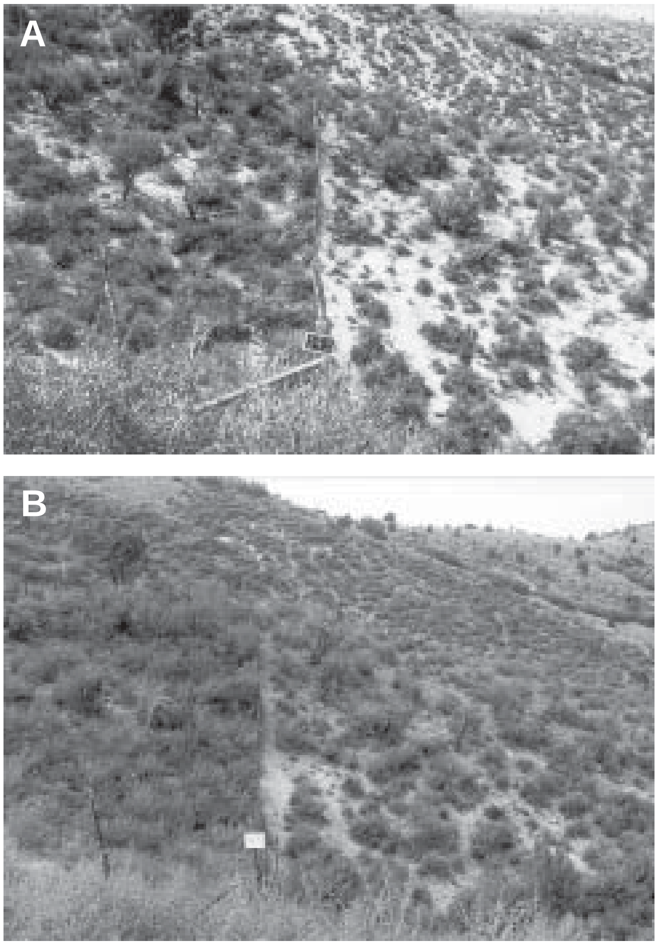


Figure 3—Exclosure (left) established in the 1930s. (A) True mountain mahogany extensively used outside (right) and recovering somewhat without use in the exclosure (left) in 1954. (B) Even with removal of cattle and significant reduction in deer numbers, the condition of the true mountain mahogany outside the exclosure has changed little by 1995. There is little difference in the curlleaf mountain mahogany inside or outside the exclosure between 1954 and 1995.

A long recovery can be accepted if the soil and watershed resources do not deteriorate appreciably during the initial stages of natural recovery. However, both the physical and chemical condition of the soil affect seedling establishment and growth. Soil surfaces must be conducive to seedling establishment if the vegetation is to recover. An open, but stable, surface may exist, but surface crusting (Army and Hudspeth 1959) or freezing may prevent seedling establishment (Hull 1966). In addition, lowering of the water table through downcutting of the stream channel can and does influence areas adjacent to the drainage. Wind erosion and lack of surface organic

Figure 4—Soil erosion from an area depleted of vegetation. Establishment of desired species on severely eroding and unstable surfaces can be difficult.

matter (Welch and others 1962) are highly detrimental to seedbed conditions. These and other features must be considered when assessing soil and watershed conditions.

Protecting the soil resource may be necessary before attempts are made to improve habitat or forage conditions. This has been a major concern in many circumstances, particularly along the Wasatch Front, within the Idaho Batholith, and in the Colorado River drainage. The vegetation in these areas can often recover satisfactorily through protection, but eroding areas may respond more slowly. In addition, the occurrence of intense summer storms and other climatic events can be expected and can have devastating and long-lasting impacts.

Management Strategy

Wildland sites in good or fair condition are usually able to recover through natural processes. However, providing protection from human-induced changes is often difficult. Big game wintering sites and spring and fall ranges may constitute small, but important, portions of a broad geographic area. Attempts to restrict use of the broad area for sufficient time to allow recovery of these seasonal ranges may not be practical. In addition, efforts to maintain high populations of game animals, or continued livestock use on these broad areas may not be compatible with natural recovery. A well designed management system to improve habitat conditions may require a long-term commitment.

Management strategies must ensure that the following conditions are created: (1) the development of suitable seedbanks, (2) the creation and protection of adequate seedbeds, (3) the protection of plants for sufficient time to provide an acceptable composition of species, and (4) the recovery of all sites, especially the most critical areas.

Impacts on Other Resources

Few areas can be managed to support one resource, yet treatment practices are often developed to enhance a single primary resource. In these cases attention must be given to the expected impacts on other resources. For example, the value and impact of management schemes on wildlife populations must be determined as these schemes influence recreation, livestock grazing, and other uses. In addition, management strategies that are used to regulate animal distribution, population numbers, and seasonal use must be developed as part of the rehabilitation program.

The decision to artificially treat an area is normally based on the value of numerous resources. For example, a site essential in maintaining a viable big game herd that may also be an important watershed area might receive treatment priority (fig. 5).

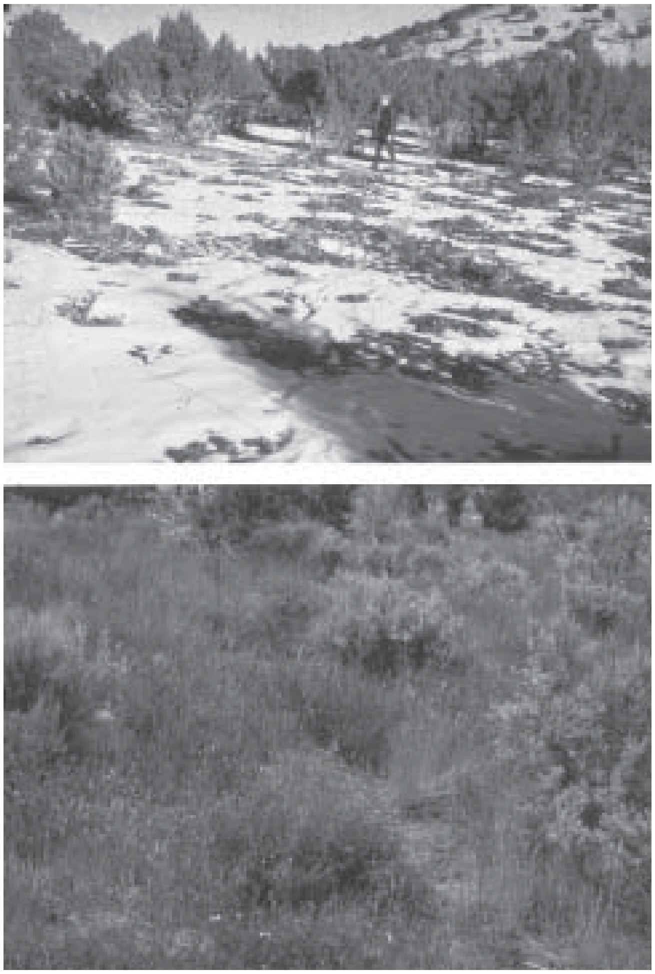


Figure 5—Important watershed and big game winter range prior to and 6 years following chaining and seeding.

Immense Areas

Wildland ranges include extensive and diverse acreage throughout the Western States (McGinnies 1972), The enormous size of this area simply precludes comprehensive treatment of all seriously depleted sites. Many sites support a desirable vegetative cover, and attempts to convert or replace native communities should not be made. Some sites support less productive and undesirable weedy species and unsatisfactory watershed conditions (Blaisdell and Holmgren 1984). However, the cost to of correcting these problems may not always justify extensive artificial treatments. Site improvement may be better attained through careful management.

Numerous sites on steep, inaccessible slopes cannot be treated with existing equipment. Topographic and vegetative conditions are usually very diverse within most areas, and site preparation and planting equipment are not always versatile enough to treat all circumstances. Consequently, some areas cannot be properly treated.

Climatic Conditions

Many arid or semiarid wildlands that occupy extensive areas within the Intermountain States cannot be satisfactorily treated using current revegetation and restoration measures (Blaisdell and Holmgren 1984; Bleak and others 1965). Arid conditions and irregular moisture patterns may not be conducive to seedling establishment. Large acreages are normally treated and seeded only once. Uniform stands may not develop, yet replanting is costly and impracticable. Bleak and others (1965) found sites in regions receiving less than 8 to 10 inches (200 to 250 mm) of annual precipitation are the most difficult to treat (fig. 6). Recent studies have identified and developed promising species for semiarid sites (Asay and Knowles 1985a,b; Rumbaugh and Townsend 1985; Stevens and others 1985c; Stutz and Carlson 1985), however, appropriate planting techniques for successful planting of these species may not be available. Many semiarid ranges, including sites supporting shadscale, winterfat, Nevada ephedra, and budsage need improvement, but changes can often be more easily attained through proper long-term management than through artificial revegetation.

Many species that occupy arid sites are extremely valuable plants, and should be retained or enhanced. However, these plants are not easily cultured and are not well suited to artificial planting. Suitable substitute species that could be used in their place are not known (Hull 1963b; Plummer 1966). Consequently, many arid and semiarid sites must be carefully managed to minimize abuse and stimulate natural recovery.

Figure 6—It is difficult to revegetate desert regions that receive less than 8 to 10 inches of annual precipitation.

Artificial Revegetation Considerations

Similar factors must be considered in determining if management or revegetation should be employed to improve a wildland disturbance. However, certain factors must be looked upon quite differently depending on which approach is used. For example, the size of an area requiring restoration or rehabilitation is a major factor to be considered. A large area may be difficult to manage due to differences in topography, access, or season of use. Consequently, improvements may not be easily achieved by management. Similarly, the area may be so diverse that artificial revegetation may be difficult to achieve using a single method or closely related methods of site preparation and seeding.

Following are some factors to consider in determining the applicability or practicality of artificial revegetation. The list is not considered all-inclusive. Other issues may also be important, particularly in specific areas. However, the factors discussed below must be considered before developing improvement measures.

Site Suitability

Plummer and others (1968) emphasized the importance of correctly discerning the capabilities of a site prior to treatment. Too often, attempts are made to convert a vegetative community to a complex of desirable but unadapted species. The site must be capable of sustaining the selected species. In addition, species included in the seed mixture must be compatible with one another and with the existing native species.

Some attempts have been made to improve shrublands by seeding grasses, or by introducing other shrub species. Sites with low precipitation, shallow soils, or both, that support black sagebrush, bud sagebrush, or shadscale have been plowed and seeded to introduced grasses. In many cases treatments have failed and less productive plants have invaded (Blaisdell and Holmgren 1984). Failure to recognize the suitability or capability of these sites has resulted in the loss of the adapted native plants.

Sufficient information is available to determine the adaptability of many introduced and native species (Asay and Knowles 1985a,b; Barker and others 1985; Carlson and Schwendiman 1986; Davis 1983a; Hafenrichter and others 1968; McArthur and others 1985; Monsen and Davis 1985; Monsen and Shaw 1983b; Plummer and others 1968; Stevens 1983a, 1987a; Stutz and Carlson 1985). Some species are difficult to establish through artificial seeding, and the desired complex of adapted species is difficult to achieve. However, it is not advisable to seed or plant substitute species that are marginally adapted but easily established.

A site may be capable of sustaining a complex array of species. However, initial attempts to reestablish certain species may be unsuccessful (Jordan 1983). Soil crusting and high salt content in the soil surface often limit seedling establishment of species on sites supporting black greasewood (Naphan 1966; Rollins and others 1968; Roundy and others 1983). Rodent foraging seriously limits seedling survival of curlleaf mountain mahogany (Dealy l978), antelope bitterbrush (Giunta and others 1978), and Martin ceanothus. Rabbits, livestock, and big game selectively graze some species, particularly broadleaf herbs, limiting their survival even when planted under favorable climatic and soil conditions. Animals tend to concentrate on seeding projects if the adjacent wildlands are void of an adequate forage cover. Weed infestation (Eckert and Evans 1967) and slow or erratic seedling growth (Jordan 1983) of many seeded species often diminish their success. Artificial plantings or natural seedings of black chokecherry, Woods rose (Monsen and Davis 1985), skunkbush sumac, and green ephedra, (Monsen 1975) often are not successful, and attempts to restore large areas from a single planting cannot always be achieved. These factors significantly influence site suitability for improvement either by management or artificial revegetation.

Community development and maturation must also be considered when designing a revegetation program. Newly developed or introduced plant materials must be able to establish, and persist and reproduce. If they are unable to reproduce satisfactorily, stands ultimately deteriorate. Fourwing saltbush, a highly productive and palatable forage plant, has been successfully established on sites once dominated by Wyoming big sagebrush, but it has been short-lived and unable to reproduce by natural seeding.

Similarly, artificial seedings of antelope bitterbrush and Stansbury cliffrose have established satisfactorily on cheatgrass ranges if the understory weeds are reduced at the time of shrub planting. Natural seeding by either shrub species has not occurred with competition from the understory weeds, and stands have slowly disappeared.

Various introduced herbs and shrubs perform favorably from initial plantings on wildland sites. However, some have failed to survive when infrequent insect outbreaks and other unusual stress events occur. Similar situations have been encountered when highly desirable native species, such as blue elderberry, have been planted on sites where the species normally does not exist, even when such sites were quite similar to the origin of collections. Blue elderberry persists when planted on big sagebrush sites unless a series of unusually dry years has occurred. Plants then become weak and disappear. Many years may pass before drought events cause blue elderberry plants to die.

Some ecotypes of a particular species demonstrate specific site adaptability; unadapted ecotypes may then be sorted out quite rapidly (Davis 1983a; McArthur and others 1983b). Other ecotypes may be equally sensitive, but climatic or biological events that affect their survival may not occur frequently. Consequently, these ecotypes may persist for an extended period before being eliminated.

Perhaps the most critical issue to be considered in revegetating semiarid and arid sites is the availability of soil moisture for seedling establishment (Jordan 1983). Attempting to seed areas that receive erratic amounts of moisture is extremely hazardous. Seeds of many species require periods of cold-moist stratification to initiate germination. In addition, developing seedlings must receive sufficient moisture to assure establishment. Attempting to plant in areas dominated by weeds, or during periods when soil moisture is unfavorable for growth, is ill-advised. Seeding species with different germination and growth characteristics can be successful if the moisture requirements of all species are met (Shaw and Monsen 1983a). Problem sites may be capable of supporting a specific array of species, but current planting techniques are not satisfactory for planting many sites. Consequently, the site must be suitable for: (1) maintaining the planted species and (2) applying currently available methods of treatment.

Status of Soil and Watershed Conditions

Sites that have been degraded and subjected to erosion are normally the most critical areas requiring artificial restoration. Protection must be provided for onsite and downstream resources. However, barren and eroding soil surfaces normally are not satisfactory seedbeds (fig. 4). Recovery of natural revegetation is often prevented because of unstable surface conditions and a limited soil seedbank. Artificial seeding, including site preparation, is difficult and costly to achieve on unstable watersheds. Areas should not be allowed to deteriorate to the point that rehabilitation or other costly measures are necessary to reestablish a plant cover.

Soil conditions must be carefully surveyed to assure that a satisfactory seedbed can be created. Too often stands of juniper-pinyon have been allowed to fully occupy steep hillsides, and woody and herbaceous understory species have been lost. The change in plant composition reduces soil protection. Tree competition must be reduced to allow recovery of the understory species that have been lost. However, control measures must provide soil protection during the period of conversion. In addition, soil conditions must be improved to provide a suitable seedbed. Chaining provides soil protection by leaving both trees and litter on site and a satisfactory seedbed is created. Burning can be used to reduce tree competition, but this control measure does not provide adequate soil protection or create a seedbed.

Problem areas may be ranked depending upon their values and the severity of the disturbance. The most critical areas may then be selected for treatment. The feasibility of treating the candidate sites must be considered in developing rehabilitation plans.

Status of the Vegetation and Presence of Weeds

Regardless of the disturbance, provisions must be made to control existing weeds or prevent their entry onto prepared seedbeds (Hull and Holmgren 1964). Complete elimination of all weedy species is not essential to planting success. Weed control is necessary to ensure seedling establishment; thereafter less desirable plants can be controlled by natural competition (fig. 7). Control may be necessary to reduce the presence of undesirable weeds or diminish the density and influence of desirable natives on establishing seedlings (Blaisdell 1949). Attempting to control weeds, and yet maintain desirable natives, is a difficult task, particularly when working on wildland situations.

In some situations weedy plants may assume dominance and prevent the natural establishment of more desirable species. The weeds may be annuals such as cheatgrass and Russian thistle, or perennials including big sagebrush or Utah juniper. Plant density must be significantly reduced to ensure establishment of seeded species. In addition, control measures must be used to prevent the immediate recurrence of weeds.

Cheatgrass is the most severe weed problem encountered on a wide spectrum of plant types within the Intermountain Region (Klemmedson and Smith 1964; Stewart and Hull 1949). Control is not easily achieved, but unless competition is reduced to a low level, few seeded species will establish.

Figure 7—Needle-and-thread grass suppressing cheatgrass and other weeds.

Appraisal of Resource Values

Restoration or rehabilitation projects have been completed on various sites to improve wildlife habitat or forage production without carefully determining the best specific locations where these resources are located. Large acreages are often treated assuming "the more acres treated, the more habitat or forage provided." This assumption is sometimes incorrect. Chaining and seeding pinyon-juniper sites was done to improve critical midwinter deer and elk habitat, even though they were not midwintering areas. The important midwinter sites may be exposed slopes and ridgetops that may support a limited number of species (fig. 5). These small confined locations are the ones that should receive special treatment.

Revegetation projects should be designed to provide cover, forage, and protection on sites where the greatest benefit can be derived. It is obvious that treatments must be done efficiently. Consequently, when chaining or using massive equipment, large acreages can often be treated cheaply. Large tracts of land can be treated easier than isolated sites. However, treatments should be designed to accomplish the goals of the project, and the needs of targeted animals.

Selective Treatment and Impacts on Associated Areas

Artificial treatments can be designed to restore critical areas indirectly. Artificial revegetation can and does benefit both the treated area and adjacent sites. Consequently, areas having good access and highly productive soils can often be treated, leaving adjacent sites to recover naturally. However, the untreated sites must be able to recover. Highly palatable species, or plants that provide seasonal forage, can be seeded onto specific sites to attract and hold grazing animals on adjacent areas (Stevens 1987b). Treating an area of sufficient size is necessary to disperse animal use and allow the seeded species and untreated areas a chance to develop. Not all untreated sites respond favorably. Areas that are nearly void of desirable species or dominated by weedy plants do not generally respond to a reduction of grazing.

Selective treatment, an important practice, can be used to promote successional changes, and supplement improved habitat, seasonal availability of herbage, and forage quality (Wight and White 1974). Adding an appropriate shrub or herb to the existing vegetation can enhance forage resources, restore specific species, and control weeds. Interseeding selected species into existing stands is an important technique to improve large areas without excessive costs.

Management and Control

Treated sites must be managed to retain species composition, plant vigor, and productiveness. Treated sites may require special protection that cannot be provided. If this occurs, the value of the project is lost. Treated areas must be of appropriate size to accommodate seasonal use during the time of plant establishment and over a long-term maintenance period. Areas must be of sufficient sizes and diversity to respond to climatic conditions and associated biotic factors that influence plant succession. Some treated areas may be heavily grazed to such an extent that weeds are able to invade during stressful periods. The treated sites must be able to accommodate all forms of use, including somewhat abnormal events such as insect attacks and drought.

Treated sites should be managed or used as initially intended. Too often areas are seeded or treated to provide big game habitat, but are then used as grazing pastures for livestock, despite the fact that the areas may not be designed to accommodate these high levels of use. Treated sites regress if not properly managed. Improper use, particularly during the period of seedling establishment, can eliminate certain species and decrease the overall success of the project.

Availability of Adapted Plant Materials

Rehabilitating ranges to benefit wildlife usually requires the inclusion of various native species in the seeding (Stein and others 1986). Restoration projects require seeding diverse mixtures of native species. Seeds of many native species are not always available and substitute species are frequently planted. The lack of adapted ecotypes of many species limits many plantings. The use of introduced grasses has facilitated many rehabilitation projects. However, the more commonly available grasses and broadleaf herbs do not satisfy all resource needs. Seed sources must be developed to assure the use of desirable and adapted native plants.

Site Improvement Costs

The costs incurred in restoration and rehabilitation ultimately determine the site treatment and seeding practices to be employed. However, it is difficult to determine the value of stable plant communities; wildlife habitat, including nongame animals; watershed protection; and recreational uses. Benefits cannot be calculated wholly on the increased production of forage. All benefits must be considered over the entire life of the project.

James N. Davis

Chapter 6

Climate and Terrain

Our knowledge of the physical requirements of cultivated plants is far advanced in contrast to that of the native and introduced species used in range plantings. Cultivated plants are usually grown as single varieties of a species under specific controlled conditions to ensure maximum yields. Native and introduced range plants often grow in species mixtures on sites that are more variable than agricultural croplands. Our knowledge of the specific requirements of individual species or varieties may not always apply with respect to interspecific competition or to the widely varying wildlands now being reclaimed or rehabilitated. Data obtained by growing native and introduced species in pure stands are only partially applicable to stand mixtures because the requirements for a species in a pure stand often differ from its needs when competing with other plant species. At present, we understand little of the effects of competition, let alone the complex interaction of climate, soil, and terrain upon which our native plant species grow (Hansen and Churchill 1961).

Any site under consideration for rehabilitation or restoration will have its own peculiar combination of environmental conditions that interact to form a distinctive environment, and thus a unique plant community. Ideally, the use and management of any resource should be based on extensive knowledge and understanding of that resource and its environment. Knowledge of the nature of the potential plant community to be rehabilitated (table 1) is a prerequisite to an evaluation of a site condition (Passey and Hugie 1962a). Site potential cannot be determined unless one becomes familiar with the complexity of its environmental parameters.

It is not the purpose of this short review to thoroughly detail all the possible responses that plants exhibit with respect to their environment. Rather, this review is to help make a person, in a general way, more familiar with how complex environmental factors can become and what their possible effects on a plant can be. Billings (1952) felt that the complexity of the interrelationships between the plant and its environment and between the various factors of the environment in themselves was almost enough to discourage any attempt at a complete analysis and understanding. To make it even more complex, there is, in many cases, an apparent compensation of one environmental factor for another. This will often occur near the boundaries of a species' range where it allows individuals of a species to occur in areas that do not appear to be normal habitat (Billings 1952). Since the environmental complex is so complicated, it has been customary to break up the environment into arbitrary factors and then study the effect of each factor on the seeded and endemic species. This approach is being used in my analysis herein.

Table 1—Climatic zones, showing major vegetational types and average annual precipitation in inches.

Climatic zone	Vegetational zone and associated shrubs and herbs	Average annual precipitation
		Inches
Lower Sonoran	Southern desert shrub: Blackbrush, creosotebush, Joshua tree, red brome, galleta grass	10
Upper Sonoran	Juniper and pinyon pine: Green ephedra, big sagebrush, antelope bitterbrush, bluebunch wheatgrass, Indian ricegrass	13
	Northern desert shrub: Big sagebrush, rubber rabbitbrush, Nevada ephedra, bluebunch wheatgrass, Indian ricegrass	10
	Salt-desert shrub: Black greasewood, shadscale, Gardner saltbush, bottlebrush squirreltail, alkali sacaton	9
	Salt-desert grassland: Inland saltgrass, alkali sacaton, Nuttall alkaligrass, creeping wildrye	9
Transition	Mountain brush-ponderosa pine: Gambel oak, bigtooth maple, black chokecherry, serviceberry	16
Canadian	Aspen-fir (canopy and opening): Mountain snowberry, slender wheatgrass, mountain brome, sticky geranium	25
Hudsonian	Subalpine herbland or spruce-fir: Red elderberry, western yarrow, letterman needlegrass, mountain brome	34
Alpine	Alpine herbland (above timberline): Cushion eriogonum, Scribner wheatgrass, red elderberry	40

Climate

Basically, climatic zones were first identified from studies of the distribution of vegetation. Various climatic values were then selected from within these vegetative types to determine if there were significant relationships between any of these climatic values and the represented plant community (Thornthwaite 1948). Daubenmire (1956) reviewed four of the most popular climatic classification schemes (and as proposed by Thornthwaite [1931, 1948]) and concluded that none of the four classifications proved adequate to define what appeared to be climatically determined vegetation zones located in eastern Washington and northern Idaho. He found that each vegetative type (or climatic zone) differed from its neighbors in the degree of summer drought, except at the wet end of the climatic gradient where lower summer temperatures became more influential. Therefore, it is generally thought that, within climatic regions or zones, quantity and seasonal availability of soil moisture, especially in the summer, are major limiting factors for the geographic distribution of plant species (Blaisdell 1958; Daubenmire 1974; Hansen and Churchill 1961; Krebs 1972; Oosting 1956). Soil moisture availability for plant growth is modified by changes in elevation, latitude, slope, or soil type. Thus, certain vegetational zones occur at higher elevations on south slopes or lower elevations on north slopes. These vegetational zones also have higher elevational limits on smaller mountains because they tend to intercept less moisture than the larger mountain masses (West and others 1975). Most dry or desert environments share two characteristics with regard to precipitation: it usually falls in one or two short seasons, and the amount received is unpredictable from year to year (Solbrig and Orians 1977).

Temperature

Temperature is one of the major factors limiting the distribution of plants (Krebs 1972). Mean annual temperatures are almost useless for ecological interpretations, for they do not indicate seasonal variation and duration. It has been shown that mean maximum and minimum values best describe the effects of temperature on plants (Oosting 1956). Temperature effects are modified by complex interactions among elevation, slope, position on the slope, aspect, and precipitation. Plant injuries from temperature changes are most often the result of freezing. Some species of browse seedlings are especially susceptible to frost damage. For example, this should be of concern if bitterbrush is to be planted and late frosts are common to the area being planted. Temperature variation (extremes) also greatly influence which species can best survive on a given site. For example, on some dry desert ranges, soil surface temperatures during the summer can range from 140 °F (60 °C) in the day to 40 °F (4.4 °C) at night. We have found that plant selections can be more easily moved from cool to warm environments than from warm to cool environments. To further illustrate the important effect that temperature has on some groups of plants, Hartley (1950) analyzed the distribution of the grasses of the world and concluded that temperature was much more important than rainfall in limiting species distribution. He also suggested that winter temperatures were especially critical.

Precipitation

Water alone, or in association with temperature, is probably the most important physical factor affecting the distribution of plants and plant communities (Krebs 1972) (table 1). Differences in rainfall patterns, whether in seasonal distribution or annual total, are reflected by differences in the naturally occurring plant populations (Daubenmire 1956). The season of precipitation, and the form in which precipitation is received, are important characteristics to consider when planning a wildland restoration or rehabilitation project. The vegetation in areas having significantly different precipitation patterns can be expected to have only a few species in common (Daubenmire 1974; Weaver and Clements 1938). In the Intermountain Region, many areas receive most of the annual precipitation as snow during the winter. Other areas receive the bulk of their moisture as rain in the warm season. In still other areas, precipitation is evenly distributed between these two periods. Plants selected for seeding should have a life cycle compatible with the precipitation pattern of the planting area. Most of the annual precipitation in cold deserts is received when temperatures are too cold to permit growth (Fetcher and Trlica 1980). Therefore, winter precipitation is believed to be most important for plant growth the following year (Wein and West 1971). There, adapted species must be able to complete their life cycle before the winter moisture is depleted or enter into a dormant state that is tolerant of severe drought. Stevens and others (1974) have shown that May precipitation has a greater significant effect on forage production than does precipitation in any other months. When most of the precipitation comes during the spring and summer, evaporative losses can be larger. If the precipitation arrives in light, scattered storms, little may remain available for plant growth. When rain falls in high intensity downpours, heavy runoff may result and leave little to wet the soil (Weaver and Clements 1938).

Many researchers have shown that the amount of precipitation has a direct effect on plant production regardless of whether the community is dominated by grasses, forbs, shrubs, or complex mixtures of these life forms (Blaisdell 1958; Currie and Peterson 1966; Jordan 1983; Kindschy 1982; Martin and Cable 1974; Sneva 1977; Stevens and others 1974; Wein and West 1971). Annual herbage production in arid rangelands can vary by several hundred percent as a result of variation in precipitation (Hannay and Lacy 1931).

An introduced species that is long-lived and easy to establish may not have a problem matching its life cycle to the season in which precipitation is received. Plummer and others (1968) determined that the average annual precipitation must be at least 9 inches (228 mm) before artificial seedings can be expected to be successful.

Soils

Under a given climatic regime, edaphic factors can strongly influence the kind and amount of vegetation produced (Gates and others 1956; Martin and Cable 1974; Passey and Hugie 1962a). To illustrate the importance of soil in plant development, a series of plants were moved to common gardens, where individuals of several species were grown on each soil type. It was determined that the differences in soil could affect plants in the following ways: germination success; growth, size; erectness of plants; plant vigor; stem woodiness; root depth; amount of pubescence; susceptibility to drought, frost and parasites; number of flowers; and date of flower appearance (Marsden-Jones and Turrill 1945). One could consult other literature and probably extend the list indefinitely. The concept to emphasize is that soil conditions can and do affect many aspects of plant development.

Most rangeland soils are normally low in nitrogen, phosphorus, and sulfur (Eckert and others 1961a; Evans and Neal 1982; Wagle and Vlamis 1961). Wagle and Vlamis (1961) found that because bitterbrush was able to fix nitrogen, soils low in nitrogen did not appear to impair that plant's performance, but soils low in phosphorus and sulfur did. Therefore, properly inoculated species capable of fixing nitrogen should not need N-fertilizer in soils deficient in nitrogen. Such species could also be of benefit to associated species that do not fix nitrogen. Mineral uptake can be expected to be affected not only by the chemical nature of the soil, but by temperature, soil moisture, light, and soil texture as well (Ames and Kitsuta 1933).

Under conditions of similar management and precipitation, fine textured soils characteristically support more perennial grasses and fewer shrubs than do coarse soils (Martin and Cable 1974). Wyckoff (1973) found that the primary factor limiting plant species diversity in a desert grassland appeared to be soil texture. He said the loamy soils consistently supported more species than adjacent sandy soils because of the probable increase in microenvironment diversity associated with the heavier soils. However, soils with either too high silt or clay content, or both, retard growth by increasing the extent and degree of branching of roots (Weaver 1919).

With regard to soil texture and related soil moisture availability for plant growth, sandy soils have the most favorable regime in arid regions. For a given amount of added free water, they are wetted more deeply, release more of the absorbed water to plant roots, lose less moisture to evaporation, and have less surface runoff. Therefore, 80 percent of moisture infiltrating sand is available for transpiration of plants (Daubenmire 1974).

High amounts of soluble salt in the soil reduce water uptake and may inhibit uptake of magnesium (Mg), potassium (K), and phosphorus (P). Nitrogen deficiency symptoms may also appear (Kleinkopf and others 1975). Gates and others (1956) found that the major significant difference between some Great Basin plant community types was the amount of salt in the soil. Plummer and others (1968) determined that soils with more than 1 percent soluble salts are usually not suitable for revegetation efforts.

The effective depth of the soil may be shallow, or somewhat restricted by the presence of a hardpan. Hardpan can form from clay, calcium carbonate, calcium sulfate, oxides of iron, aluminum, or silicon. Hardpans are common in soils of the drier areas of the Intermountain area (Daubenmire 1974). Because hardpans are essentially impervious to roots, they often determine the effective soil depth and types of plants that grow in a particular habitat. The growth rate of trees tend to vary directly with the depth of loose soil above a hardpan layer (Coile 1952).

Terrain

Elevation will have a direct effect on temperature by lowering it approximately 3 °F (1.1 °C) for each 1,000 ft (305 m) rise in elevation (Oosting 1956). Elevation also has a direct effect on precipitation received. Lull and Ellison (1950) determined that in central Utah, one should expect to receive an additional nearly 5 inches (127 mm) of precipitation for each 1,000 ft (305 m) rise in elevation.

When precipitation is received, slope, smoothness of slope, position on slope, vegetation, and soils interact to control the amount of runoff and water infiltration, which in turn affect plant growth and survival. Slope aspect and steepness also affect solar radiation received and thus the temperature at and near the ground surface (Farnes and Romme 1993).

Slope and exposure also influence amount and type of soil accumulated. Southern slopes usually have coarser soils with lower water-holding capacity than the finer textured northern slope soils (Krebs 1972). For example, in two or more areas, essentially the same in soil, cover, and precipitation, differences in soil water content were directly determined by differences in slope (Krebs 1972; Oosting 1956). Consequently, topography affects vegetation indirectly by modifying other factors of the environment (Oosting 1956). Different combinations of slope and exposure have great effects on the temperature of arid soils.

The mountains will modify precipitation patterns, airflow, and wind exposure. Local topography, with its different slopes, bluffs, ridges (with different exposures), lowland drainage lines, and depressions produce different combinations of light, temperature, and moisture that combine to produce local divergence of plant life forms and species in the Intermountain West.

Most wildland rehabilitation or improvement projects have been undertaken on fairly flat terrain, or on slopes of less than 30 percent. In recent years, steeper, rocky slopes are being rehabilitated. Topographic variation complicates the formulation of seeding mixtures and the prediction of composition of the new plant cover.

Discussion

Many researchers have concluded that plant distribution is primarily controlled by varying combinations of climatic factors and secondarily by edaphic factors (Billings 1951; Gates and others 1956; Mason 1936; Shantz 1938). Mason's (1936) conclusion that single factors or combinations of several factors could restrict the range of a species must be considered by revegetation scientists.

The effects of habitat on the plant, and of the plant on the habitat, are mutually complementary and often very complex (Weaver and Clements 1938). A plant is at once affected by the amount of heat, light, moisture, and nutrients available to it. Its life processes must go on under numerous and fluctuating variations in the environment. Plants selected for revegetation must be adapted to an ever-changing, wide range of environmental conditions. Because numerous factors operate on an organism simultaneously, each life function is a multiconditional process (Daubenmire 1974). With identical combinations of environmental conditions repeated only at rare and irregular intervals (Livingston 1934), a plant must have broad tolerance limits to be consistently competitive. The intensity of most environmental factors varies with the hour, day, and season; the rate of change, duration, and intensity of extreme values are all ecologically important aspects of the environment.

Competition undoubtedly is greatest between seedlings because of the restricted environment near the soil surface. Seedlings are especially vulnerable to the vagaries of environment. This is why many wildland plants have evolved the characteristic of seed dormancy. Successful growth of container grown plants is not a safe guide to success of seeding of these species on the same site.

Normally, successful plant establishment in an area depends on recognition of factors (climate, soil, and terrain) critical for seedling establishment. Proper composition of the species mixture sown will also affect the success of revegetation at any site.

How can one determine if the environmental conditions are adequate for the species in question? With an increase in altitude, there is an increase in precipitation and a decrease in temperature that is reflected in the natural altitudinal zonation of native vegetation. There are also zones of vegetation that reflect differential response to increasing concentrations of soil salts as one goes from higher to lower elevations. These two factors interact (elevation and salinity) and generally parallel each other as one descends into any one of the many closed basins within the Great Basin. Branson and others (1967) also noted that in addition to increased aridity and salinity with the descent into each basin, soil-particle sizes tend to become smaller as one approaches the playas. Fine textured soil can be expected to produce more severe soil moisture stresses (Branson and others 1967, 1976).

It is generally understood and has been demonstrated (Billings 1949; Fautin 1946) that shadscale is usually indicative of climatically dry, as well as physiologically dry soils. Billings (1949) showed the relationship between the presence of big sagebrush and higher available soil moisture. His data indicated that from central Nevada to eastern California, the mean annual precipitation for the shadscale zone was only about 5 inches (127 mm), while the mean annual precipitation for the sagebrush zones in northern and western Nevada was about 9 inches (229 mm) or more.

Conclusions

How can one put all these interacting factors into some kind of logical approach to help determine whether a site may warrant rehabilitation efforts? First, and most important, the amount and timing of precipitation in association with the occurrence of indicator species are important guides to species that may be successfully planted.

The presence of juniper and pinyon indicates the availability of adequate moisture for most of the commonly seeded species. Juniper-pinyon woodland normally occurs from 4,500 to 5,000 ft (1,400 to 1,500 m) to 7,000 to 7,500 ft (2,100 to 2,300 m) elevation (Springfield 1976; Woodbury 1947). The extreme range can be as low as 2,500 to 3,200 ft (760 to 980 m) (Franklin and Dyrness 1969; Johnsen 1962; Woodbury 1947), and the upper limit approaches 10,000 ft (3,000 m) (Lanner 1975; St. Andre and others 1965). There is a general tendency of junipers to extend below the pinyon component (Lanner 1975). The lower elevational limits appear about where the precipitation reaches the 10 inch (254 mm) point (Woodbury 1947). Generally, the annual precipitation is about 12 to 13 inches (305 to 330 mm) (Phillips 1977; Plummer and others 1968). The annual mean can range from about 8 to 10 inches (203 to 254 mm) (Dealy and others 1978; Phillips 1977; West and others 1975) to 20 inches (518 mm) (Dealy and others 1978; West and others 1975). The best developed woodlands occurs between 12 and 18 inches (305 to 457 mm) of precipitation (West and others 1975). Sagebrush not only occurs at elevations that juniper-pinyon occurs, but usually at higher and lower elevations beyond its normal limits (Woodbury 1947).

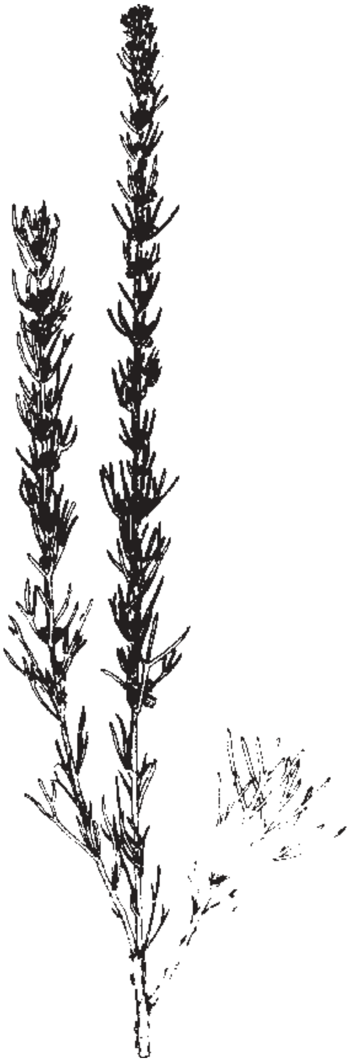
As the relative importance of pinyon increases, precipitation can usually be assumed to increase. Conversely, as the importance of pinyon decreases on undisturbed sites, the amount of precipitation can also be assumed to decrease.

The presence of appreciable numbers of shrubs that normally occur in the mountain brush zone (this could include Gambel oak, true mountain mahogany, and mountain snowberry) usually indicates favorable moisture conditions for most seeded species. Above or within the mountain brush zone, moisture is not usually a problem. At higher elevations the primary problem is selection of species tolerant of the cooler temperatures.

As one approaches the lower bounds of the juniper woodland association, potential available moisture can be predicted from the associated subspecies of big sagebrush. Winward (1983) showed that the subspecies of big sagebrush can be used to indicate the degree of droughtiness of a site. Wyoming big sagebrush is the most xeric of the group, followed by basin big sagebrush, and then mountain big sagebrush. The presence of Wyoming big sagebrush also indicates that the soils are relatively shallow and well drained with conditions that are generally warmer than those experienced by the other two subspecies. When black sagebrush and Wyoming big sagebrush are found in the same area, it indicates a more shallow or restricted soil than would normally occur in the Wyoming big sagebrush type only (Hironaka and others 1983). Basin big sagebrush generally grows on deeper soils that are well drained. If it is found growing adjacent to stands of Wyoming big sagebrush, it will occupy the more mesic sites. Mountain big sagebrush is found throughout the upper foothill and mountain areas. Some populations will grow on the lower foothill and bench areas where soil moisture is available for most of the summer. It is not uncommon to find 40 or more plant species associated with mountain big sagebrush. Where sagebrush is displaced by dwarfed salt-desert shrubs, either shadscale or Gardner saltbush, the site will probably be too dry to justify rehabilitation measures. Where available moisture is near the minimum limit, species that can be seeded successfully are limited. At such sites, one should be cautious with selections of species, site preparation, and seeding equipment.

Arthur R. Tiedemann
Carlos F. Lopez

Chapter 7



Assessing Soil Factors in Wildland Improvement Programs

Soil factors are an important consideration for successful wildland range development or improvement programs. Even though many soil improvement and amelioration practices are not realistic for wildlands, their evaluation is an important step in selection of adapted plant materials for revegetation. This chapter presents information for wildland managers on: the importance of soils physical, chemical, and nutrient considerations in wildland restoration and rehabilitation; the basis for evaluating wildland soil suitability for plant growth; effects of management activities on soil factors; assessment of soil nutrient deficiencies in terms of plant needs; development of a fertilizer prescription; and principles of fertilization of wildlands.

The Need for Soil Improvement and Nutrient Amelioration

The Resources Planning Act document (USDA 1980a) and the Public Rangelands Improvement Act (U.S. Laws and Statutes 1978) indicate that public rangelands are producing less than their potential and many are in unsatisfactory condition. These conditions pose a risk of soil loss, desertification, and lowered productivity for large areas. Both the Resources Planning Act and Public Rangelands Improvement Act stress the need to correct the unsatisfactory rangeland conditions through intensified management and improvement techniques. Accomplishing the goals set forth in Resources Planning Act (USDA 1980a) and the Public Rangelands Improvement Act (U.S. Laws and Statutes 1978) will require rehabilitation of depleted wildlands and perhaps the development of marginally productive wildlands.

Intermountain wildlands—in particular rangelands—are no exception to the conclusions drawn by these two laws regarding lands producing below their potential. Managing for improvement of Intermountain wildlands, to date, has stressed: livestock grazing strategies, manipulation or elimination of shrubby species of vegetation to improve range productivity and wildlife habitat, and restoration of watershed stability. Management of soil factors that limit plant establishment and productivity has received little attention. Soil management has been limited because of possible negative cost-benefit ratios.

Wildland soils, especially those where water is the main limiting factor are not usually cultivated, amended by fertilization, or treated to improve their physical or chemical condition. Except for stabilization of human-degraded sites such as surface mined areas, or areas where downstream values are threatened, soil management on unstable areas of inherent low productivity has not been warranted because of excessive costs.

Rehabilitation of sites impacted by surface mining and the resultant spoils has required techniques such as topsoil replacement, terracing, liming, organic soil amendments, irrigation, and transplanting mature plants with specialized equipment. Another problem in the application of soil management technology to wildlands has been the fact that most of the information has been developed for the more fertile, productive, arable lands.

Basic Factors Influencing Soil Fertility, Productivity, and Reclamation Potential

Soil development is a function of climate, organisms, relief, parent material, and time (Jenny 1941, 1980). The ability of a specific site to produce vegetation is determined by the factors that influence soil formation as well as the history of land use (Klemmedson and Tiedemann 1995a). Suitability of the soil for plant growth is determined by those qualities and properties of the natural soil that physically, chemically, and biologically provide the necessary water and nutrients for growth and development of plants. Assessment of the soil's physical state will determine if the soil is suitable for improvement efforts. On eroded lands, for example, the loss of considerable quantities of soluble organic and mineral matter and nutrients accompanies the removal of surface soil layers (Klemmedson and Tiedemann 1995a). In addition to a loss of nutrient capital, removal of the more fertile surface soil layer may expose subsurface soils having abnormal pH (high or low) that can adversely affect nutrient availability.

Erosion also causes changes in productivity that may be difficult to compensate by additional fertilizer application. Such changes are caused by decreased water infiltration, decreased water-holding capacity of the soil, a less favorable root environment, and changes in soil temperature due to a difference in albedo and other factors. The quantitative effects of such changes are not well known (Flach and Johannsen 1981). Thus, assessment of soil factors will determine whether or not improvement would be beneficial or even feasible.

Soil physical properties are related to depth, texture, structure, bulk density, permeability to water, capacity to hold water, and depth to limiting layers. Slope, although not a soil physical factor, is an important consideration in determining the suitability of a site for revegetation and its productivity potential.

Chemical characteristics exert physiological stresses on plants through their effects on plant water relations, nutrient availability and uptake, and toxicity effects related to excess concentrations of certain chemical elements. Chemical characteristics that can be used to determine soil suitability include pH, salinity, and exchangeable sodium percentage. Concentrations of total and available essential plant nutrients in the soil are also an important determinant of soil fertility.

Measuring as many of these factors as possible will assist the land manager in determining wildland soil productivity potential and will provide the means to assess possible success or failure of proposed management or improvement efforts. Although a site may grade as “high” in all categories except one, positive results will not necessarily be realized. In fact, the one factor graded as “low” such as exchangeable sodium percentage or acidity might very well impede or prohibit all efforts to improve or rehabilitate a particular site.

In situations where rehabilitation is mandated, as in fire- or flood-ravaged watersheds, mined areas, or other massive disturbances, table 1 defines soil chemical and physical factors that must be considered if revegetation is to be successful. It will become apparent to

Table 1—Table for evaluating soil characteristics for productivity potential and possible improvement.

Soil property or quality	Level of suitability			Reference
	Low (essentially unsuitable)	**Moderate**	**High**	
USDA texture	Loamy sand, sand (<18% clay)	Clay, silty, clay, (>35% clay)	Sandy loam, sandy clay loam, loam, clay loam, silty clay, loam (18-35% clay)	Brady 1974
Soil structure	Massive, single grain	Platy, blocky prismatic	Granular	Soil Survey Staff 1962
Bulk density (g/cm^3)	>1.6 cc	1.4-1.6	<1.4	Daddow and Warrington 1983; Russell 1973; White 1979
Permeability (cm/hr)	(<0.5) or (>15.0)	5.0-15 and 0.5-1.5	0.6-5.0	Soil Survey Staff 1962
Available water-holding capacity (cm H_2O/ cm soil)	<0.08	0.08-0.16	>0.16	Brady 1974; Broadfoot and Burke 1958
Coarse frag content (%)/wt	>35	15-35	<15	Soil Survey Staff 1962
Depth to limiting layer (cm)	<50	50-100	>100	Soil Survey Staff 1962
Slope %	20-30	10-20	<10	USDA 1965a; Forest Service Handbooks 2209.21 and 2209.31
Organic matter (%)/wt surface soil	<0.5	0.5-2.0	>2.0	Donahue and others 1977; Foth 1978; Hendricks and Alexander 1957
pH	(<5.1) (>8.4)	(5.1 to 6.5) or (7.4 to 8.4)	6.6 to 7.3	Soil Survey Staff 1962
Salinity (mmhos/cm)[a]	>8	4-8	<4	Richards 1954
Exchangeable sodium percentage (ESP)[b]	>15	2-15	<2	Richards 1954

[a] Measured in terms of conductivity of saturated soil extract.
[b] ESP refers to exchangeable sodium percentage.

the reader that many of the soil characteristics are not feasible or practical to amend on wildlands despite the fact that reclamation technology may be presently in use in arable cropland settings.

Seeding or planting adapted species will be the primary feasible means for restoring vegetation, and hence soil stability, to most wildland sites. Despite our inability to alter some of the soil or site conditions, awareness and characterization of soil and site factors is one of the first steps in selecting adapted species.

The importance of each of the various properties that can be used to determine soil suitability (table 1) are discussed.

Soil Texture

The percentages of sand, silt, and clay determine the texture of the soil. Particle size and the percentage composition affect the packing arrangement and the amount of actual surface area per given unit volume of soil (Fairbridge and Finkl 1979; Millar and others 1958). The amount of surface area varies inversely with the size of soil particles.

Because most of the important chemical reactions in soils take place at the surface of the soil particles (Jenny 1980), the amount of surface area per unit volume of soil is important in determining the interaction between plant roots and soils. The surface to volume ratio increases with decreasing particle size (Fairbridge and Finkl 1979; Millar and others 1958).

Texture also controls the rate at which water moves into the soil and the amount of water that can be stored in a given thickness of soil for plants to use. Clay provides the highest surface area, but if clay content is great enough to restrict air and water movement, these critical variables may limit productivity. Soils in the pure sand range have high rates of water infiltration but are low in productivity because they do not retain water or nutrients. The ideal substrate is texturally balanced soil in the loam range. Loam allows for a volume composition which leads to adequate surface area for nutrient exchange sites without compromising air and water space.

Texture can be measured qualitatively in the field by feeling slightly moistened soil. With training, an individual can learn to distinguish the major textural grades by this method. However, the most accurate procedure is to measure texture in the laboratory. For appropriate laboratory methodology, the reader is referred to Methods of Soil Analysis (Black and others 1965a,b).

Soil Structure

Soil structure refers to the “aggregation of primary soil particles (sand, silt, clay) into compound particles, or clusters of primary particles which are separated from adjoining aggregates by surfaces of weakness” (Millar and others 1965). The grouping or arrangement of particles exerts considerable influence on overall soil productivity through effects on water movement, heat transfer, aeration, bulk density, and porosity.

Variations in soil structure are: granular, crumb, platy, blocky, prismatic, and columnar, with a range of intergrades (Fairbridge and Finkl 1979). Structureless soils are either massive or single-grained. Massive soils are more or less compacted, restricting air or water movement. Single-grained soils, are generally excessively drained and low in nutrients. Soils with weak structure are susceptible to raindrop action and are potentially more erosive than soils with good aggregation.

Management considers structure to be one of the most sensitive of the soil characteristics. Machinery and grazing animals both have the potential to adversely affect the structure of the soil (Fairbridge and Finkl 1979; Gifford and Hawkins 1978; Soane and others 1981). In the case of soils high in clay, operating heavy machinery or livestock trampling may puddle the soil. When puddled soil dries, it may become impermeable to moisture, resulting in increased erosion potential and reduced availability of moisture to plants. Destroying structure of coarser soil materials also leads to increased erosion potential.

When prescribed fire is used as a management tool to eliminate residues, reduce competition, or eliminate unwanted vegetation, structure of the soil can be affected if the heat of the fire is great enough to remove litter and duff and expose the mineral soil to puddling and baking of the surface (Wells and others 1979). Prior to initiation of prescribed burning, it would be wise to conduct at least a field evaluation of the soil to determine if it may be susceptible to adverse changes in structure by fire management.

When structure is adversely affected by management, there are generally no economically feasible techniques for correcting the damage except elimination of the cause of the damage and allowing time for restoration of structure. Establishing vegetation on denuded sites will aid in restoration of structure (Fairbridge and Finkl 1979). Soil structure problems on small areas may be amenable to organic matter amendments to improve structure (Fairbridge and Finkl 1979).

Structure can be determined by trained personnel in the field where the overall characteristics of arrangement and aggregation of the soil separates in a profile can be assessed. But the most accurate assessment is by laboratory analysis.

Bulk Density (Volume Weight)

An important land management concern is the possibility of reduced vegetation productivity due to soil compaction (increased bulk density) by recreational vehicles, machinery, and livestock. Studies have shown the detrimental effects of soil compaction on the establishment and growth of range plants (Adams and others 1982; Lull 1959; Wilshire and others 1978). Bulk density of fine textured soils under heavy grazing use in Northeastern Colorado was 1.52 g/cm^3 compared to 1.34 g/cm^3 under light grazing (Van Haveren 1983). On coarse-textured soils, there was no difference between light and heavy grazing. Willatt and Pullar (1984) observed a direct relationship between stocking rate and bulk density.

Effects of soil compaction on plant growth are due to a complex interaction between many soil and plant properties, but for many situations there seems to be an upper limit or threshold bulk density value at which resistance to root penetration is so high that root growth is essentially stopped (O'Connell 1975). Restricted root penetration and elongation also reduces the volume of soil that can be exploited by a plant for essential nutrients and water, thereby causing a reduction in total growth. The established limits (table 1) are averages for intermediate textural grades (Daddow and Warrington 1983; Russel 1973). Bulk density threshold limits have been established for the various textural grades. The reclamation specialist is referred to Daddow and Warrington (1983) for limits based on specific soil textures.

Bulk density is easily measured in the field by trained personnel. See Black and others (1965a) for methodology. Laboratory procedures also determine bulk density.

Permeability

Permeability expresses the rate at which water is transmitted through the soil (Fairbridge and Finkl 1979). In the absence of precise values, soils may be placed into relative permeability classes through studies of bulk density, structure, texture, porosity, cracking, and other characteristics of the horizons in the soil profile in relation to local use experience. Soils with excessively high (>15 cm/hr) or low (<0.5 cm/hr) permeability are low in productive potential. High permeability soils have low water and nutrient retention capacity. In soils with low permeability, water has limited opportunity to enter the soil and the potential for surface runoff and erosion could be increased.

Operation of machinery and trampling by livestock have the potential to reduce permeability through their effects on soil structure and bulk density (Gifford and Hawkins 1978; Soane and others 1981). A review by Gifford and Hawkins (1978) indicates that grazing in some situations causes a marked reduction in infiltration rates of soils. Fire, in addition to altering soil structure, may result in the formation of water repellent layers that reduce infiltration and result in increased surface runoff (Tiedemann and others 1979; Wells and others 1979). In addition to increased erosion, reduced infiltration means less water available for plant growth. Prior to the use of prescribed fire, the potential for development of water repellency and other soil permeability problems should be evaluated. This would necessitate determining the soil texture to detect soils high in clay where soil sealing and puddling problems may arise from elimination of the litter and duff layers.

Permeability can be increased by mechanical treatments such as contour furrowing, terracing, pitting, and water spreading (Vallentine 1971). Specialized machinery such as the rangeland imprinter (Dixon and Simanton 1977) has also been used to promote increased water infiltration.

Permeability is best measured in the field with infiltrometers. Infiltrometers are generally of two types: double ring and rainfall simulators (Wisler and Brater 1959). The double ring infiltrometer is the easiest to set up, use, and interpret.

Available Water-Holding Capacity

Available water is the portion of stored soil water that can be absorbed by plant roots to sustain life. It is that portion of the water that remains in soil after excess water has drained away and the rate of downward movement has decreased materially (Veihmeyer and Hendrickson 1950). Available water-holding capacity depends on bulk density, soil texture, and coarse fragment content (Broadfoot and Burke 1958). See tables in Broadfoot and Burke for specific information on available water-holding capacity with soils of differing texture, bulk density, and percent coarse fragments. Soils in low and moderate ranges are inhibited from being highly productive simply because of their inability to store water and retain nutrients for plant use. Low water-holding capacity would be particularly restrictive to plant productivity in low to moderate precipitation zones or zones with irregular precipitation, especially when dry periods are long and unpredictable in their occurrence. This is the case in many areas throughout the Intermountain West.

Through effects on permeability, any management practice that results in reduced infiltration will cause an increase in surface runoff with the end result of reduced soil water storage.

The determination of available water-holding capacity is a laboratory procedure requiring specialized equipment.

Coarse Fragment Content

Coarse rock and gravel in soils include fragments greater than 2 mm in diameter. The size and amounts of coarse fragments in the soil influence nutrient storage capacity, root growth, moisture storage, water infiltration, and runoff, primarily through their dilution of the mass of active soil. The basis for the arbitrary limits (sizes and percentages) have been determined, taking into consideration interference with agricultural machinery (table 1). Thus, limits may not be as restrictive for seeding methods used to reclaim some rocky or stony wildlands.

Coarse fragments are easily measured using sieving screens of known dimensions.

Depth to Limiting Layer

The depth of soil available for root development will have considerable influence on the forms and types of plants that can inhabit a site (Jenny 1980; Kramer 1969). Shallow soils with restrictive layers near the surface generally can support only drought-tolerant or drought-avoiding plants that normally have shallow roots. A depth restriction may be bedrock, a hardpan or caliche layer, a high water table, a marked textural change (such as loam over gravel), or soil horizons having a limiting effect due to high bulk density or toxicity, such as high salinity.

Physical barriers such as carbonate layers (caliche) that develop in arid regions, and clay layers, can be broken up by ripping or deep chiseling (Vallentine 1971).

Slope

Slope is an important variable in the ability of a site to absorb and retain moisture. It follows that slope is a major determinant of the erosivity of a site—as slope increases, erosion potential increases. Also, as slope increases, the ease with which vegetation is established diminishes.

Slope steepness aggravates effects of management on soil characteristics. Changes in protective soil cover, structure, permeability, and bulk density that would not cause increased surface runoff and erosion on gentle slopes (<10 percent) could pose a serious threat to soil stability as slopes approach 30 percent. Effects of fire on physical soil characteristics and erosion are also amplified by increasing slope steepness (Tiedemann and others 1979; Wells and others 1979; Wright and Bailey 1982).

Organic Matter

All materials of vegetable and animal origin formed in or added to soil are collectively referred to as organic matter (Fairbridge and Finkl 1979). Most of the organic matter added to soils originates from dead plant parts in the form of litter on the surface and decomposition of roots below the surface (Fairbridge and Finkl 1979). Cultivated soils contain only 1 to 5 percent organic matter and Intermountain Great Basin semi-arid wildland soils would generally contain less than 3 percent (Foth 1978; Hagin and Tucker 1982). However, the small amount present can modify the soil's physical properties and can strongly affect its chemical and biological properties.

Organic matter is responsible for desirable soil structure. It increases soil porosity, improves water and air relations, and reduces erosion by wind and water. Chemically, organic matter is the soil storehouse and cycling center of most of the nitrogen (N), 5 to 60 percent of the phosphorus (P), and up to 90 percent of the sulfur (S) (Kowalenko 1978). Availability of nutrients, of course, depends on the rate at which organic matter is decomposed and incorporated into mineral soil. Also of importance is the capacity of organic matter to hold nutrient elements such as potassium (K), calcium (Ca), and magnesium (Mg), similar to the way that clays hold these elements in base exchange equilibria (Brady 1974). In addition, organic matter, by release of acid humus, aids in the extraction of elements from primary and secondary minerals.

The ratio of carbon (C) to nitrogen is an important determinant of nitrogen availability. The normal ratio in undisturbed surface soil (upper 15 cm) is 10 or 12 to 1 (Tisdale and Nelson 1975). As the C:N ratio widens, nitrogen availability is reduced because microbes responsible for organic matter mineralization utilize the available N. Nitrogen fertilization should be considered when this ratio exceeds 12:1.

Depletion of soil carbon by long-term cultivation has been well documented for croplands (Jenny 1933). However, the picture for carbon depletion associated with grazing is not as definitive. Milchunas and Lauenroth (1993) compared soil carbon in grazed areas with that in ungrazed areas for 37 sites around the world. Soil carbon in grazed sites was greater or equal to that in ungrazed for about half of the sites.

Operation of machinery on wildland soils would be expected to incorporate surface accumulations of organic matter in the form of litter and humus. Increased mineralization of this organic matter would tend to create a wide C:N ratio, resulting in short-term reductions in N availability. Thus, it may be necessary to amend the soil with N fertilizer.

Intense fires have generally been shown to reduce organic matter content of the soil surface to a depth of 2 cm, but light or moderate intensity fires cause no change (Wells and others 1979).

There is presently no economically feasible or practical means for amending organic matter content of wildlands on a large scale. Restoration of vegetative cover by reducing grazing, or complete rest of heavily grazed lands, will help restore the organic matter level over time. Although untested on wildlands, nitrogen fertilization has proven effective in the cropland setting for maintaining organic matter levels (Tisdale and Nelson 1975). The potential for organic amendments to alter plant succession was demonstrated by Klemmedson and Tiedemann (1994, 1998). They studied areas inside and outside an abandoned sheep corral on degraded subalpine range of the Wasatch plateau in Utah to determine the influence of 37 years of use of the corral on soil and plant development. The corral had been abandoned for 15 years at the time of the study. Organic matter additions by animal dung significantly increased storage of organic carbon in vegetation, litter, and the 0 to 5 cm and 15 to 30 cm soil layers. Cover of meadow barley (*Hordeum brachyantherum*), a component of the predisturbance vegetation of the plateau was nearly 12 times greater inside the corral than outside. On a larger scale, adding sewage sludge to rangelands shows promise as a means of increasing production and ameliorating organic carbon of the soil (Fresquez and others 1990).

Organic matter must be measured in the laboratory by a qualified chemist or laboratory technician. It is measured as organic carbon by combustion procedures. With soils high in pH, it is important to distinguish organic carbon (that associated with organic materials) from the inorganic carbon associated with carbonate salts.

Soil Reaction

The pH, or degree of acidity of the soil, is an indicator of the chemical condition of the soil as it relates to plant nutrition (Allaway 1957). The full impact of low or high pH can be fully realized if it is understood that it represents the negative log of the hydrogen ion concentration. A pH of 4 has a 10-fold greater hydrogen ion concentration and acidity than pH 5. Optimal pH for nutrient availability is between 5.0 and 7.5, with greatest availability at about 6.5. High and low pH have a significant effect on nutrient availability (table 1). At low pH levels, mineralization of nitrogen is decreased and limited primarily to the formation of NH4-N as the only available N source (Dhaube and Vassey 1973).

In strongly acid soils (pH <5.0) plant establishment and growth may be adversely affected by toxic levels of aluminum (Al), manganese (Mn), and iron (Fe), and by deficiencies or low availability of calcium (Ca), magnesium (Mg), and molybdenum (Mo) (Donahue and others 1977) (fig. 1). In highly alkaline situations (pH 8.0 and above) the availability of certain other nutrients is depressed.

From a soil nutrient amelioration standpoint, P and iron (Fe) are likely to present more problems than other nutrients that become limiting such as Mn, copper (Cu), zinc (Zn), and boron (Bo) (Black 1957). The native supply of the latter four nutrients is apparently adequate to offset effects of low pH on availability. Nitrification is reduced at pH levels of 4.5 resulting in reduced nitrogen availability (Stevenson 1965). Then, too, at a higher pH unacceptable amounts of Mo will be released (Blackbourn 1975).

Fire is the principal management practice that exerts an impact on soil pH. Soil acidity is reduced in the surface soil by burning as a result of release of basic cations by combustion of organic matter and heating of minerals (Wells and others 1979).

The effect of pH on nutrient availability emphasizes the importance of this factor. Whether or not a pH adjustment can be accomplished practically may be the deciding factor for reclamation of a depleted wildland site from a soil improvement perspective. Problems with excessively low pH (rare in Intermountain rangelands) can be corrected by liming. For example, to increase the pH of a sandy loam from 5.0 to 6.5 would require approximately 3 metric tons/ha. See Fairbridge and Finkl (1979) for liming rate calculations.

More common to the Intermountain region are areas of soils with high pH. Most practically, these soil types are treated by selecting adapted species to seed or plant. If it is determined that a high pH is unacceptable, soils can be treated by acid or acid-forming compounds such as sulfur. Sulfur is slow but inexpensive and reasonably permanent. Alkaline soils are often harder to correct than acid soils because they may not only present problems due to the high pH, but are often saline (Tinus 1980). The reclamation of salt-affected soils may not be practical on arid wildlands since a large amount of water is required to leach salts.

The pH of a soil can be measured in the field with a colorimetric test kit or with a portable pH meter. It is one of the easiest and least expensive field measurements of soil chemical characteristics that can be made.

Salinity

The failure of plant establishment or depauperate, patchy growth of plants on salty soils has been recognized since man began to grow crops. Salts detrimentally influence plants by: limiting the availability of moisture (Miller and Doescher 1995), by osmotic inhibition (Bernstein 1961, 1963; Slatyer 1961), and by specific toxic effects on metabolic processes (Miller and Doescher 1995; Richards 1954). Availability of water is reduced because of the increase in solute suction of the soil water as salinity increases. Osmotic inhibition is thought to influence plant growth because of an excess of salts taken up from soils high in salinity (Bernstein 1961, 1963; Slatyer 1961). Specific toxicity is a detrimental effect on plant growth because of excessive accumulation of certain ions.

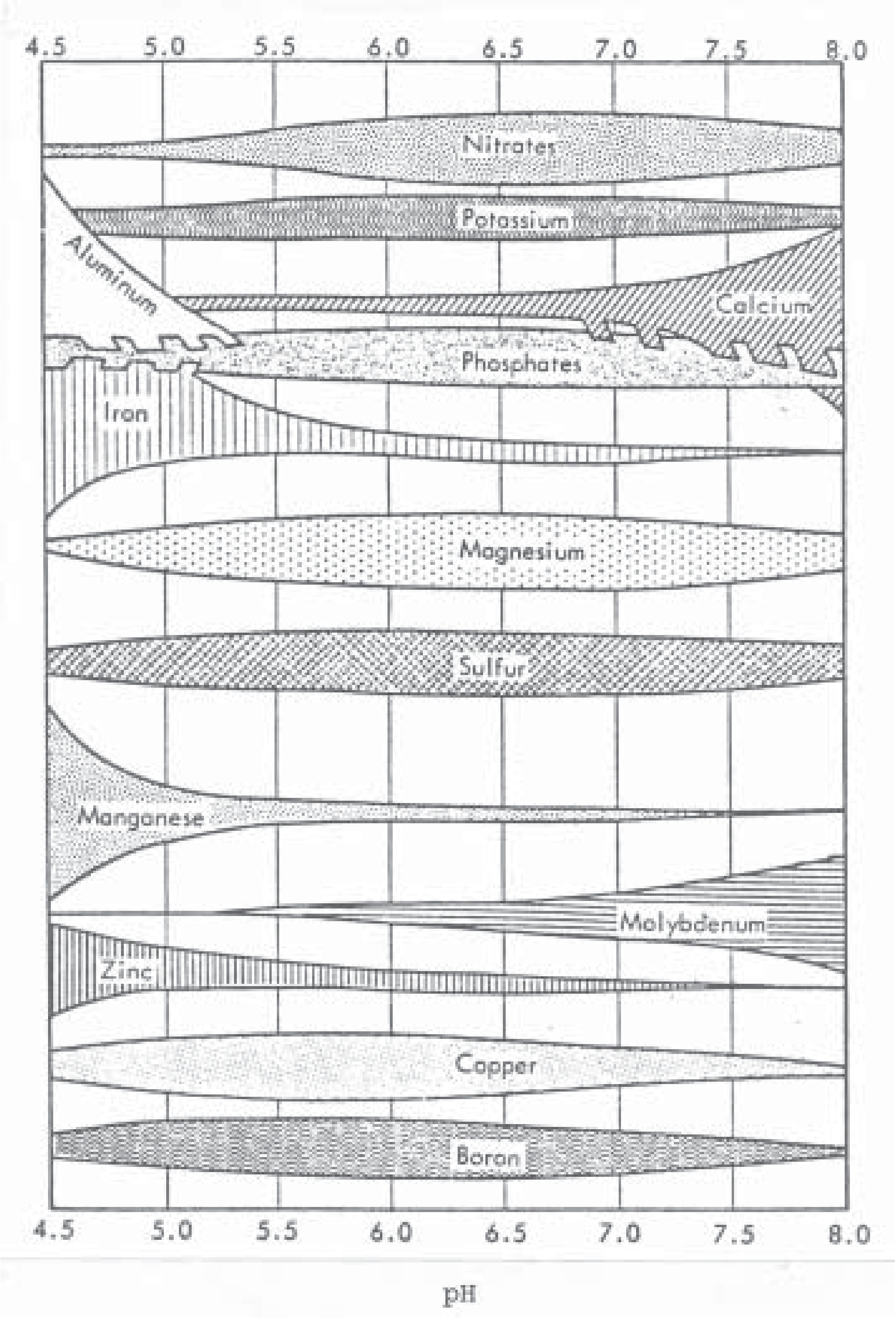


Figure 1—Effect of pH on nutrient availability. Modified after University of Kentucky Agricultural Station Soils Staff (1970).

Ions that are frequently found in high concentrations in saline soils include chloride, sulfate, and bicarbonate. At excessive levels, the influence of these ions on plant growth involves biochemical interferences and nutrient deficiency (Hagin and Tucker 1982; Miller and Doescher 1995). The effect of salinity on plant growth is scaled and based on agricultural crop response to various levels of salts (table 1) (Richards 1954; Scofield 1940). This classification of plant growth in relation to various salinity levels refers to the salt status of the soil in the active root zone. Surface layers may be highly contaminated by surface incrustations of salt, which is not a problem to established plants as long as salts are not later translocated to the root zone. Surface concentrations of salinity may, however, inhibit seedling establishment (Levitt 1980).

In agricultural cropping systems, fertilization of plants in saline soils may be beneficial by reducing the yield-depressing effects of salts, as long as the salinity level is within a low or medium range. In general terms, when the salinity is high enough to depress yield by 50 percent or more, fertilization will yield low returns (Bernstein and others 1974). However, an overall negative effect may result if fertilizers are not carefully selected. The added fertilizers may contribute to an increase in osmotic pressure of the soil solution because of added salts (Champagnol 1979). In the wildland setting, salinity problems are best solved by selecting plant materials that are adapted to grow well in those environments (Miller and Doescher 1995). Where there is a heavy crust of surface salt, it may be necessary to use container or bare-root planting stock since young plants developing from seed may be killed by high osmotic pressures. Soil tillage may also be used to incorporate the highly saline surface layer into the lower layers thereby diluting the osmotic effect and providing a more acceptable surface layer for seeding.

Salinity can be readily measured in the field with a portable solu-bridge test kit.

Exchangeable Sodium Percentage (ESP)

ESP refers to the proportion of the adsorption complex of a soil occupied by sodium. It is expressed as follows:

ESP = exchangeable sodium (milliequivalents/100 g soil)/ cation exchange capacity (cec) (milliequivalents/ 100 g soil) x 100

If a high proportion of the exchange sites are occupied by sodium ions, soils can become very alkaline (pH 8.5 to 10.5). The effect on soil structure is disintegration and disbursement that can lead to slow rates of infiltration or to impermeability. The exchangeable sodium percentage at which soils disperse is correlated to clay type. An ESP of 15 is a good approximation of the level at which dispersion occurs for most clays (Donahue and others 1977). Soils with ESP of 15 are referred to as sodic soils (formerly called black alkali soils). Soils within intermediate levels (2 to 15 percent) are rated as fair in terms of suitability. Sodic soils are the most difficult to reclaim and least likely to be worth the cost (Thompson and Troeh 1978). Therefore, selection of adapted plant species rather than soil management becomes the most applicable management tool. See USDA Agricultural Handbook No. 60 (Richards 1954) for methods of reclamation.

Exchangeable sodium requires a laboratory procedure for measurement.

Other Factors that Influence Reclamation Potential and Soil Suitability

Other variables such as parent material and aspect influence potential site productivity and the ease or difficulty of revegetation. Because there are several variables that affect soil development (and subsequent productivity), an individual variable such as parent material is difficult to quantify. However, as a general ranking, we would suggest a productivity potential array as: pumice<sand and sandstone<limestone<granitic and gneiss<volcanic ash<basalt.

Productivity potential by aspect (exposure) is also a complex parameter to quantify because it depends on the steepness of slope, latitude, and elevation. Exposure influenced soil moisture, nitrogen, organic carbon, and soil water retention in the Snake River Plains of Idaho (Klemmedson 1964). Northerly exposures were more favorable for plant growth than were southerly exposures as manifested in higher contents of nitrogen and organic C and higher levels of soil moisture and moisture retention. The interaction of slope position and exposure was more complex.

For the Intermountain area at low to mid-elevations, northerly and easterly aspects would be expected to be more mesic and, therefore, more productive than the southerly and westerly exposures. These exposures should also be easier to revegetate. However, at higher elevations such as the alpine and subalpine, this trend may be reversed because the southerly and westerly slopes receive more solar radiation resulting in a longer growing season than the north and east aspects.

Certain soil types are generally associated with a given vegetative complex. A detailed discussion of the soil/vegetation community or habitat type relationship is beyond the objectives of our effort in this chapter. The reader is referred to Daubenmire (1970), Klemmedson and Smith (1978), West and others (1978), Passey and others (1982), and Steele and others (1981).

Importance of Soil Nutrients to Plant Growth

Plant growth requires an adequate supply of all nutrients essential for the formation of tissue and for the various processes related to photosynthesis, energy transformation, respiration, and reproduction. Functions of the essential elements in plant metabolism are varied and complex with none having a simple, single function in the economy of plant growth and establishment. For example, nitrogen is a component of amino acids (proteins), vitamins, alkaloids, and chlorophyll. Nitrogen also controls growth and fruiting of most plants (Chapman 1966; Epstein 1972; Russell 1973). The micronutrient, iron, is a component of enzymes, oxidases, and peroxidases; it acts as a catalyst in the synthesis of chlorophyll; and it is an activator of biochemical processes such as respiration, photosynthesis, and symbiotic N fixation (Holmes and Brown 1957; Shaw and others 1975; Tisdale and Nelson 1975).

Past Research on Fertilization

Fertilization has been the most extensively studied of the soil management tools available to the land manager. Soil fertility is one of the few factors inherent to a site that can be implemented on a large scale as part of a wildland improvement program. However, fertilization of wildland sites on a large scale has not been practiced to date. High cost-benefit ratios are largely responsible for the limited use of fertilization on an operational basis. Herbage yield has been the primary basis to date for determining cost-benefit ratios. Other benefits have largely been overlooked. Consideration of other benefits may not bring fertilization of wildlands into profitability but they deserve consideration in decisions concerning the possibility of fertilization to improve productivity.

Fertilization may be helpful in emergence and survival of seeded species (Clary and Tiedemann 1984; Klock and others 1975a), but results are highly variable among species and climatic regimes (Vallentine 1980). Other potential benefits should be considered:

- Increased soil protection because of enhanced foliar cover and root mass (Carpenter and Williams 1972; Cook 1965; Tiedemann 1983)
- Enhancement of plant nutritional quality (Carpenter and Williams 1972; Duncan and Hylton 1970; Duvall 1970; Vallentine 1980)
- Improved plant vigor (Carpenter and Williams 1972)
- Desirable alterations of botanical composition (Duncan and Hylton 1970)
- Aid in the management of use patterns and movement of livestock and wildlife through improved nutritive value and palatability of forage (Brown and Mandery 1962; Carpenter and Williams 1972; Hanson and Smith 1970)
- Extension of the period of green forage (Hanson and Smith 1970; Holt and Wilson 1961; Vallentine 1980)

Of the studies we reviewed, there was little in common among them with respect to nutrient combinations, rates of application, test species, or length of study. Nor was there consistency in assessment of the soil nutrient status prior to treatment to determine the potential for obtaining a positive response. Responses vary by site, soil, and climate. Impressive responses in yield, forage quality, and plant vitality were observed in field trials by Eckert and others (1961a), Cook (1965), Bowns (1972), Baldwin and others (1974), Carpenter (1979), and Tiedemann (1983). Responses to fertilizers were positive in pot trial studies by Eckert and Bleak (1960), Hull (1962), Johnson (1969), Klock and others (1971, 1975a), Tiedemann (1972), and Tiedemann and Driver (1983). Carpenter and Williams (1972) provided a comprehensive synopsis of fertilization of rangelands. Vallentine (1980) is also an excellent source of information about range fertilization.

The application of fertilizer to wildlands has not consistently resulted in increased dry matter production. Some fertility studies have indicated negative responses related to plant competition and moisture availability. Depleted soil moisture reserves due to rapid growth of annual species were reported by Sneva (1978), Wilson and others (1966), and Kay and Evans (1965). In these trials the applied N increased competition between the annual grass, cheatgrass, and native perennial species which resulted in retrogression of the native species and increases in annuals. McKell and others (1959) noted the necessity of adequate soil moisture for plant growth on annual ranges. Applications of nitrogen made early in the growing season stimulated plant growth which in turn led to a faster depletion of available soil moisture, in fact, enough to retard the growth of summer growing plants. Addition of nitrogen to disturbed sagebrush steppe slowed the rate of succession and allowed annual plants to dominate through the fifth year (McLendon and Redente 1991).

Many of the fertility trials reviewed were undertaken without the benefit of soil nutrient concentration or availability assessments or characterization of soil physical and chemical properties. The lack of information on the status of nutrients other than those being tested and physical and chemical characteristics of the soil could lead to an unbalanced fertilization prescription. Because N is often the nutrient most limiting for plant growth in wildlands (James and Jurinak 1978), attention should be directed to enhancing the N capital. In addition to N, other macronutrients P and K and a secondary nutrient S are likewise important (Klock and others 1971, 1975). Fertilizers are most generally applied for their content of these four elements.

When single superphosphate is applied to amend phosphorus deficiencies, sulfur in the form of calcium sulfate is an accompanying, often overlooked, benefit. Single superphosphate contains 12 percent S. Treble superphosphate has only 1 percent S (Shaw and others 1975). In a series of field trials conducted by Cook (1965) to determine the effect of fertilizers on yield increase and forage quality, increases of the various factors measured were attributed to the primary nutrients. When complementary additions of N and treble superphosphate were applied, differences in some of the characteristics were striking: yield of crested wheatgrass was 18 percent over the N-only treatment, protein content 19 percent over the N-only treatment, and total digestible nutrients 16 percent over the N-only treatment. Smaller responses for the N-only treatments suggest further increases were deterred by lack of P or, perhaps, another limiting nutrient. Synergistic effects in the multielement treatments were undoubtedly occurring, but because pretest levels of available nutrients were not assessed, it is not known which nutrients were limiting. Actual amounts of S applied in these trials ranged from 1.5 to 6 lbs/acre (treble super-phosphate is 1 percent S). These amounts would be sufficient to amend low to marginally low sulfur deficiencies in soils (Tiedemann and Lopez 1983).

In a study by Bowns (1972) in which no soil nutrient assessment was made, large amounts of sulfur were added along with the primary nutrients, N and P, as ammonium sulfate and treble super-phosphate. Increased biomass, gross energy, and crude protein were attributed to N and P whereas S may well have been as important as a limiting nutrient. In the interior Pacific Northwest, sulfur has been shown to be almost as limiting as N (Klemmedson and Ferguson 1973; Klock and others 1971, 1975a; Tiedemann 1972).

One aspect of wildland fertilization that has received little emphasis is the differential nutrient requirements of various native plant species. Tiedemann and Klemmedson (1973) noted differential responses of four native grasses to deletion of individual nutrients in pot trials. In later trials, there were substantial differences in responses of a native grass Arizona cottontop and annual rye (Klemmedson and Tiedemann 1986). In pot trials with snow eriogonum, the only response was to the addition of N in soils that were severely deficient in both N and S (Tiedemann and Driver 1983).

Determining the Adequacy of Soil Nutrients

The complexity of soil chemistry and the necessity of proper and judicious use of chemical fertilizers support the need for soil assessment. A complete assessment also allows for characterization of site potential as it relates to specific plants and their range of adaptability—essential for planning best management practices to realize maximum sustained yield. Thus, the chemical and physical inventory serves to characterize wildlands and delineate those having potential for reclamation or improvement.

If there is assurance that other soil and environmental factors discussed in Section II: Basic Considerations are at reasonably optimal levels, the first step in development of a fertilizer prescription is determination of the total concentrations or availabilities of individual nutrients. Many fertilizer amendment studies and operations proceed with little information on concentrations of total or available soil nutrients. The result may be an erroneous interpretation of the results of such studies or operations. Liebig's law of the minimum and the Mitscherlich law (Stalfelt 1972) are often disregarded in decisions regarding fertilization (Klemmedson and Tiedemann 1995). The essence of these laws is that growth of a plant is dependent upon the amount of nutrient presented to it in minimum quantity (Odum 1959).

If more than a single nutrient is limiting in supply, the addition of one alone may produce only small increases in growth as compared to the addition of all that are limiting (Dean 1957). The added individual nutrients are effective only until another becomes limiting. The combined addition may actually produce a synergistic effect. A greenhouse pot study of orchardgrass yields as a function of three increments of N as urea, with and without addition of 57 ppm of S (fig. 2) demonstrates Liebig's law of the minimum

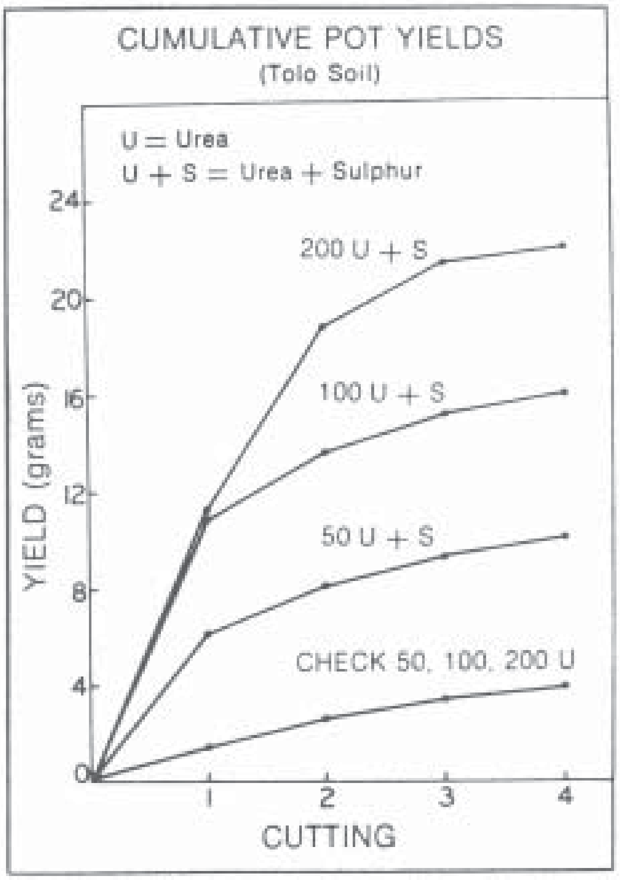


Figure 2—Cumulative yield of orchardgrass in response to several levels of urea and urea plus sulfur from Klock and others (1971).

(Klock and others 1971). All treatments received adequate P and K. Orchardgrass yields with additions of N at 50, 100, and 200 ppm as urea were the same as the control (check) treatment. When S, at 57 ppm, was added with increments of 50, 100, and 200 ppm of urea, there was a continuous increase in plant yields. Similar results were obtained with bitterbrush on granitic soils by Klemmedson and Ferguson (1973). These studies highlight the importance of determining the supply of all soil nutrients prior to application of fertilizer amendments.

As with deficiencies, excesses of one or more elements, whether naturally occurring or induced, can have deleterious or negating effects in the nutrition of plants. Excessive application of fertilizers is avoided by assessing the soil fertility status beforehand.

Soil nutrient analyses are usually made by State Agricultural Extension Service Laboratories. These laboratories will provide instructions on sampling methodology, number of samples to collect, and preparation of samples for shipment. State Extension Agents can assist in the determination of the nutrients that need to be measured based on their experience. They can also assist with the interpretation of the results of soil analyses for nutrient content.

Total Nutrient Concentrations

Evaluation of total concentrations of soil nutrients provides an estimate of the long-term nutrient-supplying capability of a given soil. The soil substrate or parent material is the source of most elements required for plant growth. Among these are phosphorus (P), calcium (Ca), potassium (K), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and cobalt (Co). Decomposition and relative amounts of individual nutrients released depend on the nature of parent and soil material, climate, and the presence of organisms important in decomposition processes (Buol and others 1973; Hallsworth and Crawford 1965).

Soil phosphorus and sulfur, in addition to their important role in plant growth and physiological function, are important in the accrual of organic carbon and nitrogen (Walker and Adams 1958).

Nitrogen is unique in its accrual to the soil nutrient capital. Atmospheric nitrogen gas is the primary source of nitrogen for the soil (Stevenson 1965). However, the major storehouse of N is soil organic matter (Kowalenko 1978) and since organic matter is limited in semi-arid environments (Hagin and Tucker 1982; Klemmedson 1989), N is usually the major limiting nutrient. Nitrogen accrual to the soil occurs principally through the N-fixation process, whereby N is converted from the gaseous form in the atmosphere to forms usable by higher plants. Blue-green algae (*Nostoc* and *Anabaena*) in the surface soil, free-living bacteria (*Rhodospirillum*, *Clostridium*, and *Azotobacter*), legume symbiosis with *Rhizobium*, and actinomycete nodulation of several genera of wildland plants are principally responsible for this source of N accrual (Stevenson 1965). Klemmedson (1979) indicates that N-fixation by actinomycete nodulation occurs in species of eight western genera—alder, ceanothus, mountain mahogany, dryas, elaegnus, wax-myrtle, bitterbrush, and buffaloberry. Actinomycete nodulation and N-fixation also occurs in cliffrose (Nelson 1983).

Precipitation appears to represent a minor part of nitrogen accrual to agricultural soils—7 to 20 kg/ha/year (Stevenson 1965)—but may be important for wildland soils where N requirements are less. In some parts of the United States, however, the input of N by precipitation may be much lower—less than 2 kg/ha/year in the interior Pacific Northwest (Tiedemann and others 1978, 1980).

The atmosphere is an important source of sulfur from burning of fossil fuels and geothermal discharge (Strahler and Strahler 1973), with resultant deposition as dry fallout and precipitation.

While the normal ranges of total concentrations of nutrients in agricultural soils of the United States is readily available (table 2), such information is not generally available for wildland soils. However, levels would be expected to be at the lower end of the range given for agricultural soils, with the exception of such elements as Mg and Ca in arid land environments, where large reserves are held in the soil storehouse because of minimal leaching (Charley 1972). There are also exceptions for total N. Tiedemann and Furniss (1985) found N levels in excess of 0.7 percent in surface soils of curlleaf mountain mahogany stands. Tiedemann and Clary (1996) observed total N concentrations in excess of 0.4 percent in the upper 12 inches (30 cm) of soil in Gambel oak stands in north-central Utah.

Available Nutrient Concentrations

Of more immediate utility than total concentrations of individual nutrients is the determination of the available concentrations. Available nutrients normally represent only a minor proportion of the total nutrient capital. Available N (nitrate- and ammonium-N), for example, may represent 1 to 2 percent of the total organic N capital of the soil (Stevenson 1965). For available cations, the gap between total and available concentrations are usually much greater.

Table 3 presents values of low, marginal, and high availabilities for all of the soil nutrients essential for plant growth. Values are also presented for unacceptable levels that may be toxic to plants or in excess of

Table 2—Normal range of total concentrations of nutrients occurring in agricultural soils and soil factors for determining deficiency and excess (adapted from Tiedemann and Lopez 1983).

Element[a]	Total in soils	Soil type in which deficiency is likely	Notes	Reference
N	0.05 percent to slightly more than 0.5 percent in mineral soils	Sandy, especially in high ppt. area; low in organic matter	Rate at which N becomes available varies greatly and, hence, analysis for total N is usually of little help in determining immediate fertilizer practices. Excessive N can result in salt buildup.	Harding 1954; Jones 1966
P	0.09-0.13 percent	Weathered and acid; calcareous		Bingham 1966; Jenny 1930
K	1.7-2.5 percent	Light, sandy; acid; organic		Parker and others 1946; Ulrich and Ohki 1966
S	0.01-0.06 percent		High S concentrations occur in gypsiferous soils; neither total S nor reducible S significantly correlated ($p = 0.05$) with either plant yields or S uptake.	Burns 1967; Eaton 1942
Ca	0.1-2.0 percent in soils free of Ca carbonate; 1-25 percent in calcareous soils	Humid, sandy	Soils vary widely in content.	Chapman 1966; Millar 1955
B	2-100 ppm		B excesses occur in soils derived from marine sediments and in arid soils.	Bradford 1966; Krauskopf 1972
Cu	2-140 ppm	Alkaline and calcareous; leached, sandy soils; soils fertilized heavily with nitrogen; leached, acid	Excess Cu can occur in soils derived from Cu-ore sources.	Chapman 1966; Mitchell 1948; Reuther 1957; Reuther and Labanauskas 1966; Swain 1955
Fe	10,000-100,000 ppm	Calcareous, poorly drained manganiferous		Krauskopf 1972; Wallihan 1966
Mg	5,000 ppm	Acid, sandy; imperfectly drained; alkaline	Mg excess can occur in soils where more than 90 percent of CEC is saturated with Mg. No correlation between total Mg and a soil's crop-producing potential.	Embleton 1966; Kelley 1948; Prince and others 1947; Reichle 1970
Mn	0.2-3,000 ppm	Calcareous; heavily manured and limed; very sandy-acid	Total Mn is not a good measure for plant availability.	Krauskopf 1972; Labanauskas 1966; Swaine 1955
Mo	0.2-10.0 ppm	Highly podsolized soils with low Mo retention capacity	Availability of Mo highly dependent on pH.	Johnson 1966; Krauskopf 1972; Robinson and Edgington 1954
Zn	10-300 ppm	Acid-leached, sandy; alkaline; granitic, gneisses; organic soils; clays with low Si/Mg ratio	Zn availability is pH dependent; decreases 100-fold for each unit increase in pH.	Chapman 1966; Lindsay 1972; Swaine 1955

[a] B = Boron; Ca = Calcium; Cu = Copper; Fe = Iron; K = Potassium; Mg = Magnesium; Mn = Manganese; Mo = Molybdenum; N = Nitrogen; P = Phosphorus; S = Sulphur; Zn = Zinc.

legal limits. Toxic levels will often be a consequence of pH problems and can be moderated with liming amendments to adjust pH to acceptable levels. To determine the available supply of an element, concentration (ppm) must be converted to the decimal value by multiplying by 1×10^{-6}. This value is then multiplied by the weight of the surface 15 cm of soil, which is estimated at 2.2×10^{6} kg/ha. For available N (from nitrate), a high level of supply would equal 18 ppm (table 3). Multiplying 18 ppm by 1×10^{-6} and by 2.2×10^{6} kg/ha would equal 40 kg/ha of nitrate-N. Assuming 2 percent total N in plant tissue, this level of nitrate-N is adequate for production of about 2,000 kg/ha of forage.

Other procedures assess the adequacy of soil nutrients, but a detailed discussion is beyond the scope of this text. These other methods are briefly described below.

Visual Symptoms—Certain visual symptoms in plants are indicative of nutritional deficiencies. Some of these are easily diagnosed such as change

Table-3—Proposed guidelines for assessing fertility status of wildland soils[a] (adapted from Tiedemann and Lopez 1983).

	Availability			**Unacceptable levels of selected elements**	**Extraction method**	**References**
Nutrient[b]	**Low**	**Marginal**	**High**			
	- - - - - - - - - - - - - - - -	- - *ppm* - -	- - - - - - - - - - - - - - - -			
Nitrate						
N	<9	9-18	>18		Water extract	Massee and Painter 1978; Stroehlein 1980
P	0-15	16-30	>30		Bray	Thomas and Peaslee 1973
P	<6	6-11	>11		Sodium bicarbonate	Ludwick and Rogers 1976; Massee and Painter 1978; Thomas and Peaslee 1973
K	<60	61-120	>120		Ammonium acetate or sodium acetate	Ludwick and Rogers 1976
SO_4S	<6	6-15	15-30	>30		Ensminger and Freney 1966; Massee and Painter 1978; Reisnauer and others 1973
B	<0.5	0.5-1.00	1.0-5.0 Sensitive crops may have visible injury	5-8	Hot water	Reisnauer and others 1973; Schafer 1979; Stroehlein 1980
Cu	0-0.2		0.2	10-40	DTPA	Reisnauer and others 1973; Schafer 1979; Stroehlein 1980
Fe	<2.0	2.0-4.0	>4.0		DTPA	Ludwick and Rogers 1976; Viets and Lindsay 1973
Mg	<25	25-50	>50		Ammonium acetate	Doll and Lucas 1973
Mn	0-0.75		>0.75	10-60	DTPA	Ludwick and Rogers 1976; Schafer 1979; Stroehlein 1980; Viets and Lindsay 1973
Mo	<0.1 (pH 6)		0.10-0.20	>0.3		Reisnauer and others 1973; Schafer 1979
Se				>2.0		Schafer 1979
Zn	<0.5	0.5-1.0	>1.0	20-40	DTPA	Ludwick and Rogers 1976; Schafer 1979; Viets and others 1979

[a] Selected trace elements should be analyzed from this list if they are a demonstrated regional problem. Many quantitative limits shown in this section are not supported by research findings.

[b] B = Boron; Cu = Copper; Fe = Iron; K = Potassium; Mg = Magnesium; Mn = Manganese; Mo = Molybdenum; N = Nitrogen; P = Phosphorus; Se = Selenium; SO_4S = Sulphate-sulphur; Zn = Zinc.

in leaf color, leaf scorching, or leaf deformation. Because they have similar nutrient requirements, deficiency symptoms within a specific plant family are generally quite similar. Plants of the goosefoot and mustard families, for example, have a high requirement for boron; members of the legume family are very sensitive to a deficiency of potassium (Donahue and others 1977). Pictorial descriptions of deficiency symptoms in plants for the essential elements are well documented; see Chapman (1966).

Tissue Analysis—For established plantings, tissue analysis may be used in conjunction with soils tests to develop a fertilizer prescription. Interpretation of tissue analysis results is more complicated than for concentrations of total and available soil nutrients. Also, information on nutrient concentrations in wildland plants and the relationships to soil nutrient status (sufficiency or deficiency) is negligible. Concentrations in tissue vary widely among species, plant part, and season. Interpretation may also be confounded by luxury consumption of certain elements. See Ulrich (1952) and Walsh and Beaton (1973) for more detailed information on tissue analyses and interpretations.

Greenhouse Bioassy—Another procedure for determining nutrient availability is greenhouse bioassy, such as the technique of Jenny and others (1950), commonly referred to as a pot trial study. This procedure is a practical way of determining nutrient needs for individual plant species using actual field soil samples. Although particularly applicable for study of macronutrient availabilities, it can also be used to assess micronutrients. This test involves determining biomass yield of a test species in response to deletion of individual nutrients from a full nutrient treatment. A control treatment (no added nutrients) is also established. Bioassay nutrient availability trials have the advantage that quantitative fertilizer prescriptions can be tailored to a particular species or mix of species being considered for revegetation purposes. A limitation of this method is that the effect of soil physical characteristics is not taken into account (such as permeability, bulk density). It also does not account for moisture limitations and the moisture/nutrient interactions that are encountered in the wildland setting. For a detailed discussion on methods and assessment of results for this technique, see Tiedemann and Lopez (1983).

Field Trials—Field experiments are a means of determining nutrient needs by actual on-site trials. Calibrating nutrient requirements to yields can be accomplished by carefully planned and executed outplantings. However, it should be kept in mind that recommendations based on field trials are site specific for the plant species tested. Standard guides to investigations of this type are available; see Hauser (1970) and Mukerjee (1960).

Development of a Fertilizer Prescription

The simplest procedure for developing fertilizer amendment needs is to match soil test results with the values presented in table 3. The amount of each element that needs to be supplied for low, marginal, and high levels of nutrient availability have been developed (table 4). To convert these values to actual rates of fertilizer application, the decimal value of the elemental concentration of a particular nutrient in the fertilizer is divided into the desired application rate of that element. For example, with N at low availability, there is a need to supply 56 kg/ha (table 4). The amount of ammonium nitrate fertilizer that must be applied is 56/0.32 = 172 kg/ha of actual fertilizer.

If more than one element is at a low level of availability, it will be desirable to apply a single fertilizer that contains as many of the limiting nutrients as possible. It should be noted that rates of more than one element cannot be controlled. We suggest keying application rate of other nutrients to the needed rate of application of N, P, or K to assure adequate amendment of these macronutrients. For example, in a situation where both N and S are at low availability, if the rate of ammonium sulfate application were based on sulfur needed (6 kg/ha), it would be equivalent to 25 kg/ha of fertilizer. Since this fertilizer contains 21 percent N (table 5), the rate of N application would only be 5 kg/ha—a 90 percent reduction from actual needs of 56 kg/ha. Ammonium nitrate could be used (in addition to ammonium sulfate) to achieve the proper level of N fertilization.

One important point to highlight in application of fertilizers is the need to maintain a balance of fertility. Application of an excess of one element will likely result in rapid depletion and limited availability of other elements. Voisin (1964) proposed a “law of correction of soil imbalances” that states that “any imbalance of available mineral elements existing or appearing in the soil because of the nature of the latter, as a result of removal in harvested crops, because of fertilizer application or for any other cause, must be corrected by application of the necessary fertilizing elements so that optimum balance among the soil elements is restored, producing high biological quality in the plant and the maximum yield compatible therewith.” In essence, any nutrient that is exhausted must be replenished and imbalances must be corrected.

Table 4—Fertilizer recommendations based on inherent status (table 3) (kg/ha) to be applied based on average soil bulk density (= 1.35 g/cm^3) (adapted from Tiedemann and Lopez 1983).

Nutrient[a]	Low	Marginal	High	Notes	References
N	56	17-22	0		Amburgey 1964; Massee and Painter 1978
P	29	22	15	To convert from P to P_20_5 multiply by 2.25.	Amburgey 1964
K	32	16	0	To convert from K to K_20 multiply by 1.20.	White 1979
S	6	2	0		Massee and Painter 1978
Ca	6				Viets and Lindsay 1973
B	1.7	0.8			Reisnauer and others 1973
Cu	5				Murphy and Walsh 1976
Fe	30	15		For acid soils—FeEDTA; for neutral soils—FeHEEDTA or FeDTPA; for alkaline soils—FeDTPA or FeEDDHA.	Wallihan 1966
Mg	7	3.5	0		Sirker 1908; Stone 1953
Mn	pH <7.0 6 pH >7.0 11	pH <7.0 3 pH >7.0 5	pH <7.0 5	Lime induced deficiency can be corrected by acidification.	Murphy and Walsh 1972
Mo	0.11	0.03			Murphy and Walsh 1976
Zn	11	6	0		Murphy and Walsh 1976

[a] B = Boron; Ca = Calcium; Cu = Copper; Fe = Iron; K = Potassium; Mg = Magnesium; Mn = Manganese; Mo = Molybdenum; N = Nitrogen; P = Phosphorus; S = Sulphur.

Table 5—Elemental composition of some common available fertilizers.

Material[a]	N	P	K	S	Mg	Ca	References
	- - - - - - - -	- - - - - - - -	*Percent*	- - - - - - - -	- - - - - - - -		
Ammonium nitrate	32.5						Fairbridge and Finkl 1979
Ammonium phosphate	11.0	48		3			Sulphur Institute 1982
Ammonium sulphate	21.0			24			Sulphur Institute 1982
Ammonium phosphate-sulfate	16.0	20		15.4			Sulphur Institute 1982
Calcium nitrate	15.5				1.5	19.3	Fairbridge and Finkl 1979
Copper sulphate				11.8			Sulphur Institute 1982
Phosphoric acid (liquid)		23-24				0.2	Fairbridge and Finkl 1979
Potash (potassium-chloride)			52				Fairbridge and Finkl 1979
Potassium magnesium sulphate			15-18	18-23	11		Donahue and others 1977
Potassium sulphate			44	18			Fairbridge and Finkl 1979
Single super phosphate		8-9		12		13-15	Fairbridge and Finkl 1979
Trebel super phosphate		18-20		1		9-13	Fairbridge and Finkl 1979
Urea	42-46						Sulphur Institute 1982
Zinc sulphate				13-18			Sulphur Institute 1982

[a] Ca = Calcium; K = Potassium; Mg = Magnesium; N = Nitrogen; P = Phosphorus; S = Sulphur.

Application of Fertilizers on Wildland Soils

Plant nutrients differ in the way they may be applied most effectively as fertilizers because of differences in their chemical properties, amounts required by plants, chemical and biological activity in the soil, and solubility, which varies according to their formula and physical condition (Cook and Hulbert 1957). The emphasis on proper application of fertilizers should be considered equally critical to the selection of fertilizers. Four reasons for this emphasis are elaborated upon here:

First, optimum time of fertilizer placement should coincide with adequate moisture availability. Nutrients are ineffective in dry soil. If leaching by water will not be the means by which nutrients are translocated to the root zone, fertilizers should be placed where roots have access to the nutrients (Cook and Hulbert 1957). For the Intermountain West, surface applications of fertilizers are most effective if applied in late fall after some precipitation has been received. This allows ample time for microbial transformations of fertilizer compounds such as urea and assures movement of mobile ions into the rooting zone.

Second, mobility of fertilizer elements and nutrient absorbing characteristics of the vegetation must be considered. For example, surface applications of phosphorus (an immobile nutrient) are likely to be more effective with shallow, fibrous-rooted species such as perennial grasses than plants with taproots such as forbs and shrubs. For fertilizer compounds with nitrate-N and sulfate-S, two relatively mobile nutrients, surface applications would be effective for perennial grasses, forbs, and shrubs.

Third, in fertilizer placement, a plant's demand for various nutrients at different stages of growth should be taken into account. Maximum demand for nutrients occurs in the young plant and early growth stages of perennials. Rapid growth can only take place when adequate enzymes are present and, therefore, only after the plant has absorbed a sufficient quantity of the minerals necessary for correct enzymatic function. However, the demand never ceases completely. Should some of the minerals become limiting at a later stage, damage and eventual plant death may occur. Seedlings should have ready access to nutrients for early growth yet direct contact with fertilizer could be detrimental because of the osmotic effect of salts depriving the seedling of water.

Fourth, application with regard to physical and chemical soil factors must be considered. The effect of pH on nutrient availabilities illustrates the importance of considering soil chemical properties. Fertilizers applied to soils with pH less than 5.1 or greater than 8.4 will not likely be effective in promoting plant growth because nutrients will become unavailable. Soil physical properties can also affect fertilizer effectiveness. A soil with a very slow infiltration rate, for example, may impede overall nutrient availability to plants, because little of the fertilizer will be transmitted to the root zone and will be vulnerable to removal by surface runoff.

Much of what we know about fertilizers and fertilization is based on agricultural practices that may not be suited to the wildland situation. Nevertheless, the basic concepts of plant-soil relationships are applicable. If it is decided that a fertilization program will be done, proper application is essential.

A number of application methods are available to the land manager. However, many of these are not practical in wildland settings. Broadcasting on the soil surface has been the most widely used method of applying granular fertilizer (Vallentine 1980). Where chaining, or other vegetation-clearing, soil-disturbing practices is employed, the prescribed fertilizers could be spread prior to clearing, thus allowing for some incorporation caused by the soil disturbance. The same recommendation would be appropriate for areas to be reseeded by drilling. Soil incorporation is particularly important for phosphorus fertilizers.

On annual grassland in California, helicopter application was considered fast and practical on rangeland too steep for ground application (Duncan and Reppert 1966). Spreading of granular and foliar fertilizer by airplane has likewise been a practical means of fertilizing wildlands, and at a much lower cost than with helicopters.

Foliar application of micronutrients and secondary nutrients in a wildland setting may be a practical and logical method for improving impoverished areas with identified deficiency symptoms. Foliar application may be particularly beneficial where nutrient uptake through the plant roots is restricted or where soil incorporation is prohibitive. Also, foliar application is the fastest way to correct deficiencies of micronutrients. Attempts to supply the major nutrient requirements such as N, P, and K by foliar application may not be successful because of the required high rates and repeated applications causing foliage scorching and increased expense (Hagin and Tucker 1982).

The addition of specific secondary nutrients or micronutrients to amend specific needs requires careful planning in their application because of the high cost involved and adverse consequences of toxicity due to excessive, uneven application. These minor and secondary elements are applied most economically at the same time as macroelements. The amounts needed (table 4) are generally so small that separate applications are difficult. One word of caution: the addition of specific micro- and secondary elements to take care of specific needs is applicable only in areas where soils are known to be severely deficient. The consequences of improper application can be devastating and protracted.

Some plant nutrients have been successfully applied by seed coating (Murphy and Walsh 1972). A number of benefits are realized: (1) even distribution of nutrients over treated areas; (2) nutrients readily available for a more even emergence and survival of seedlings; (3) assurance of more uniform stand establishment, often with less seed per acre; (4) most efficient in terms of labor and other application costs. One disadvantage is that seed coating cannot be used to build soil nutrient reserves. It is used primarily for early emergence and survival.

Conclusions

The foregoing information was given to provide an overview of the soil factors that affect the potential success of wildland rehabilitation efforts. It is obvious that it is not economically feasible to correct some soil conditions on wildlands. Even though there may be no economically feasible treatments for overcoming adverse soil conditions, it is important for rehabilitation specialists to be able to recognize these problems, and in some cases be able to quantify their magnitude. Although fertilization is a readily available technique for amending soil nutrients, it is considered to be a “high input” option (Marschner 1986). “The low input option, and perhaps the most feasible means of managing nutrient stress is to encourage the development of species that are either adapted to or can tolerate low nutrient levels, or those that can ameliorate N limitations by symbiotic N fixation” (Klemmedson and Tiedemann 1995).

There is a rapidly emerging understanding of the morphological and physiological features of plants that are adapted to grow and survive in nutrient-limited environments. Consideration of these adaptations in the process of selecting plants for revegetation should greatly improve chances for success in revegetation of nutrient-limited sites. Most species of a stress tolerant strategy tend to be small in stature (Grime and Hunt 1975) with an inherently slow growth rate, thereby, resulting in a low demand on the soil nutrient supply (Chapin 1980; Grime 1977).

Despite low nutrient absorption rates, species from soils of low fertility status maximize nutrient acquisition by maintaining a large root biomass, and high root:shoot ratios (Chapin 1980; Marschner 1986), increased length (Marschner 1986) and branching (Troughton 1980) of roots, strongly developed mycorrhizal associations (Mosse 1973), and greater root longevity (Chapin 1980).

Plants that fix N by symbiosis such as those of the legume family hold promise as a natural means of providing N to wildland plantings (Blackbourn 1975; Rumbaugh 1983). Several genera of native shrubs such as alder, ceanothus, bitterbrush, cliffrose, and buffaloberry are also known for their ability to fix atmospheric N (Klemmedson 1979; Nelson 1983; Righetti and others 1983). Although research on the effectiveness of these plants in improving the N supply of wildland sites is in its infancy, these plants hold promise of reducing or perhaps even eliminating fertilizer N amendment needs on wildlands in the future. Several herbaceous species of legumes such as alfalfa, yellow sweetclover, cicer milkvetch, sainfoin, and sulla sweetvetch are already in use for this purpose (Rumbaugh 1983).

Other chapters in this book address the issue of species adapted to vegetation zones and specific site conditions. The reader is also referred to Aldon and Oaks (1982), Monsen and Shaw (1983b), Tiedemann and Johnson (1983), and Tiedemann and others (1984b).

Stephen B. Monsen

Chapter 8

Controlling Plant Competition

Selecting Methods and Procedures for Plant Control

Generally, range or wildlife habitat improvement projects seek to achieve desirable plants through the elimination or replacement of undesirable species or both. Control measures are thus designed to: (1) reduce the competitive effects of existing species (Evans and Young 1987a,b; Robertson and Pearse 1945), (2) allow the establishment of seeded species (Harper and Benton 1966; Toole and others 1956), and (3) facilitate reestablishment, or improve the vigor of, desirable native plants (Plummer and others 1970a; Stevens 1987b).

Although control measures are often needed to reduce weedy competition, wholesale elimination of a species is not always necessary. Some practices, including chaining or burning (Plummer and others 1968), are used to reduce the density of target species and promote changes in the composition of the existing community.

Chaining and burning have been used to stimulate regrowth of decadent stands of antelope bitterbrush (Edgerton 1983; Martin 1983), mountain mahogany, cliffrose, and aspen. These processes improve availability of Gambel oak (Plummer and others 1968), and the forage production of big sagebrush (Young and Evans 1978b) sites.

Control measures are often sought that will eliminate all existing species, particularly on sites dominated by cheatgrass (Young and others 1976b), medusahead, or cluster tarweed (Carnahan and Hull 1962; Hull and Cox 1968). Disking, plowing, or use of chemicals are most effective where complete control measures are required (Eckert and Evans 1967; Haas and others 1962). Remnant native plants are useful and should be retained on most range or wildlife sites. However, control measures are seldom so refined that individual species can be retained when others are destroyed.

If seeding is to be successful, the existing competition must be sufficiently reduced to allow establishment of new plants (Evans and Young 1978). If a mixed array of plants are seeded, the period of establishment may be prolonged by 2 to 5 years.

Consequently, to be effective, considerable reduction in the presence of existing plants is often necessary (Monsen and McArthur 1985; Stevens 1987b). In addition, the control measures used must also prevent the recovery of targeted species for sufficient time to allow seeded species to fully establish (Fulbright 1987; Hutton and Porter 1937).

Methods of Plant Control

Mechanical Control

Various techniques and implements are available to mechanically treat rangelands (Abernathy and Herbel 1973; Anderson and others 1953; Herbel and others 1973). Many implements used in conventional agriculture have been adapted for use on wildlands. Trained personnel are normally available to operate, modify as necessary, and maintain the machinery. Consequently, many range and wildlife habitat improvement projects rely on the use of modified farm equipment. Numerous equipment items have also been developed specifically for range and wildland sites (Larson 1980). The functions, capabilities, and uses of equipment used in wildlands are described in chapter 9.

Mechanical control measures may be more or less effective in reducing unwanted plants than burning or herbicide treatments. However, some aspects of mechanical control provide advantages to overall rehabilitation and restoration programs. Attributes of mechanical treatments are summarized as follows:

1. Different types of equipment are available to treat specific circumstances.
2. Treatments can be selectively used to remove target species.
3. Mechanical control can be effective in the removal of live plants and seeds.
4. Treatments can be conducted at different seasons to retain or lessen impacts on key species.
5. Treatments are not always restricted to a specific season or period as is burning or chemical control.
6. Control measures usually aid in creating a seedbed, and in seeding.
7. If necessary, litter and surface protection can be provided to lessen runoff and erosion.

Fire and Herbicide Control

Fire and herbicides are viable methods of controlling plants. Both techniques have specific limitations and advantages (Hyder and others 1962; Pechanec and Stewart 1944; Young and Evans 1978b). Either are applicable measures if weedy species can be selectively controlled and desirable plants can be retained or are able to recover. Both methods can be used to eliminate competition prior to seeding (Young and Evans 1978b; Young and others 1976a,b). Descriptions and use of herbicides and fire are discussed in detail in chapters 10 and 11.

A considerable amount of plant residue and surface litter is often left in place following herbicide treatments. This debris may enhance the seedbed (Evans and Young 1984). However, neither burning nor herbicide treatment provides a suitable seedbed for most species. Some means of mechanical seeding or seed coverage is required to plant an area following burning or spraying (Evans and Young 1984). In contrast, mechanical plant control measures, chaining, disking railing, and so forth not only remove weedy competition but simultaneously aid in seeding.

Biological Control

More than one approach is usually feasible for reducing the density of undesirable plants. Land managers have some latitude in selecting treatments for most rehabilitation projects. Sometimes, biological control measures are quite effective. Regulating grazing intensity, seasonal use, and selective foraging can improve the vigor and density of certain plants (Hubbard and Sanderson 1961; Vallentine 1989). Unregulated grazing can harm and even destroy well planned projects. Grazing of range and wildlands is considered a biological control measure, as foraging impacts by domestic livestock, wildlife, and insects can, in part, be regulated. Grazing also impacts other biological systems affecting plant communities.

Improvements achieved through controlled grazing and seeding (Shown and others 1969) are usually most noticeable on mesic sites. Blaisdell and Holmgren (1984) reported that the composition of desert shrublands, including certain salt desert shrublands, will respond favorably to grazing management, although changes may require many years of careful treatment. Improvement in vegetative conditions is often a cumulative response. Plant density may increase as plant vigor improves and more seed is produced to facilitate seedling establishment. These changes often occur over a long period of careful management.

Grazing can be used to reduce the presence of some weedy or less desirable plants. Cattle grazing has been effective in reducing seed production and stand density of cheatgrass, but has not been effective in elimination of the annual grass. Plummer and others (1968) reported that grazing of burned stands of Gambel oak by livestock and deer aided in suppressing shrub regrowth. However, species not eagerly eaten by grazing animals are difficult to control without excessive damage to other plants.

Regulating livestock grazing has been an effective means of improving the vigor and density of selected existing plants (Astroth and Frischknecht 1984). Broadleaf herbs and some grasses that are sought by grazing animals may not recover even though a significant reduction in grazing occurs. Species such as alfalfa (Rosenstock and others 1989), small burnet, arrowleaf balsamroot (Plummer and others 1968), and bluebells continue to be selectively used even when livestock or game numbers are reduced. Changing the grazing season is most beneficial to species of herbs highly preferred by grazing animals (Frischknecht 1978).

Elimination of livestock grazing of some preferred shrubs including Stansbury cliffrose, Martin ceanothus, curlleaf mountain mahogany, and antelope bitterbrush has resulted in improved plant vigor. However, if heavily browsed, these shrubs may require 3 to 5 years to respond. Forage yields and seed production may respond dramatically, yet recruitment of new seedlings may be prevented by understory weeds. Thus, many shrublands disrupted by grazing and infested with annual weeds may not recover satisfactorily as a result of simply eliminating grazing.

Regulating game use of seriously depleted rangelands has been achieved by seeding selected portions of the habitat. Revegetating segments of some big game winter ranges has succeeded in concentrating game use on the seeded areas. This has lessened grazing of adjacent ranges and allowed for natural recovery. This practice is particularly successful if highly palatable species are planted to attract grazing animals and change seasonal use. Orchardgrass, small burnet, penstemon, black sagebrush, fourwing saltbush (Nichlos and Johnson 1969), sainfoin, and alfalfa can be seeded in areas where they are adapted to attract and regulate animal use. Other plants, particularly Lewis flax, mutton bluegrass, wild buckwheat, prickly lettuce, salisfy, showy goldeneye, redstem ceanothus, and creeping barberry are species that demonstrate similar usefulness. These species often recover quickly following restoration treatments. Not all provide a major part of the diet for game or livestock, but they are selectively grazed and attract animals.

Livestock grazing is often recommended as a method of dispersing and planting seed by trampling. Eckert and others (1987) report soil relief is important to seed entrapment, germination, and seedling establishment. Moderate trampling favors emergence of perennial grasses; heavy trampling is detrimental to the emergence of perennial grasses and forbs. Moderate trampling can be both beneficial or detrimental to seedling establishment depending upon the position in the soil where seeds germinate. Surface germinators are enhanced by moderate trampling, but species requiring more soil coverage are not.

Grazing systems are not always effective measures for controlling weedy plants or enhancing the establishment and increase of desirable species. Once weeds such as juniper and pinyon, broom snakeweed, halogeton, red brome, or cheatgrass gain dominance, their density may not be diminished by changing grazing practices. Other more desirable plants are not likely to increase unless the weedy competition is reduced. Consequently, seriously depleted plant communities recover very slowly or not at all with grazing management. Unless a number of desirable remnant plants exist, the change may be too slow and ineffective to be regarded as a viable alternative.

Successional Changes

Other means of biological control can be employed to bring about changes in plant composition. Natural changes in plant succession following logging or wildfires can affect large areas. Many sites cannot be revegetated by artificial plantings, but significant improvement can be achieved by protection and natural changes. Slight shifts in plant composition on extensive areas can significantly influence forage or habitat resources. Natural changes in the density of broadleaf herbs, particularly Utah sweetvetch, arrowleaf balsamroot, or nineleaf lomatium can occur as a result of fire in sagebrush or bunchgrass communities. A slight increase can be beneficial to spring and summer foraging by game and wildlife. Similarly, an increase of wild buckwheat or black sagebrush, on harsh, exposed winter ranges can significantly enhance winter forage conditions for some big game animals. Fluctuations in density and herbage production of certain shrubs including big sagebrush, low rabbitbrush, and antelope bitterbrush occur as the composition of understory weeds is reduced. Redstem ceanothus and western chokecherry increase rapidly as overstory trees are removed. Rather dramatic differences can occur within a short time. The natural shift in species presence, density, and vigor can substantially change the seasonal forage base and habitat conditions.

Both logging and burning are commonly used to improve wildlife habitat conditions in many forest communities (Steele and Geier-Hayes 1987). The approach of altering successional change normally requires a long period, but is a well-accepted management technique. Other considerations such as maintenance and economic costs are easily justified. Natural recovery of depleted arid and semiarid rangelands does not occur quickly, and artificial rehabilitation is often recommended. Nevertheless, sites can be managed to facilitate improvement through natural succession.

Differences in annual precipitation and other climatic conditions have long-term effects on plant communities (Bleak and others 1965; Plummer and others 1955). Drought conditions can eliminate or weaken certain species. Contrasting “wet years” can enhance establishment and increase plant density. Implementing revegetation measures during favorable years or periods is advisable, but predicting “good years” is not always possible. Delaying or implementing control measures until years when favorable moisture appears likely to occur can be justified.

Improvements in plant communities are not restricted to years or periods of high precipitation. During the drought period of 1987 to 1990, cheatgrass and other annual weeds produced extremely low seed crops. Seed production of native perennial grasses was more favorable, and considerable spread of the perennials occurred.

Delaying plans for control measures until mid or late winter when buildup of winter moisture occurs is possible in many circumstances. Coordinating plans for artificial control treatments to coincide with expected natural community changes should be carefully considered.

Insect and disease outbreaks (Nelson and others 1990) (see chapter 15), wildfires, winter injury (Nelson and Tiernan 1983), and other factors can result in extensive plant dieoff. Contingency plans should be developed to capitalize on these situations.

Factors Influencing the Selection of Methods and Equipment

Primary Objectives

Land rehabilitation or restoration measures are developed to satisfy certain objectives. Most often, range and wildlife habitat rehabilitation and restoration programs are designed to: (1) improve forage quantity and quality, (2) enhance vegetative cover for wildlife, (3) control weeds and their management problems, (4) improve or maintain esthetic and recreational values, (5) correct watershed problems, and (6) enhance the succession and natural development of native communities.

If improvement of forage production is a principal objective, measures required to create a managed pasture situation may be justified (Astroth and Frischknecht 1984; Cook 1966). Seeding or treating to support a single species, or grazing at a specific period may justify extensive conversion treatments (Cook 1966). Thus, disking, plowing, or herbicide spraying would likely be required to eliminate competition and successfully seed a specific crop. If year-long foraging is desired or needed to sustain wildlife and livestock, a complex of species would be needed (Monsen 1987). Treatment practices would be used that would facilitate the introduction of some species without the complete elimination of others (Monsen and Shaw 1983c).

Attempting to minimize the impacts of treatments upon esthetics or selectively reducing certain species while retaining others are complex actions that must be contemplated in selecting appropriate equipment. In most cases, the selection of equipment or treatment practices is ultimately based on the need to control weedy plants. Other factors, although important, generally do not dictate restoration measures. If plant competition cannot be controlled, treatment procedures should not be implemented.

Plant control measures are usually closely aligned with seeding or planting. Techniques that reduce competition, provide a good seedbed, and permit planting in one operation are preferred (Schumacher 1964). However, not all of these objectives can usually be achieved in one procedure. The effectiveness of rehabilitation or restoration programs is determined by the control measures and seeding procedures used. A land manager must select the appropriate equipment and treatments that will modify the vegetation in the manner desired.

Sites that provide the greatest potential for forage production (Anderson and others 1953) or for improved wildlife habitat values normally justify the greatest investment. Complete renovation and seeding can be justified on areas that yield high returns.

However, attempting to evaluate the importance of a site based upon forage production is often unwise. Sites that furnish midwinter forage, especially during adverse winter conditions, are extremely valuable locations. They furnish critically needed forage and cover, although production may not be comparable with other sites. Attempting to restore those areas using costly and extensive procedures may be well justified. For example, planting or enhancing the status of wild buckwheat, green ephedra, or smooth sumac on small restricted sites can significantly improve the midwinter range condition of many critical game ranges.

Various criteria have been developed to identify range sites that should or should not be treated (Cook 1966; Plummer and others 1968). Some recommendations do not advise treating steep slopes or shallow soils when an increase in herbage production would not occur. However, these sites are usually an integral part of the habitat for game animals and watershed resources. Forage productivity may not be as important as animal concealment or watershed protection.

Rehabilitation or restoration measures must be compatible with circumstances at the planting site. Treatments must be conducted in a manner that will yield the greatest return. Sites should be evaluated to determine their productive capabilities. Improvement measures should be designed to assure that adapted plants and techniques are used to achieve plant establishment and survival.

Most ranges, and particularly game ranges, are diverse sites. Usually only one method is used to treat an entire area. However, several different measures are often justified to revegetate individual portions of an area being treated.

Site Access

Topography and surface conditions influence the operability of equipment used in rehabilitation and restoration. Many range and wildland sites include some steep or poorly accessible areas. Getting equipment onto a site and furnishing support and maintenance during the operation is essential. Aerial seeding and anchor chaining are perhaps the most versatile techniques currently available for treating mountainous terrain (Skousen and others 1986). Equipment of this type is expensive to transport, consequently, it is not economical to treat small areas or fragmented tracts that require numerous moves and frequent “setup.”

Rough, irregular sites limit the use of most conventional machinery. Rocky soil conditions and dense woody vegetation interfere with equipment operation and cause considerable breakage.

Topography also influences seasonal access and operating efficiency and effectiveness. Uprooting and breakage of woody plants is best accomplished when soils are partially frozen and plants are cold and brittle. Late fall and early winter access is necessary to treat many shrublands. Treatment of riparian sites is best accomplished during periods of low runoff and when soils are dry. This often requires late fall and winter access.

Soil surface conditions may differ considerably on irregular sites. Soils may be moist and frozen on certain aspects, yet dry and friable on adjacent sites. Differences can be great enough to reduce the success of plant control measures. Yet, delaying treatment until all sites are open and accessible may not be practical. Consequently, the period when sites can be effectively treated may be very short for some rather large areas.

Status of Existing Vegetation

Plant Competition

Usually only one or two species of undesirable plants are of primary concern. However, mixed stands can and do support different growth forms (shrubs and grasses) that require different control measures.

Most perennial herbs cannot be eliminated by surface scarification resulting from railing or chaining (Barney and Frischknecht 1974; Tausch and Tueller 1977). These plants must be uprooted by disking or plowing (Cook 1966; Drawe 1977), or eliminated by chemical spraying, or in some cases, burning (Robertson and Cords 1957). Annual herbs, particularly those that produce a buildup of seed in the soil, must be treated in a manner that kills existing plants and prevents or reduces establishment by seed (Evans and Young 1987b; Young and others 1969). Deep plowing or scalping to sidecast surface soil and weed seeds away from planting furrows are appropriate techniques (Schumacher 1964). Herbicide spraying can also be used to prevent floral or seed development (Evans and others 1976). Weeds can also be consumed by fire if burning is done before seeds drop from the plant (Plummer and others 1968).

Large woody plants and rough rocky sites are not conducive to soil tillage such as plowing or disking. These areas can be burned if sufficient fuel is available to carry a fire. Mechanical control measures are usually limited to railing, chaining, or other techniques that uproot or crush the vegetation. These practices usually create a good seedbed. Chemical spraying can also be effective on trees and large shrubs, although selective herbicides are recommended in order to prevent damage to desirable species that may be present.

In most instances, a combination of treatments is needed to gain control over sites dominated by more than one weedy species. For example, chaining or burning juniper-pinyon woodlands may successfully control the trees, but cheatgrass would not be affected.

Plant Tolerance and Response

Many resprouting species recover following cutting, burning, pruning, or chemical defoliation (Vallentine 1989). Repeated treatments may be necessary to eliminate these species. Treating at the appropriate season can increase vegetative kill. In addition, the establishment of seeded species and the recovery or release of other existing natives can result in further suppression of the targeted plants (Wight and White 1974).

Undesirable species that recover by root sprouting, stem layering, or other means of vegetative propagation must be uprooted (Allison and Rechenthin 1956) or chemically treated. Repeated treatments or a combination of treatments may be necessary to eliminate particularly persistent or noxious weeds (Vallentine 1989). Such retreatments may be justified on highly productive ranges, meadows, and riparian areas. However, complete control may not be practical on most sites.

Complete elimination of resistant herbs is not always warranted. If density or recovery of weedy plants does not interfere with the establishment of seeded species or the recovery of desirable natives, extensive control is not necessary (Monsen and Turnipseed 1990). Spot treatment or treating narrow strips or bands may be sufficient to interseed weedy sites (Schumacher 1964; Stevens and others 1981b; Wight and White 1974). Clearings must be large enough to allow seedling establishment and normal plant growth (Giunta and others 1975). Treated sites should remain free of weeds for 1 to 3 years to allow establishment of seeded plants.

Control of annual weeds usually requires the elimination of live plants and new seedlings (Davis and Harper 1990; McArthur and others 1990a). Most annuals, particularly cheatgrass, medusahead, Russian thistle, and Belvedere summer cypress, recover quickly following treatment if soil-borne seeds are allowed to germinate (Evans and Young 1984). Removal of the live plants is not sufficient to assure successful seeding. New weed seedlings can appear quickly enough to suppress seeded species.

Mechanical or chemical fallowing is used to reduce newly germinating weed seedlings, although present restrictions limit the use of some herbicides. Deep furrow drilling (Young and McKenzie 1982), disk chaining (Wiedemann 1985), anchor chaining (Davis and Harper 1990) using the Dixie (Jensen 1983) or Ely chain, pipe harrowing, or other soil tillage treatments can be successful in eliminating weed seedlings. Soils are not completely plowed or turned with these implements, but sufficient tillage occurs to uproot and kill enough weeds to allow establishment of planted seedlings. Soil surfaces must be overturned 3 to 5 inches (8 to 13 cm) by disking to bury most weed seeds deep enough to prevent emergence.

The Extent and Duration of Weed Control

The foremost issue in most restoration or rehabilitation projects is the establishment of seeded species. Weeds must be eliminated during this period to assure seedling establishment and survival (Samuel and DePuit 1987). Many grasses and broadleaf herbs seeded on rangelands establish quickly and grow rapidly (Houston and Adams 1971). Once these species achieve initial establishment, they are sufficiently competitive to resist extensive competition. In contrast, many shrub seedlings establish much slower and are vulnerable to competition for a number of years (Giunta and others 1975).

Weeds must be controlled for extended periods to allow slow-growing species time to establish. Many introduced weeds have unusual regenerative capabilities and can suppress seedling establishment of many natives, particularly some shrubs. Young stands of shrubs such as Stansbury cliffrose, green ephedra, serviceberry, skunkbush sumac, curlleaf mountain mahogany, blackbrush, and Martin ceanothus can be severely decimated if cheatgrass, red brome, or medusahead are allowed to reestablish 3 to 5 years after the shrubs are seeded (Plummer and others 1968). Seedlings of these shrubs are vulnerable to excessive herbaceous competition for many years following seeding. Even though the shrub seedling may survive 1 to 3 years, their ultimate survival is still tenuous.

Seeding companion species is a viable and recommended method of reducing the early reentry of weeds (Vallentine 1989). Some perennials are sufficiently competitive to prevent recruitment of weeds, yet allow the establishment of slower growing seeded species. Timothy, orchardgrass, mountain rye, alfalfa, western yarrow, and Sandberg bluegrass are frequently seeded in alternate rows with shrubs or slower developing herbs to control the rapid entry of weeds. Manipulating row spacing, seeding rates, and planting at different dates are methods useful in attaining establishment of slow-growing species (DePuit and others 1980; Samuel and DePuit 1987). Seeding nurse crops or companion species under arid conditions must be done carefully to prevent unnecessary competition.

Most woody plants, including stands of juniper-pinyon, big sagebrush, matchbrush, rabbitbrush, black greasewood, or snowbrush ceanothus do not need to be completely eliminated to allow the establishment of seeded species (Plummer and others 1968). The presence of some remaining plants may actually be helpful. These species may be partially thinned or damaged by railing, chaining, or burning. Their recovery, either through new growth or by reproduction, is usually not rapid enough to prevent establishment of the seeded species.

Thinning, suppression, or partial elimination of some plants are often required to release other associated species. In many projects the recovery of certain native herbs and shrubs is of primary importance. Partial control of the dominating weedy species is often sufficient to release the remnant plants (Aro 1971). The released plants recover quickly and are able to provide considerable competition within 1 to 2 years. Favorable recovery of Woods rose, blue elderberry, black sagebrush, low rabbitbrush, black chokecherry, fourwing saltbush, spiny hopsage, antelope bitterbrush, desert bitterbrush, squawapple, Apache plume, and many other shrubs has occurred following control of associated plants.

Plant control must have a long-term effect (Hull and Stewart 1948). Some plants recover and reoccupy the site if only a few plants are left following treatment. Big sagebrush, Sandberg bluegrass, and black greasewood are examples of plants that recover rapidly and may reduce recovery of other desirable species (Johnson and Payne 1968).

Effects of Control Measures on Seedbed Conditions

Range sites that do not harbor desired plants usually must be seeded to achieve a more desirable vegetative composition (Eckert and Evans 1967). Regardless of whether sites require seeding or will recover naturally, a suitable seedbed is necessary (Eckert and others 1987). Seeding is usually programmed to coincide with weed control or site preparation treatments. Seedings are usually more successful if conducted soon after weedy competition is removed (Young and others 1969) to take advantage of the seedbed conditions created by disking, railing, and chaining (Plummer and others 1968). It is important that plant control methods create or improve the seedbed. Generally, mechanical treatments overturn or disrupt the soil surface. Disrupting the soil surface by deep plowing or other drastic measures can destroy favorable seedbed conditions. Tillage provided by chaining, pipe harrowing, or railing is usually sufficient to adequately cover seed and compact the seedbed, but is less disruptive to the soil surface than plowing or disking.

If plant control measures are also used to facilitate seeding, the work should be conducted at the optimum time for seed germination and seedling establishment (Bleak and Miller 1955). This may or may not coincide with the optimum period for plant control. Seeding is sometimes done during inappropriate periods to take advantage of loose soil conditions or soil sloughing. Seeding is often done immediately after a burn in loose ash and flocculated soils. Seeding is not recommended in midsummer or when seeds may germinate prematurely. If plant control measures are relied upon to cover the seed, the operation should be done when soils are tillable and proper planting depths are attainable. Chaining sites when soils are dry and loose results in deep planting and a very loose seedbed. These conditions are not conducive to seedling establishment. In contrast, chaining areas in early winter when soils are wet and slightly frozen prevents deep seeding and results in a firm seedbed. Broadcast seeding on top of snow over disturbed soil can be a successful seeding practice.

In general, mechanical plant control favors seeding as soil disturbances and tillage create a useful seedbed. Burning or spraying may leave some surface residue or litter that can aid seedling establishment, but additional seeding methods are normally required.

Availability of Personnel and Equipment

Although many factors influence the selection of equipment and techniques to treat wildlands, the availability and operative experience of existing personnel is a primary consideration. Most implements used on wildlands are costly and are not widely available. In addition, these implements are often used on steep, inaccessible sites that require highly skilled operators. A large support staff, spare equipment, and repair facilities may be required to sustain a major rehabilitation project. Without this contingent of personnel and equipment, rehabilitation procedures may not be effective. However, using the wrong piece of equipment cannot be justified simply because of poor preparation and planning.

Treatment procedures are usually as effective as the equipment operator. Chaining, railing, or plowing results differ considerably among operators. Field personnel and equipment operators should be advised of their role and responsibility in rehabilitation projects. Although methods used on steep slopes should be designed to lessen water runoff, equipment operators must be given flexibility to safely and efficiently operate the machinery. Chaining or railing up and down steep slopes does not always create rills or generate damaging runoff. Sufficient litter and surface debris usually remains in place to control erosion when juniper-pinyon or brush fields are treated.

Equipment operators should be directed to map or plot travel routes ahead of time to allow efficient operation of all equipment. Procedures used in monitoring fire suppression activities should be adopted to assist revegetation when aircraft or large equipment are used.

Economic Benefits and Treatment Costs

Attempting to project and quantify operation costs and resulting benefits is difficult for range and wildlife projects. Equipment operation costs including transportation, setup, maintenance, operations, and depreciation are identifiable expenses. However, equating returns based solely upon herbage production is not indicative of all benefit values. For example, attaching an accurate value to the establishment of certain secondary species that provide seasonal forage or protective cover for wildlife is difficult. Also, attempting to place a value on the habitat resources of a changing plant community is equally difficult. The long-term values of rehabilitation projects, particularly watershed protection, stability of wildlife populations, esthetics, and recreational uses are important considerations in most improvement projects. In addition, the continued degradation and loss of resource values, and the increased rehabilitation costs of deteriorated sites that are left untreated is of major consideration. All treatment benefits should be recognized in order to select appropriate plant control measures.

Treatment Impacts on Associated Resources

Converting the vegetative composition from one plant type to another (for example, trees to herbs) creates a dramatic change in scenery. Also, removing existing mature plants and establishing other species that have the same life form will still create a significant change in appearance for a number of years following treatment. Young plantings provide differences in ground cover, animal concealment, esthetics, forage production, and so forth. However, some benefits are registered quickly including improvement of ground cover and forage production.

Visual impacts are most noticeable immediately after treatment (burning, chaining, plowing). However, these effects are usually short lived. Natural changes usually occur rapidly and mask initial impacts. Foregoing appropriate restoration measures because of the initial impacts to esthetics is not justified. Plant communities that support weedy species are usually esthetically unpleasant as well, and the conversion process should be viewed as an improvement.

Plant manipulation procedures are a part of the improvement process. Sites dominated by weedy annuals or supporting unwarranted numbers of woody species should be regarded as disclimax conditions. Restoration of these areas will ultimately enhance all resources.

Certain steps may be taken to limit visual impacts, particularly when extensive changes are proposed. Treatments can be used that retain some plants in appropriate areas. Treatments can be laid out in a mosaic design to lessen visual impact. Treatments that result in straight lines and square corners are not recommended. Treatments can also be conducted over a period of years to stagger the number of acres treated at one time, and allow some sites to recover satisfactorily before further treatment is initiated.

Sites located on similar aspects can be treated at the same time leaving areas on different aspects for later treatment. If this is done, areas treated at any one time should be large enough to support the increased use that is normally imposed on new seedings. In addition, restoration measures should be confined to the areas needing treatment. Attempts to appease esthetic concerns should not result in inappropriate areas being treated simply because they are less visible, and problem areas left untreated because of high visibility.

A variety of herbaceous and woody species can and should be seeded in most areas to provide initial cover and herbage. Many native herbs and some shrubs that are released when weeds are removed will recover quickly. In almost all situations, the recovery of desirable natives can be encouraged to effectively enhance the initial cover. Chaining, railing, and burning can be used to stimulate regrowth and improve vigor of certain species through the removal of weedy competition. Antelope bitterbrush, snowbrush ceanothus, blue elderberry, chokecherry, Gambel oak, and Rocky Mountain maple are but a few of the shrubs that respond quickly. Quick recovery under more arid circumstances is often more difficult to achieve, but seedings of big sagebrush, rabbitbrush, winterfat, and fourwing saltbush grow quickly and can be used to lessen initial visual impacts.

Site renovation programs are often conducted to rectify and protect highly valuable onsite and associated offsite resources. Important watersheds often require treatment to maintain downstream values. Wildlife habitat projects may be required to stabilize game herd productivity, reduce heavy animal losses that occur during harsh winters, and prevent trespass damage to agricultural crops. The related resource values of most range and wildland projects are important, and few restoration projects are developed to satisfy or benefit one resource.

Richard Stevens
Steven B. Monsen

Chapter 9

Mechanical Plant Control

When planning a restoration or rehabilitation project, proper equipment selection should be a high priority. Equipment should be selected that is adapted to the treatment site, and that when properly used, will fulfill and add to the objectives of the treatment. Equipment should be economical and ecologically sound.

Basic equipment available and commonly used in range and wildland restoration is described in this chapter along with primary functions and principal areas of use. For the convenience of the reader, equipment has been grouped into three categories.

1. Seedbed preparation equipment
    - Disks and plows
    - Chains and cables
    - Pipe harrows, rails, and drags
    - Land imprinters
    - Root plows
2. Seeding equipment
    - Drills
    - Broadcast seeders, ground broadcasting, aerial broadcasting, fixed-wing, helicopters
    - Seed dribblers
    - Brillion seeder
    - Surface seeder
    - Interseeders
    - Hydro seeders
3. Special use equipment
    - Transplanters
    - Roller choppers
    - Dozers and blades
    - Trenchers, scalpers, gougers
    - Fire igniters
    - Herbicide sprayers
    - Steep-slope scarifier seeders

Seedbed Preparation Equipment

Disks and Plows

Disks and plows are designed to turn over soil and surface debris, kill existing vegetation, and prepare a seedbed (table 1).

Moldboard Plow—Plows with large curved bottoms (moldboards) with blades or shears and large curved wings above. Each moldboard can be independently spring-loaded to enable each bottom to rise when obstructions are encountered.

Disk Plow—Consists of a single gang of a few to several disks on a frame supported by wheels. Each disk is slanted at an angle to the vertical, with a separate bearing and frame attachment.

Brushland Plow—A specially designed rangeland disk. The brushland plow consists of seven pairs of opposite, opposing disks attached to spring-loaded arms that are connected to a heavy duty frame supported by three wheels. Each pair of disks is independently suspended (fig. 1) (Larson 1982).

Off-Set Disk—Two rows or gangs of disks are set at an angle to each other (fig. 2) (Brown 1977; Larson 1982). Angles are adjustable. Disks cut in two directions, turning over soil and vegetation both ways. Disks can be smooth or cutout (table 1).

Disk-Chain—An anchor chain, with cutout disks connected to every other link (fig. 3). Varying lengths of disk-chains are connected to either end of a double roller bar, forming an “A” with the apex forward and the roller bar back. A spreader bar is connected from the center of the roller bar to the apex. The length of the spreader bar determines the angle of the chains and disks. Chains are connected to each other; the roller bar is connected by swivels (Wiedemann 1985).

Table 1—Description, primary areas of use, and limitations of some major seedbed preparation equipment.

Equipment	Description	Primary area of use	Limitations
Disk-plow	Single gang of a few to several disks mounted on a frame.	Deep plowing of rock-free and debris-free soil. Controls deep rooted plants.	Restricted to fairly rock-free and large debris-free sites. Slow speed. Large amount of power required to operate.
Brushland plow	Pairs of disks connected to independently suspended spring-loaded arms. Arm connected to heavy duty frame with wheels.	Shallow plowing on smooth, rough, rocky, and uneven terrain. Controls grasses, forbs, and nonsprouting shrubs. Low maintenance costs.	Will not control sprouting shrubs. Difficult to transport. Operational speed is slow.
Off-set disk	Two rows or gangs of disks set at an angle to each other.	First gang of disks turn soil and vegetation. Second gang turns soil and vegetation in opposite directions. Vegetation is cut up and broken. Controls most grasses, forbs, and small nonsprouting shrubs. Works well on dry, heavy, and moderately rocky soils.	Cannot be operated in soil with large rocks and on slopes over 30 percent. Fairly slow operational speed.
Smooth anchor chain	Anchor chain weighing 40 to 160 lb per link, 90 to 350 ft long, with swivels on either end and sometimes in the middle.	Moderate soil scarification. Uproots and breaks off trees and shrubs and releases understory vegetation. Covers seed. Cost per acre to operate is moderate. Can be operated on uneven rocky terrain. Ideal for removing trees, releasing understory shrubs, grasses and forbs, and covering seed.	Will not control sprouting shrubs. A less than acceptable job of killing nonsprouting shrubs and trees. Will ride over young, flexible trees.
Ely-anchor chain	Anchor chain weighing 40 to160 lb per link, 90 to 350 ft long, with steel bars or railroad rails welded cross ways to chain links. Swivels are attached at either end and throughout.	Uproots and breaks off trees and shrubs. Releases understory vegetation. Percent kill of shrubs and trees is higher than with a smooth chain. Does an excellent job of scarifying soil surfaces and covering seed. Can be operated on rough, rocky terrain. Cost to operate is moderate.	Has tendency to hook and drag trees, and rolls downed trees and shrubs to the middle of the chain. This lifts the chain off the ground, resulting in poor soil scarification. Can uproot and kill some understory vegetation.

(con.)

Table 1 (Con.)

Equipment	Description	Primary area of use	Limitations
Dixie sager	Anchor chain weighing 40 to 160 lb per link, 90 to 350 ft long, with railroad rail welded to each side of each link horizontal to the link. Crown of rail welded next to link. Swivels are attached at either end and throughout.	Uproots and breaks off trees and shrubs. Releases understory vegetation. Does an excellent job of uprooting and killing big sagebrush, scattering smaller pinyon and juniper, and scarifying the soil. Covers seed. Can be operated on rough, rocky terrain. Cost of operation is moderate.	Does not work well in full pinyon-juniper stands. Trees are hooked by the railroad rail and are dragged along. This lifts the chain off the ground and results in poor sagebrush kill and soil scarification.
Cables	Cable 1.5 to 2 inches thick, 100 to 550 ft long, with swivels at both ends and throughout.	Will uproot larger trees, slightly scarify soil surface and cover seed. Can be used on rocky, uneven terrain. Cost of operation is low. Ideal for removing scattered large trees and releasing understory shrubs.	Percent kill of trees is lower than with smooth, Ely, or Dixie-sager anchor chains. Soil is poorly scarified.
Pipe harrow	Spiked pipes trailed behind a spreader bar. Pipes are attached to spreader bar by swivels at equal intervals along bar.	Scarifies soil surface, removes small brittle shrubs, covers seed. Ideal for interseeding desirable species into sparse vegetation stands. Works well on rocky land and uneven terrain. Cost of operation is low. Seeding can occur concurrently.	Does not control plants other than brittle shrubs. Soil scarification is limited on compacted soil.
Land imprinter	Cylinder or drums with various configurations, sizes, and shapes of angle iron welded to the drum surface. Seed dispensers may be attached to frame-tow bar combination.	Operation on rough, rocky, and brush covered terrain on most soil types. Creates small depressions. Seeds are deposited into depressions in a firm seedbed. Cost of operation is moderate.	Does not work well in dense shrubs or grass communities or on compacted and rocky soil.
Root-plow	Straight or V-shaped blade attached to shanks. Shanks are attached to a trailing draft or arm or tow bar, dozer blade, or dozer frame.	Used to undercut undesirable grasses, forbs, shrubs, and small trees in soils free of large rocks. Works well in dry soils.	Not adapted to shallow, rocky, steep, or wet areas. Kill of sprouting and rhizomatous species may be low. Cost of operation can be high.

Figure 1—Brushland plow.

Figure 2—Off-set disk.

Only one tractor is required to operate a disk-chain. Seeding and disking can occur simultaneously. Broadcast seeders can be connected to the roller bar on a trailing trailer. Seed boxes have been placed over the roller bars.

Principal Areas of Use—Disks are designed to kill plants by turning over sod, vegetation, and debris; and for preparing a seedbed. Disk plowing has the advantage of leaving plant material at or near the soil surface. Offset disks and moldboard plows are well adapted to fairly deep soils with few large rocks and debris. Offset disks are fairly effective on moderately rocky soils taking out small and medium shrubs, but not effective when worked in large shrubs and trees that have large woody stems and heavy roots.

The brushland plow was developed specifically for range and wildlands. It is well suited to rocky, rough, and uneven terrain. This plow does a good job of killing low growing nonsprouting shrubs. Each set of disks, being independently suspended, will lift up and go over rocks and debris leaving the other sets in the ground.

The disk-chain is designed for use on smooth, rough, uneven, and rocky terrain in all vegetative types ranging from grass communities to large shrubs and sparse stands of small trees. Width of treatment is determined by width of the roller bar. Roller bars vary from 24 to 46 ft (7.3 to 14 m) wide. Width of roller bars and length of chain determine disk angle and distances between disk cutting points. If complete disturbance and vegetation turnover is desired, spreader bar or chain length is increased, causing the angle of the chain to the roller bar to be readjusted. When it is desirable to have some area undisturbed (interseeded), spreader bar or chain length is decreased. Care must be taken in extending the spreader bars too far. If the angle between the spreader bars and the chain exceeds 30°, excessive wear to the components will result. Broadcast seeding can occur simultaneously with disk chaining from a broadcaster mounted on a trailing trailer (fig. 3A) that throws the seed forward behind the disks and ahead of the roller bars that covers the seed. Drill boxes can be mounted directly over the roller bars that deposit the seed directly onto the roller bar, and subsequently in front of the roller bar that cover the seed and turns up the seedbed (fig. 3B). The disk-chain is an ideal piece of equipment for large sites, strips, and localized site seeding in sparse trees and shrub stands. The disk-chain does an excellent job in reducing the density of cheatgrass and perennial species.

Chains and Cables

Cables and anchor chains and modified anchor chains are generally pulled between two crawler tractors for the purpose of removing or thinning trees, shrubs, and grasses and for covering seed (table 1).

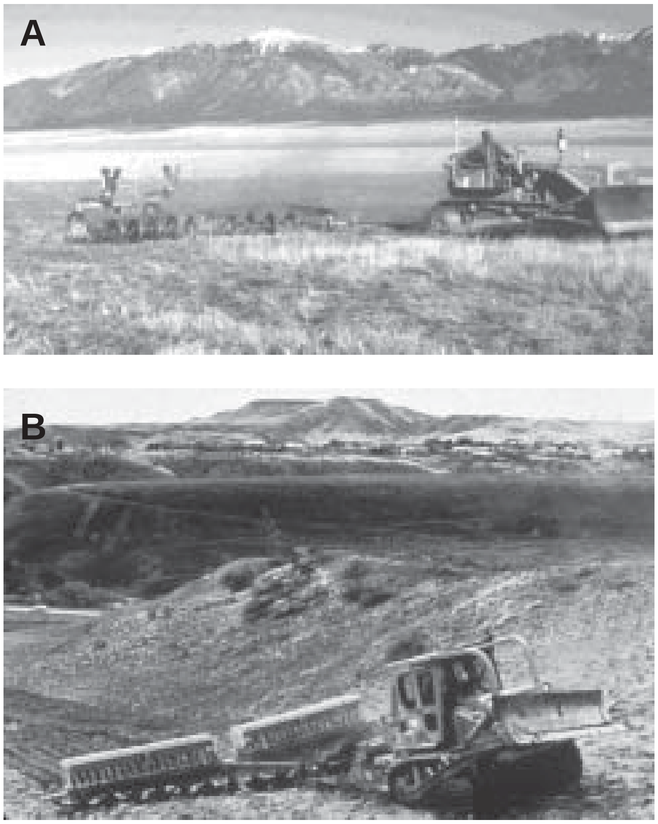


Figure 3—Disk-chain. (A) Seed broadcast with electric powered cyclone seeder. (B) Disk-chain with seed boxes mounted above roller bar.

Cables—The steel cable is 1.5 to 2 inches (3.8 to 5 cm) thick and 100 to 550 ft (30.5 to 168 m) long. Swivels are required at both ends and are sometimes installed in the center of the cable. They are necessary so that the cable does not unwind, and to permit the cable to rotate and keep itself relatively free of trash and debris.

Anchor Chain—A destroyer or cruiser-type anchor chain, 40 to 160 lb (13.6 to 72.6 kg) per link (fig. 4) (Davis 1983b; Larson 1982; Roby and Green 1976) varies in length from 90 to 350 ft (27 to 107 m). Swivels (fig. 5) (Larson 1982) are required at both ends and are recommended additionally, at least in the middle of the chain.

Ely Chain—This device consists of anchor chains with steel bars (fig. 5). Hard surfaced railroad rails are I-beam (fig. 5 and 6) welded crossways to every link, every other link, or every third link (Larson 1980). Bar length will vary with link size but should extend 4 to 6 inches (10 to 15 cm) beyond both sides of the link. Swivels are required on both ends of the chain and intermediately throughout the chain. Chain length

Figure 4—Smooth anchor chain.

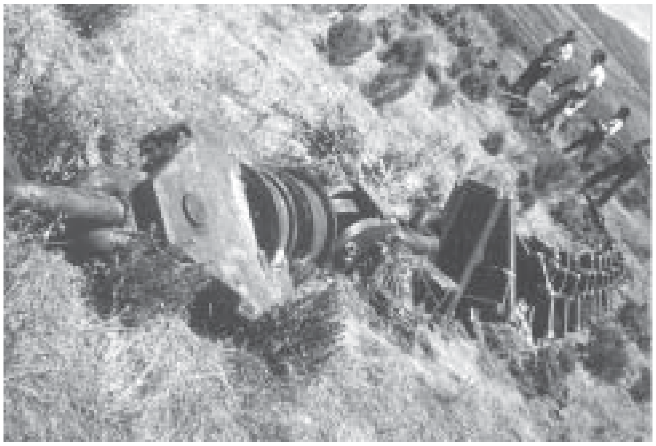


Figure 5—Swivel within an Ely chain.

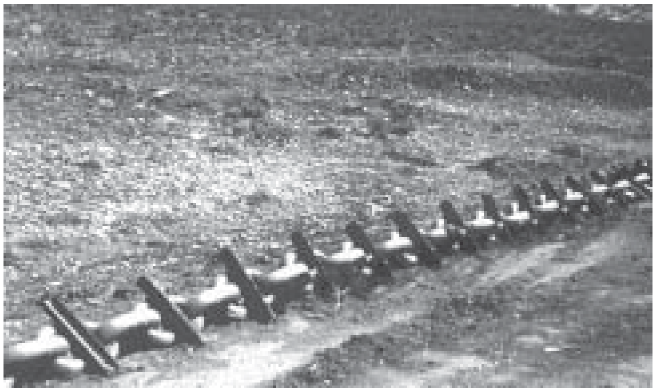


Figure 6—Ely chain. Anchor chain with railroad rails welded crossways on every other link.

varies from 90 to 350 ft (27 to 107 m) long. The ten to 15 lead links at either end of the chain are left smooth because this part of the chain is not in contact with the ground.

Dixie Sager—An anchor chain with a railroad rail welded to each side of each link, horizontal to the link (fig. 7) (Larson 1982). Length of rails depends on link length. The rail should be approximately one-half the total length of the link. Rails are welded with the crown of the rail next to the link, and base of rail out. Swivels are required on both ends of the chain and intermediately throughout the chain. Chain length varies from 90 to 350 ft (27 to 107 m). Ten to 15 smooth lead links are on each end of the chain.

Disk-Chain—See “Disks and Plows” section, “Disk-Chain” paragraph.

Principal Areas of Use—Anchor chains and cables are primarily used to uproot trees and shrubs, to create seedbeds, to top and prune large shrubs, and to cover seed (table 1). Some grasses and forbs can also be uprooted. Use is also limited due to concerns for protection of archaeological sites, damage to nontarget vegetation, and aesthetic and hydrologic impacts.

Anchor chains and cables are pulled behind two crawler tractors traveling parallel to each other. To

Figure 7—Dixie Sager. Anchor chain with railroad rails welded horizontally to both sides of each link.

Figure 8—Uprooting pinyon and juniper with an anchor chain. For maximum results chain should be dragged in a loose J-shape as is being done.

be effective, chains and cables should not be dragged or stretched taut, but must be dragged in a loose, J-shaped (fig. 8), U-shaped, or half circle pattern. The half-circle configuration provides the greatest swath width, lowest percentage kill, and should only be used in mature, even-age tree stands. Kill and disturbance increases as the width of the J- or U-shaped pattern decreases. Chain length to swath width ratio of 2:1 to 3:1 are commonly used. As the proportion of young trees and shrubs increase, chaining width should decrease in order to achieve the greatest amount of kill. Individual chain link weight varies from 40 to 160 lb (18 to 72.6 kg). The heavier the link, the better the chain stays on the ground, and the higher the percentage kill.

Chaining commonly occurs on slopes of up to 50 percent grade (Vallentine 1980). Chaining can occur up and down or across the slope without adversely affecting watershed values.

Success in removing trees and shrubs varies with species composition, age structure, density, and rooting habit. Trees in mature, even-age stands can be killed more effectively and efficiently than in uneven-age stands. Young trees less than 48 inches (1.2 m) tall may not be killed with single or double chaining because the chain may ride over them. Small junipers can be uprooted and killed more effectively than small pinyons that tend to be more flexible than junipers. Sprouting trees and shrubs may resprout following chaining. Anchor chains can be used to improve esthetics and livestock movement in burned tree and shrub stands, particularly those with a large number of standing dead trees and shrubs.

Chaining generally does not increase runoff or erosion. The opposite generally happens; runoff and erosion are decreased through increased retention and detention of surface water. This is the result of the large amounts of debris, trash, shrubs, litter, and trees that are deposited and left on the soil surface and the establishment of seeded vegetation. Downed trees, shrubs, and plants increase ground cover and protect the soil from wind and water erosion. In addition, they provide favorable microenvironments for plant establishment, growth, and protection. Live standing trees provide only canopy cover, very little ground cover, and little, if any, retention and detention of surface water.

Percent kill and amount of soil disturbance increases with link size. Ely chains do a good job of scarifying soil and preparing a desirable seedbed. The Ely chain has a tendency to roll downed trees and shrubs to the center of the chain. Tree and shrub kill is improved with an Ely chain over a smooth chain.

The Dixie sager was designed to uproot big sagebrush. It does an excellent job of uprooting sagebrush and scattered pinyon and juniper. The Dixie chain will do a better job than a smooth chain of soil scarification, and of sagebrush, small juniper, and pinyon kill. The Dixie sager does not work well in full pinyon-juniper stands since the railroad rails tend to hook trees and carry them along; this lifts the chain off the ground and reduces soil scarification and the number of trees and shrubs killed. Smooth chains are preferred when the objective is to release and open up tree and shrub communities such as big sagebrush, aspen, mahogany, serviceberry, Gambel oak, chokecherry, bitterbrush, cliffrose, winterfat, and shrubby eriogonum. When removing trees and most shrubs, twice-over chaining is necessary. The first chaining completely uproots some trees; however, many trees are not completely uprooted and are laid down in the direction of chaining. The second chaining should occur in the opposite direction, this generally uproots and tips the downed trees over. Most shrubs that come in contact with the chain are uprooted or broken off near ground level. Twice-over chaining increases percent kill and topping of shrubs. Seeding should occur between chainings, as the second chaining covers the seed. If single chaining occurs, seeding should take place prior to chaining.

First and second chainings can follow each other in the fall, with seeding occurring between chainings. Another technique is to chain once during the summer months. Uprooted and partially uprooted trees are allowed to dry before seeding and the second chaining is done in the fall. The dry trees and limbs break up easily and are fairly well scattered over the areas with the second chaining. Trees, limbs, and dry foliage create excellent microclimates for seedling establishment. Once-over chaining may be adequate when sufficient understory remains, trees are mature, and seeding is not planned. Cabling is less effective than chaining in removing trees; however, cables disturb

Figure 9—Pipe harrow consisting of spreader-bar and trailing spiked pipes.

the understory less. Use of a cable of lighter link chain is satisfactory where it is desirous to leave some trees or shrubs or to remove dead material from old shrubs and stimulate new growth.

It is generally advantageous to leave downed trees in place and not pile or burn them. Some advantages to leaving trees in place include: (1) increased amount of infiltration by increased retention and detention of surface water; (2) increased ground cover; (3) decreased erosion; (4) cover maintained for wildlife; (5) big game and livestock movement onto the treated area is encouraged, resulting in more even distribution and use; (6) provides shade for livestock and big game; (7) decreased livestock trailing; (8) seedling establishment is improved, especially of shrubs, and (9) cost of piling and burning is eliminated. Some advantages to removing trees are: (1) improved vehicular access; (2) enhanced access to all forage by grazing animals; (3) lower rodent density; (4) reduction in fire potential, and (5) improved esthetics.

Pipe Harrows, Rails, and Drags

Pipe harrows, rails, and drags are used to scarify soil surfaces, prepare seedbeds, cover seed, thin or reduce shrub density, and to release shrubs by removing top growth (table 1).

A pipe harrow consists of a spreader bar (usually railroad rails) and trailing spiked pipes (fig. 9). The spiked pipes are attached at equal distances along the spreader bar with swivels (Larson 1980, 1982). Cables or chains connect the spreader bar to a tractor. Rails come in various configurations. An A-rail is a rigid frame with the apex forward (Larson 1980, 1982). Rails consist of any number of tiers of rails connected with chains or cables that are dragged at right angles to the direction of travel. Drags consists of chain link fence, trees and shrubs drags, and combinations of rails and chains (fig. 10).

Principal Areas of Use—A pipe harrow can be used to uproot, break off, or thin shrubs; scarify soil; and cover seed (fig. 11). A pipe harrow can be very useful for preparing a seedbed and interseeding desirable species into sparse grass, forb, shrub, and tree stands, and for removing and thinning plants and seeding rocky and otherwise inaccessible areas. Weight of pipe harrows can be increased by filling the

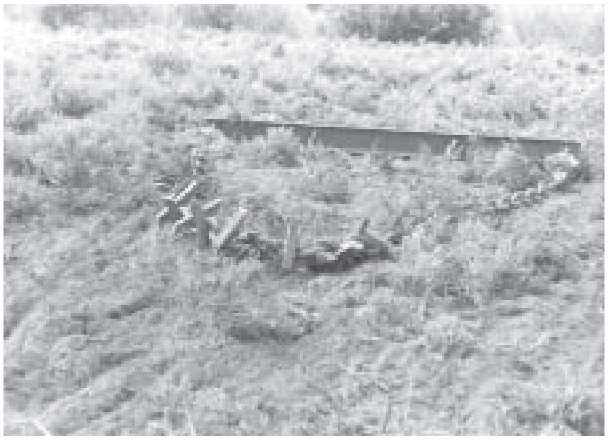


Figure 10—A drag consisting of an I-beam Ely chain combination being used to thin sagebrush and cover seed.

Figure 11—Pipe harrow and Hansen seed dribbler being used to seed shrubs and cover herb seeds to improve interspaces between pinyon and juniper trees and Gambel oak. Herbs were broadcast seeded prior to treatment.

spiked pipes with cement; increasing weight increases scarification. Rails are used for removing shrubs and covering seed. Rails are less effective than pipe harrows. Chain link fence, trees or shrubs drags are used to prepare a seedbed and to cover seed. Broadcast seeding can take place simultaneously with pipe harrowing, railing, and with drags.

Land Imprinter

The land imprinter (fig. 12) was developed by USDA Agricultural Research Service for covering broadcast seeds and creating microdepressions in the soil to improve moisture collection and infiltration (Dixon 1980). The equipment was designed to operate on untilled surfaces, and can be used to treat burns, or other disturbances where remnant vegetation should be retained (table 1).

The land imprinter consists of cylinders or rollers mounted on a single axle. The axle is attached to a steel tubular or pipe frame with a tongue for pulling. Cylinder surfaces have various configurations, and sizes, and shapes of angle iron welded to the surface of each drum. Angle irons make indentations or imprints in the soil (Larson 1980). Cylinders or rollers can be constructed from discarded asphalt rollers or similar items (Johnson 1982). The cylinders can be filled with water to increase weight and allow for deeper imprints. Broadcast seeders can be mounted on the frame assembly to dispense seed over the imprints; or a grain box can be mounted in front of the rollers with seed being distributed on the surface and impacted into the soil by the imprinter. The imprinter is commonly about 10 ft (3 m) wide, with individual angle irons 6 to 10 inches (15 to 25 cm) deep with vertical lengths between 3 to 4 ft (0.9 to 1.2 m) long. A 60 to 125 hp tractor is required to tow most land imprinters.

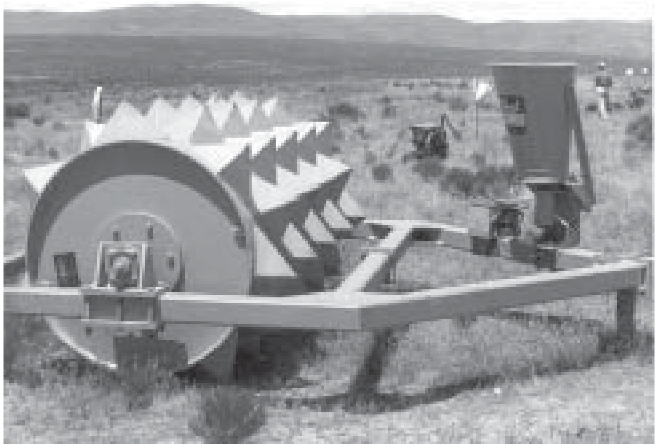


Figure 12—Land imprinter equipped with an electric broadcast seeder.

Principal Areas of Use—The land imprinter is designed to be towed over burned and low stature brush and herbaceous vegetation where other control measures are not used. The weighted cylinders are able to crush and compact standing vegetation, providing litter and surface protection. However, Haferkamp and others (1985) reported that both regular drill seeding and deep furrow drill seeding were more successful than imprint seeding on an unprepared Wyoming big sagebrush and Thurber needlegrass site. Imprint seeding is practical on sites where weed competition is low, and excessive debris does not interfere with seed placement.

The imprinter is well suited for seeding on loose, unstable seedbeds and barren surfaces left after a fire or light disking. Impressions can be created in the soil to reduce soil movement and deterioration of the seedbed. However, imprinting cannot eliminate soil erosion on all sites for extended periods. The V-shaped furrows or inverted pyramids are effective in collecting moisture and creating variable seedbed conditions that extend the germination period, and often tend to favor seedling success. The various surface configurations result in small furrows aligned at different directions, creating different microsites that may benefit the establishment of multispecies seedings.

Haferkamp and others (1985) found that seedling establishment on loose soil was greatest from broadcast seeding followed by imprinting, and that imprinting prior to seeding was not as effective. These investigators found imprint seeding more successful than drill seeding of areas disked prior to seeding. These results may not be universally applicable.

Placement of most seeds into a firm seedbed usually improves seedling establishment. Small seeds generally benefit from shallow seeding. The land imprinter lends itself to this type of seedings.

The imprinter appears useful on heavy textured soils where surface crusting can be expected, such as areas where black greasewood dominates. The machine can be used to retain and incorporate litter into the soil surface, reducing the potential for crusting. However, the machine should not be operated when soils are moist, or during periods when excessive compaction may occur. The machine is suited to seeding mine and roadway disturbance where loose, rough surfaces are created following ripping of spoil piles, dump sites, and temporary roads.

The imprinter can operate on most rough sites that are free of large rocks or obstructions. It can treat slopes up to 45 percent (Larson 1980), but it is not well suited to extremely irregular terrain. The land imprinter is not able to treat dense, erect shrubs with stems having a diameter greater than 3 to 4 inches (7.6 to 10 cm). Larson (1980) reports the imprinter is capable of production rates of over 4 acres (1.6 ha) per hour, which is somewhat less than conventional drill seeding. However, equipment breakdown and maintenance is generally less for imprinters. Imprint seeding can be used in conjunction with herbicide treatments. Spraying often leaves standing litter and dead plants that interfere with most conventional drill seeding, but not with an imprinter.

The imprinter may also be used to aid in site improvement by natural seeding. Imprinting of seed formed within the treated area can often be achieved if a sufficient seed reservoir is present and treatment is completed at the proper season.

Root Plows

Root plows are used to uproot undesirable grasses, forbs, shrubs, and small trees (table 1).

A root plow is a straight or V-shaped blade attached to two shanks (Larson 1980, 1982). Shanks are attached to a trailing draft arm or towbar, which are attached to the rear of a crawler or rubber tired tractor. Shanks can be attached to dozer blades, dozer frames, or as a front-end tractor attachment. Fins may be attached to the top of the blade.

Primary Areas of Use—Shearing blades are pulled or literally pushed through the subsoil at desirable depths, cutting off and uprooting most vegetation to the cutting depth. Fins attached to the top of the cutting blade provide some vertical cutting action and can move severed roots and root crowns to the surface. Plants with severed roots generally die from lack of water, and plants whose roots are exposed die of desiccation. Hot dry periods are the ideal time to root plow. Rate of kill is generally higher in loose soils. More power is required to root plow in hard, dry soil than in damp soils. Plants are, however, less likely to reestablish in dry soils (Larson 1980).

Root plowing kills most desirable and undesirable shrubs and nonrhizomatous grasses and forbs. Seeding is generally required following root plowing. Broadcast seeding can be accomplished simultaneously. Root plowing is limited to deep soils that are fairly free of rocks and obstructions.

Seeding Equipment

Drills

Drills dispense and place various types of seed in the most ideal situations for germination and establishment. Drills adapted to range conditions require most or all of the following characteristics:

1. Minimum drill breakage and maintenance under rough, rocky, and brushy conditions.
2. High clearance.
3. Heavy duty frame.
4. Individually suspended planters that can adjust independently to irregular planting surfaces.
5. Disk furrow openers that have depth regulators.
6. Seed boxes that will accommodate seed of various sizes and shapes, including seeds with appendages.
7. Seed agitators in each seed box that will prevent seed bridging and allow for even flow of seed to seed metering devices.
8. Precise metering devices for each seed box.
9. Baffles in seed boxes to maintain even seed distribution.
10. Devices for accurate and rapid setting of seeding rate.
11. A seed metering device that will disperse fluffy, plumbed, or trashy seed when these types of seed are used.

Seeding multiple species with varying sizes, shapes, and surface characteristic requires multiple seed boxes, each with differing seed metering devices and rates. Seeding depth requirements also vary between species. Some modifications to, and incorporation of equipment to facilitate these requirements have occurred. A variety of drills are available; however, all have some but very few possess all of the above required characteristics.

Primary Areas of Use—The Rangeland drill (fig. 13) was designed by the Forest Service specifically for rangeland use (Larson 1982; Roby and Green 1976; USDA Forest Service 1967; Young and McKenzie 1982). This drill possesses many desirable characteristics. It is well adapted to seeding rough, rocky terrain; however, breakage and down time can result in areas with heavy brush and trash. Some of the many improvements and modifications made to the Rangeland drill (Young and McKenzie 1982) have resulted in

Figure 13—Three Rangeland drills with drag pipes and depth bands.

the development of the deep furrow drill. Special adaptations are available to seed fluffy and trashy seed (Laird 1980). Depth bands (fig. 14) are fairly effective in regulating seeding depth except in loose soils. The deep furrow Rangeland drill is especially effective in creating water catchment impressions. Rangeland drills come in a number of models and sizes. Service, parts (USDA Agricultural Research Service 1967), and operation (USDI Bureau of Land Management 1976) manuals are available.

The Truax drill seeder (fig. 15) incorporates many desirable characteristics plus all the features of the Rangeland drill with the exception of high clearance. It is designed to seed rangeland sites and rough terrain where dense litter has not accumulated. The wheels and disks are positioned for planting using hydraulic cylinders. The drill has been designed to transfer weight from the machine to the ground engagement planters through elastometer torsion knuckles, unlike units using mechanical linkage. This has reduced breakage and eliminated regular repairs.

The Truax drill has three different seed boxes designed to accommodate seeds of different sizes and shapes. Seed metering is independently regulated for each seed box. A front mounted seed box is designed to plant small hard seeds. A second box is used to plant fluffy or trashy, lightweight seeds, and the third seed box is used to plant larger grain-size seeds. Seeds are metered through the small seed box and the grain-size seed box using a fluted feed regulator. Fluffy seeds are removed from the seed box by picker wheels, which remove and deposit a specific amount of seed. The picker wheel is driven by a chain and sprocket system that is attached to a ground wheel. Seeding rates are controlled by changes in the sprockets, through use of a bicycle-type derailer. The fluffy seed box contains an auger type agitator to assure uniformity in seeding rates. Pin agitators are mounted over the seed gate within the large seed box to provide uniform movement of seed. Under harsh conditions the machine requires 5 hp per planter row to effectively operate. Seed boxes are positioned directly over the drop tubes, which eliminate plugging of the seed in the tubes.

Figure 14—Individually suspended arm on a Rangeland drill. Disk furrow openers are equipped with depth bands and a drag chain.

Figure 15—Truax drill with three seed boxes and three sets of drops that can seed three different seed mixes or species at the same time at different rates and depths.

Seed slots or furrows are created by one leading concave, notched, no-till disk that is mounted on a slight angle. Seeds are directly placed in the soil, and compacted with a press wheel. A V-shaped cast iron press wheel is available and is used in hard soils to break up clods. A more universal type pneumatic press wheel is also available, and is better suited for wet or moist sites as mud does not accumulate on the wheels.

Depth bands are available and can be mounted or removed from each disk with four nuts. Different depth bands can be used to regulate planting depths ranging between 0.25 to 2.0 inches (0.6 to 5 cm).

The Truax drill is an improvement over the Rangeland drill as it provides three different seed boxes that can be independently regulated to meter seeds of different shape and condition. Bridging of seed in the seed tubes has been eliminated. Depth bands are much easier to remove or exchange, and better control of planting depths is maintained. The press wheels provide a better, firm, and compacted seedbed. Repair and operation costs are much less due to a new design of the supporting weight of the unit.

A number of reclamation and no till drills have been developed in the past 10 years. Each has their own characteristics, advantages, and disadvantages. Drills that have shown application on various range and wildland conditions include: Oregon press drill, Horizon (fig. 16), Tye (fig. 17), Haybuster, Great Plains, and Amazon (fig. 18) no till, stubble, and pasture drill.

The Rangeland and Truax drills are well adapted to seeding areas that have been cleared of trees and shrubs or burned. These drills have the capacity to seed many rangeland species out of one to three seed or fertilizer boxes or both (fig. 19).

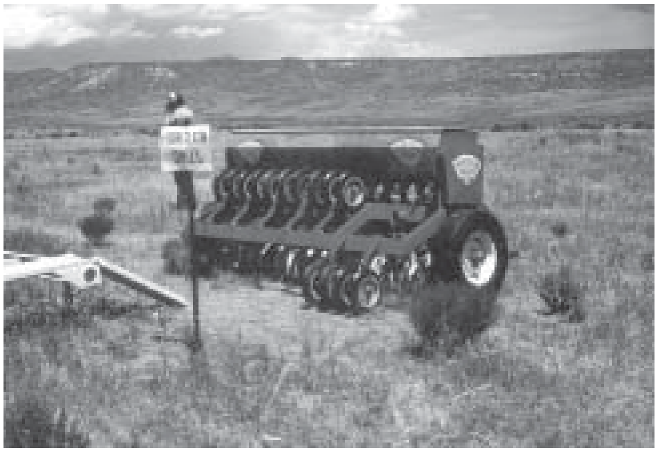


Figure 16—Horizon drill with four press wheels down and 10 press wheels in the up position. Press wheels can aid in seedling establishment of some species. Species are separated in seed boxes according to seeding requirements.

Figure 17—Tye drill with four seed boxes and drops. Individual species or groups of species can be seeded at differing depths and rates and with or without press wheels.

The inability to regulate seeding depth, especially in loose soils on undulating topography, and with surface and shallow seeded species, is a major problem with the Rangeland drill. Seeding depth, especially shallow seeding, cannot be properly regulated. Seeds are deposited and covered in the bottom of furrows created by the disk-furrow opener. In loose soils the furrow generally fills in with soil, covering the seed even deeper. Drills being pulled uphill will generally seed deeper than when pulled on the level, and shallower when going down hill. Many wildland species require surface seeding or very minimal seed coverage (fig. 20). Most species are, however, ideally seeded ¼ to ⅜ inches (0.6 to 0.9 cm) deep. Most drills do not have the capacity to seed at these shallow depths. The Truax drill, however, does provide precise seeding depth and rate of seeding capacity. Drop tubes on many drills can be pulled from between and placed behind the furrow openers, so the seed will be deposited on disturbed soil.

Seeding rate adjustments on most drills are rated for small grains. Care must be taken to ensure that proper seeding rates occurs. Many wildland species have small seed, and when seeded singly may require

Figure 18—Amazon no-till drill.

Figure 19—Mixture of grasses, forbs, and fourwing saltbush seeded with the Rangeland drill. Fourwing saltbush was seeded through separate drops, independent of grasses and forbs.

being mixed with a carrier such as rice hulls. Individual species or mixtures can be seeded down one drop or a group of seed drops by partitioning seed boxes according to needs.

Stumps, downed trees, tree limbs, large shrubs, trash, large rocks, gullies, and moderately steep slopes can limit the use of many drills. Multiple hitches that accommodate two or three Rangeland drills have been developed (fig. 20) (Larson 1980).

Most no till and reclamation drills have heavy duty frames, individually suspended planters that adjust independently, multiple seed boxes, precise seeding range and depth adjustments, the ability to handle fluffy, plumed, and smooth seed of many sizes, and press wheels. They do not have sufficient clearance to operate on rocky sites, or sites with downed trees and other debris, or in gullies.

Prepared sites and semiwet and irrigated pastures can be effectively seeded and interseeded with many no-till drills (Bauder and others 1985).

Conventional grain drills are not well adapted to most range and wildland conditions. They are generally too lightly built; planters are not individually suspended, and many rangeland species will not flow evenly through their metering devices. In addition, the seeding depth regulators may be inadequate, and many species will be seeded too deep.

Broadcast Seeders

These devices broadcast seed by means of a blower or rotary spreader. There are two basic types of broadcasters, those that employ a blower or air source, and those that employ some type of rotary wheel to distribute seed.

Principal Areas of Use—Broadcast seeding can be an economical means of seeding large, as well as small areas and inaccessible sites where other equipment cannot function. Consequently many extensive and vital wildlands can only be seeded by broadcast seeding.

Figure 20—Rangeland drills followed by sagebrush seeders and chain drags. Species requiring seed coverage are put through Rangeland drills. Species that require surface or near-surface seeding are run through the sagebrush seeders.

Broadcasting is an effective means of uniformly distributing seed; however, scarification is required in most cases to incorporate seed into the soil. In only a few instances can seed be broadcast planted and expected to establish well on an unprepared seedbed. Broadcasting onto a tilled or roughened surface can be successful if natural soil sloughing occurs enough to bury the seed. For some species a firm seedbed is normally required to reduce surface evaporation and provide good seed-soil contact. Broadcast seeding alone normally does not achieve these results.

Aerial or ground broadcast seeding normally requires more seed than drilling. Approximately 33 to 50 percent more seed is recommended for broadcast planting. With proper seed coverage, most grasses, broadleaf herbs, and some shrubs can be successfully broadcast seeded. Where costly and scarce seeds are being used, they should be planted only where they have the best chance to establish.

Small seeded species are often planted too deep with drill seeding. Soil compaction and crusting that can occur with drill seeding is generally not a problem with broadcast planting. In addition, broadcast seeding, when compared to drill seeding, does not dislodge or impair existing plants and allows for quick recovery of native and onsite species. Rodent seed predation and insect damage is generally less with broadcast seedings. Drill seeding occurs in rows, which rodents tend to follow.

Seeds have been pelletized or coated in an attempt to increase planting success and to eliminate the need of soil scarification. To date, these treatments have not proven effective.

Ground Broadcasting

This is a method for uniformly broadcasting seed from handheld or vehicular mounted seeders. Seed is generally distributed by means of a rotary wheel. An airstream has been employed in a few ground seeders (McKenzie and others 1981).

Ground broadcasters can be operated manually by a tractor's track or by hydraulic, gasoline, or electric motors (fig. 21). They can be mounted on trucks, trailers, or tractors and other prime movers, and attached to various types of seedbed preparation equipment. A new concept in hand broadcast seeders has been developed by Truax Equipment Company called the Truax Seed Slinger. This unit is similar to older, conventional handheld broadcast seeders, however, it consists of a rigid plastic seed box that is partitioned into two compartments. Having two independent metering systems, seeds of different size, density, and condition can be uniformly distributed across rough terrain. It is designed to simultaneously distribute

Figure 21—Two electric broadcast seeders mounted on a crawler tractor that is pulling a pipe harrow.

fluffy seed kept in one seed box compartment with hard or smooth seed stored in the second compartment. Hard or smooth seeds drop directly out of the bottom of the seed box through an adjustable gate onto a rotating fan plate that throws or distributes the seed. A wire agitator is mounted in the bottom of this seed box to prevent seed bridging and maintain uniform flow or movement of the seed. The agitator, consisting of a wire rod, is positioned in the bottom of the seed box and attached to a shaft driven by the hand crank. As the hand crank is turned by the operator, the wire rod is moved up and down driven by a cam lever. Seed in the fluffy seed box is metered by two picker wheels, and deposited onto the rotating fan plate. The pickers remove a selected amount of seed and seeding rates can be regulated by speed of hand cranking. Seed bridging is controlled or prevented by an auger agitator. Seed can be distributed from 4 to 25 ft (1.2 to 7.7 m) depending upon seed density and wind conditions. The seeder can be mounted on all terrain vehicles, wheel tractors, or small cats and operated using a 12-volt motor.

Principal Area of Use—Broadcast seeders are used to seed areas that are inappropriate for drill seeding, such as rocky or rough terrain, rocky soils, areas with large amount of debris, and small, irregularly shaped areas. Broadcast seeders can be used alone or in conjunction with seedbed preparation equipment. Broadcast seeding coupled with anchor chaining, disk-chaining, pipe harrowing, land imprinting, drilling, scalping, harrows, or other seed coverage treatments is often preferred over drill seeding. Costs are generally much lower than for drilling. Variable planting depths are achieved by broadcasting which often favors mixed species plantings.

Sagebrush, rabbitbrush, forage kochia, and a number of other species do best with surface seeding on a disturbed surface. Broadcast seeders have been designed to facilitate surface seeding. With proper equipment, multiple species mixtures with differing seeding requirements can be seeded simultaneously.

Aerial Broadcasting

Aerial broadcasting using fixed-wing aircraft and helicopters is used to distribute seed over large areas and on rough terrain where slope steepness and irregularities, rock, or debris make drilling impractical (fig. 22).

Aerial broadcasting is usually the most economical method for seeding large acreages. This technique is also applicable for narrow corridors, roadways, disturbed right-of-ways, fence lines, and riparian drainage ways. Aerial seeding is an effective method for uniformly distributing a variety of seeds.

Seed hoppers within the fuselage of the fixed-wing aircraft (fig. 23) hold the seed. An electric rotary or Venturi spreader distributes the seed. Agitators within the seed hopper help to assure continuous and uniform seed flow. Small obstacles can obstruct seed passage. Venturi-type spreaders use the propeller slipstream to carry the seeds out of the base of the

Figure 22—Broadcast seeding a chained pinyon-juniper area with a fixed-wing aircraft.

Figure 23—Loading seed into a fixed-wing aircraft seed hopper.

seeding device and spread them beneath the aircraft (Larson 1980).

Seeding rates are computed based on hopper gate opening, air speed, and elevation of the fixed-wing aircraft. Desired seeding rates can be achieved with frequent monitoring. Ground spotters, “flaggers,” or automatic flag dispersed equipment must be employed to assure uniform seed distribution. Fixed-winged aircraft generally operate at an elevation of under 50 ft (18.3 m), and at an air speed of 80 to 100 miles (128 to 160 km) per hour (USDA Agricultural Research Service 1976). Under favorable wind conditions and level terrain, flight elevation may be between 15 to 30 ft (4.5 to 9 m). Most fixed-wing aircraft have the capacity to carry approximately 1,000 lb (455 kg) of seed, but larger aircraft may carry three times this amount. Seed is usually distributed on a strip varying in width from 100 to 250 ft (31 to 77 m).

Helicopters equipped for aerial seeding have a suspended seedbin or an attached seed hopper that holds 250 to 2,000 lb (113 to 907 kg) of mixed seed. Seeding width can vary between 25 to 250 ft (7.6 to 76 m). Helicopters normally operate at 15 to 25 ft (4.5 to 7.6 m) above the ground at an airspeed between 35 to 50 miles (56 to 80 km) per hour. Lower speeds may be used to reduce seed drift and for precise seed placement. Seedbins are equipped with agitators and blower spreaders to regulate seed flow and spread.

Principal Areas of Use—Fixed-wing aircraft broadcasting is an effective technique for distributing seed over large range and wildland sites (National Research Council 1981). Planting success is usually dependent upon time of seeding, seedbed conditions, and thoroughness of seed coverage. Aerial seeding is particularly useful for seeding mountain brush, pinyon-juniper, and big sagebrush sites where chaining is used to cover the seed. Burned areas can be successfully revegetated with aerial seeding followed by proper seed coverage, in some cases seed coverage may not be necessary. Aerial seeding has also been a successful method of seeding desirable species into aspen, Gambel oak, and other deciduous tree and shrub stands just prior to leaf fall. No further treatment is required as seeds are covered by the falling leaves.

Large acreages can be aerial seeded in an extremely short time period. Major revegetation projects can often be more successfully seeded using aerial techniques and chaining than drill seeding, as plantings can be completed during short planting periods or windows when seedbed and weather conditions are most favorable. Aerial seeding can be conducted when wet soil conditions hamper drilling. Drill seeding occurs at a much slower rate than does aerial seeding. Many times it is impossible to physically get over large acreages during critical seeding periods with drills. This can result in considerable acreages being seeded out of season or totally omitted. With aerial broadcasting, seeding can be delayed until late fall or early winter, and then seeded in a relatively few days using aircraft, chain, rail, or cable scarifiers.

Irregular seeding patterns can occur with aerial seeding where poor flagging or spotting occurs, and from wind drift. Irregularities in seed placement and density may not be too serious if there is a fair native population, as this allows for natural recovery of native species.

Aerial seeding is often the only appropriate technique available for seeding deteriorated wildland sites, particularly when the terrain is inaccessible to motor driven vehicles. However, level and more gentle sites are often selected for drill seeding. Consequently, areas requiring special or tailored treatment are often ignored in favor of more conventional operating systems on less important sites. Aerial seeding should be recognized as an appropriate method of seeding, and used in areas where drills have proven less effective and are more costly to use.

Fixed-wing aerial seeding requires access to a landing strip and loading site. Normally, aerial seeding is much less costly than drilling unless the aircraft must be transported a considerable distance, or a landing site is not available close to the project. Aerial seeding may be used as a means of “overseeding” or as one of a number of methods used to seed a single site. Species like alfalfa, clover, big sagebrush, rabbitbrush, small burnet, or forage kochia can be successfully established by broadcasting on a rough seedbed. These species can be overseeded following drill seeding. Seeds that germinate quickly and early in the spring are often lost to frost if fall planted. Species that require winter stratification can be fall seeded with conventional equipment; species best adapted to spring planting can be aerially overseeded in spring at an appropriate date. Aerial seeding is also an effective method of seeding different seed mixtures on specific sites.

Aerial seeding requires a number of field support personnel, flaggers, and loaders. Seed must be prepared and available for rapid loading (fig. 24) and seeding. Seeding is often limited to early morning hours when flying conditions are most satisfactory and safe. Winds over 10 miles (16 km) per hour can create unsafe seeding conditions.

Normal monitoring of wind conditions and planting procedures will help to increase the probability of seeding success. Aircraft should not be allowed to operate under less than favorable conditions. Aerial seeding can be done in such a short period that minor delays are insignificant.

Helicopters are usually selected over fixed-wing aircraft if irregular-shaped sites and variable terrain are seeded and when air strips are unavailable. Effective seeding of right-of-ways, fence lines, steep slopes,

Figure 24—Loading seed into a seed hopper suspended from a helicopter.

small areas, rocky terrain, and specific species placement can be accomplished with helicopters.

Helicopter seeding is recommended for planting high elevation sites, streambanks, and roadways where fixed-wing planes do not operate as safely or satisfactorily.

Downdraft and wind can cause seeds of different species to dissipate and fall separately, sometimes creating differences in stand composition and density. Variation in seeding and establishment is often advisable, allowing for natural succession and spread of desirable species. Drift can be reduced by slowing air speeds and the distance from the seedbin to the ground. Markers or flaggers can aid in more complete and even seed distribution.

Helicopters equipped with seedbins (fig. 25) or seed hoppers (fig. 26) that broadcast seed over large and small areas are used in aerial broadcasting projects that require more maneuverability than fixed-wing aircraft. They can also function more economically when seeding small, irregular tracts or when precise placement of seed is required. Helicopters require small landing pads, and thus can be used to seed sites where a conventional landing strip is not available to service a fixed-wing aircraft.

Figure 25—Seed bins attached to a helicopter. Seed is dispersed by airflow.

Figure 26—Seeding small and irregular areas on rough terrain from a seed hopper suspended from a helicopter.

Seed Dribblers

Seed dribblers deposit selected seed onto crawler tractor tracks (fig. 27). The seed is carried forward, dropped onto the soil, and pressed into a firmed seedbed. Tractor-pulled seed dribblers deposit seed directly into prepared seedbeds.

The Hansen seed dribbler (fig. 27A) and thimble seeders (fig. 27B) (Larson 1980; Stevens 1978, 1979) are tractor-driven seeders, mounted on fenders of crawler tractors with drive wheels positioned on top of and driven by tractor tracks. Seed is gravity fed on both dribblers. A fluted shaft, similar to metering devices on most grain drills, moves the seed out of the Hansen dribbler. Seeding rate is determined by seed size and position of an adjustable gate over the fluted shaft. In the thimble seed dribbler, a spoked wheel with small cups attached to spokes rotates through the seed, filling the cups with seed. Seed is dropped through an opening and deposited on top of the tractor tracks. Seeding rate is determined by size of cups and number of spokes with cups attached.

Seed is deposited on tractor tracks by both dribblers. Seed is then carried forward on the track and deposited on the ground where it is pressed into the soil. The weight of the tractor buries the seed into a firm seedbed with the track cleates creating small water

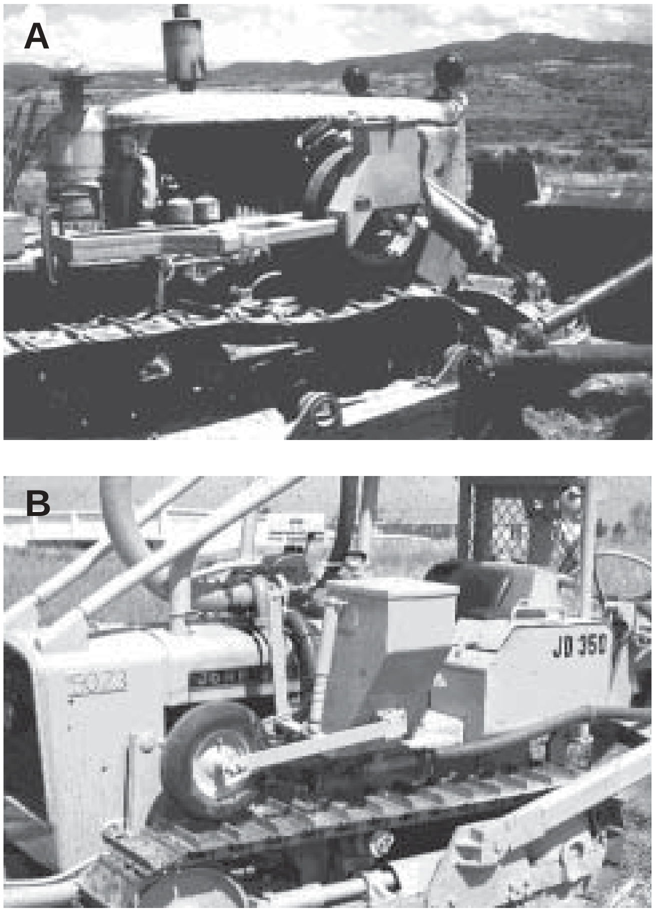


Figure 27—(A) Seed dribbler and (B) thimble seeder mounted on the fender of crawler tractors. The Drive wheel meters seed onto the tractor track which moves the seeds forward and deposits them on the ground. Tractor weight buries the seed in a firm seedbed.

catchment depressions. Thimble seeders have been modified to operate in conjunction with scalpers and to dispense seed within the scalp.

Primary Areas of Use—Dribblers are ideal for planting species that require firm seedbeds or whose seed is in short supply or extremely costly. The Hansen dribbler, being gravity fed through a fluted shaft, does not handle fluffy, plumbed, or trashy seed well. The Thimble dribbler will handle all types of seed. Generally, seedling establishment of shrubs and forbs is greater when seeded through a dribbler than when broadcast or drilled. Species that require minimal coverage, like rabbitbrushes, sagebrushes, asters, and forage kochia establish much better when dribbled than when drilled. Dribblers are generally used in conjunction with other operations like chaining, cabling, and pushing trees and shrubs.

Depending on seed size, 0.25 to 1 lb of seed per acre (0.28 to 1.12 kg/ha) can be seeded through one dribble during one-way chaining. Dribblers can be placed on both tractor tracks and operated during both passes of a two-way chaining. If dribblers are only used during one chaining, the second chaining is preferred.

Brillion Seeder

The Brillion seeder (fig. 28) consists of a two-compartment seed box mounted above and between two standard cultipackers. Each cultipacker consists of closely spaced, V-shaped, grooved steel wheels. The grooves of the two cultipackers are offset. The first cultipacker smooths and firms the seedbed and makes small furrows. The fluted seed metering device broadcasts the seed between the cultipackers onto the created furrows. The second cultipacker, which is offset, covers the seed in the original furrows and creates new ones. The two compartments in the seed box allow for seeding two types or mixes of seed.

Primary Areas of Use—The Brillion seeder is used to seed smooth areas. It creates an excellent firm seedbed and can seed at quite precise rates.

Surface Seeder

Surface seeders have been developed to accommodate species that require surface, or near surface seeding. The surface seeders consist of a seed box that drops the seed onto a line of tires that gently push the seed into the soil surface (fig. 20).

Primary Areas of Use—Some species that require surface seeding on disturbed soil include the sagebrushes, rabbitbrushes, asters, and forage kochia. Surface seeders provide the means for depositing seed onto the surface of disturbed soil. Use is restricted to areas where a tractor can operate.

Figure 28—Brillion seeder.

Interseeders

Interseeders are designed to seed desirable species into existing vegetation with minimal disturbance. Interseeders consist of a one- or two-way scalper or furrow opener and a heavy-duty seeder (Monsen 1980a, 1979; Stevens 1983a,b, 1979; Stevens and others 1981) (fig. 29A,B). Seeders are driven by rotation of a press wheel. Seed is metered out by a fluted shaft or a spoked wheel with cups attached on the spoke ends. Scalp or furrow depth can be regulated with a depth regulator wheel or hydraulics of the tractor. Seed is covered by the press wheel or drag chain.

The Truax single row seeder is designed to plant large irregular-shaped seeds, including acorns and nuts, in a single row. Seeds of different size can also be planted by exchanging the finger-pickers, which remove seeds from the seed box. The seed box is divided into three separate compartments. Seed of different species can be placed in each compartment and metered independently to control the distance between seeds placed within the furrow. Consequently, seed placement within and between species can be carefully regulated.

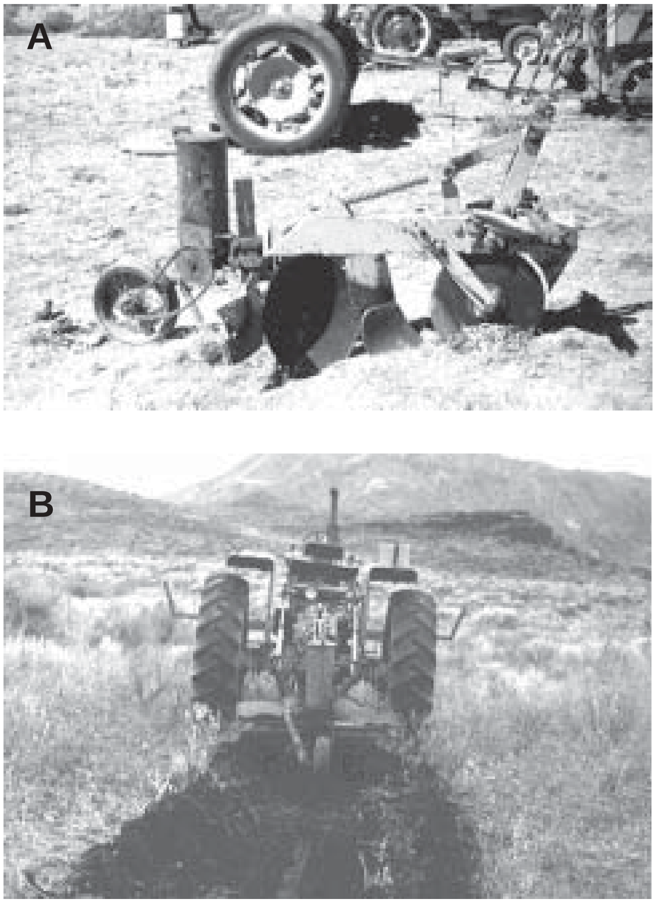


Figure 29—(A) The scalper-interseeder consists of a fire plow and Hansen shrub seeder. (B) Seeding bitterbrush and alfalfa into a sagebrush community with a scalper-interseeder.

Figure 30—The scalper removes competitive vegetation and creates water and snow catchment basins.

A single disk is positioned in front of the machine, and when drawn into the soil, cuts the dense sod or surface litter. A single shank is mounted directly behind the disk opener and is drawn into the soil to create a seedbed or furrow. Gauge wheels are attached to the machine to control planting depths. After seeds are deposited, one 16-inch press wheel is used to compact the seedbed. The seeding mechanism is activated by a drive chain through sprockets mounted on the press wheels and the base of the seed box.

Primary Areas of Use—The use of interseeders is restricted to soils that are fairly free of rock, roots, and stumps, and to terrain on which the tractor can safely operate. Grasses, forbs, and shrubs can be seeded through interseeders with or without previous seedbed preparation. Scalpers or furrow openers remove existing competing vegetation and create water and snow catchment basins (fig. 30). Interseeders are used as a single unit, or two or more units can be mounted on a toolbar (fig. 31).

Fluted shaft seeders, unless modified with a drum agitator, will handle only smooth seed. Thimble type seeders will plant all types of seed, including fluffy, plumed, or otherwise trashy seed.

Interseeders are used to establish desirable species in cheatgrass and other annual communities, monotypic grass stands (fig. 32A,B), perennial communities, burned areas, and disturbed sites. On these sites, establishment of seeded species can be superior to broadcast and drill seeding.

The Truax single-row seeder can be used to interseed shrubs or herbs into established stands of sod or weeds and can be operated on any terrain on which a cat or wheel tractor can safely travel.

Figure 31—Two shrub interseeders connected to single tool bar.

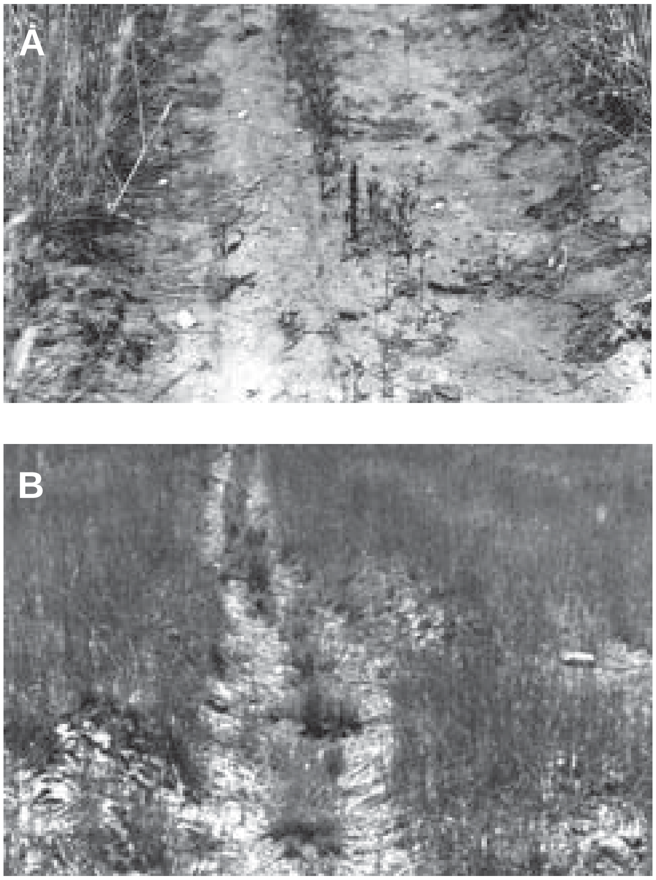


Figure 32—Grass stand scalped and seeded with desirable forbs and shrubs (A) 1 year and (B) 3 years following seeding.

Hydroseeder

Hydroseeders (fig. 33) are designed to apply seed, fertilizer, soil amendments, and fiber mulch to the soil surface in a hydraulic spray. Hydroseeders consist of a truck or trailer, tank, pump, discharge nozzle, and engine. The tank is equipped with various types of agitators to assure uniform mixing. The pump sprays the mixture up to 200 ft (61 m). Interchangeable nozzles provide for various spray patterns and quantity of delivery. Nozzles are designed to rotate horizontally and vertically.

Principal Areas of Use—Hydroseeders are generally used to seed steep slopes or very rocky areas. There are a number of disadvantages to hydroseeding. They include: (1) seed is not placed in the soil, (2) seed and seedlings can dry out, (3) some seedlings cannot grow through the mulch, (4) seed can be damaged by agitators and pumps, (5) precocious germination can occur as a result of moisture in the mulch, (6) seeding may be done during unfavorable seeding periods, (7) expense, and (8) large water requirements.

Special Use Equipment

Transplanters

Transplanters are tractor-drawn implements that scalp the soil surface and open a furrow. Bareroot stock, wildings, cuttings, or container-grown plants are placed in the furrow and soil are packed around the plant roots (fig. 34).

Transplanters consist of a heavy frame, a furrow opener, a set of packing wheels, an operator seat, and

Figure 33—Hydroseeding roadcuts and fills.

Figure 34—Transplanting big sagebrush wildings into a cheatgrass community during early spring when soil moisture is high.

a place to store seedlings. A single-disk coulter, semiautomatic seedling placement device and scalper may be installed on some machines. Transplanters are towed or mounted on crawler or rubber tired tractors and four-wheel drive vehicles. The furrow opener cuts open a furrow in which the seedling root system is placed. The packing wheels are angled inward to close the furrow and compact soil around the roots of the transplant.

Principal Areas of Use—Shrubs make up the majority of plants that are transplanted on range and wildlands. However, grass, forbs, and trees are also transplanted. While transplanting is fairly expensive compared to direct seeding, it has its place. Transplanting can be economically utilized on critical big game, upland gamebird, and livestock ranges; disturbed sites; sites with high erosion potential. It is also widely used in high esthetic value recreational areas, windbreaks, shelterbelts, and riparian sites.

Bareroot stock, wildings, container-grown stock, and cuttings can all be transplanted successfully using a transplanter (McKenzie and others 1981; Stevens 1979, 1980a,b; Stevens and others 1981b). Generally, bareroot stock and wildings are the most economical, producing the most established plants for dollars expended.

For best results, transplanting should occur in the early spring when soil moisture content is high and chances for spring storms are greatest. Fall transplantings are less successful, primarily due to frost heaving and drying. Care must be taken to ensure that packing wheels firmly pack soil around the root system.

Transplanters can consistently plant 1,000 to 1,500 plants per hour. Transplanters are restricted to soil at least 18 inches (45.5 cm) deep that is free of large rocks, roots, and stumps. Transplanters must be built heavy enough to meet adverse site conditions.

Transplanters equipped with automatic pickup and placement fingers have not proven practical with transplants that have multiple or fibrous root systems (McKenzie and others 1981).

Survival rate varies with species. Species with fibrous root systems survive much better than those with a single or few taproots.

Roller Chopper

Roller choppers are used to (1) push over, uproot, and chop up trees and shrubs with the main trunk at ground level less than 6 inches (15.3 cm) diameter, (2) create seedbeds, (3) cover seed, (4) create water catchment basins, and (5) to stimulate shrubs by pruning to 12 inches (30 cm) above ground level.

Roller choppers consist of a steel, 5 ft by 12 ft (1.5 m x 3.7 m) diameter drum with 12 grader blades evenly spaced and welded vertically around the outside of the drum (fig. 35). Intake and drain plugs are installed to allow the drum to be filled with 800 to 900 gallons (3,000 to 3,400 L) of water. Steel frames, tongue, and hitch are attached to both ends of the drum.

Primary Areas of Use—As the roller chopper is pulled forward, the weight, combined with the cutter blades, tips over, uproots, chops up, and kills trees and shrubs with main stem diameters of less than 6 inches (15 cm). When pinyon and juniper have invaded grasslands, shrublands or chained areas, the roller chopper has been used successfully to remove them.

Broadcast seeding can occur ahead of, or simultaneously with roller chopping. Seeds are pushed into the ground and covered with soil and litter. Water and snow catchments are created by the action of the cutter blades. Creation of a good seedbed, seed coverage, litter for seedling protection, and moisture retention and increased water infiltration all combine

Figure 35—Roller chopper being used to kill and cut up pinyon and juniper trees, create a seedbed, and cover seed.

for good germination and seedling establishment. Serviceberry, curlleaf and true mountain mahogany, bitterbrush, and cliffrose have all been stimulated by pruning with the roller chopper.

Dozers and Blades

Dozers and blades are widely used in range improvement projects. They are used to remove trees and shrubs, pile brush and slash, scarify areas, construct roads, and dig trenches, firebreaks, and other excavations.

Dozers are used in a standard configuration; a straight concave blade solidly mounted to a crawler or rubber-tired tractor (Larson 1980). They can also be modified as follows:

1. As a three-way dozer with multi-purpose dozer blade that is adjustable for height, tilt, angle, and pitch hydraulically (fig. 36) (Larson 1980).
2. As a brush, or forest rake with a special blade that consists of vertical teeth generally with replaceable tips, or a vertical toothed implement that is attached to a standard or three-way blade (Larson 1980; Roby and Green 1976).
3. As a hula dozer with a standard dozer blade with hydraulic side tilt and pitch that is often equipped with four removable digger teeth spaced along the blade (a hinged push-bar attachment is available for mounting above and in front of the blade).
4. With a shearing or clearing blade, a straight or V-shaped solid blade with straight or sharpened cutting edges along the bottom (Larson 1980).

Primary Area of Use—Blades are used to uproot, cut off, move, pile, and windrow trees and shrubs; build or clean roads, fences, and fire lines; construct trenches, basins, and terraces; move and pile rocks and debris; prepare seedbeds and planting sites; and grade and carry out general excavation.

Figure 36—Three-way dozer reshaping a streambank.

Trenchers, Scalpers, and Gougers

Trenchers, fireplows, gougers, and furrowers are used to construct trenches, scalps, depressions, and furrows for the purpose of intercepting runoff, collecting snow and precipitation, preventing erosion, removing competing vegetation and seed, creating a seedbed, and promoting plant establishment and growth.

In the case of double-disk contour and Rocky Mountain trenchers, one or two large disks are mounted on a crossbar or shank. Disks rotate hydraulically to allow for operation in two directions. Disks and crossbars are hydraulically controlled and will adjust to the contour of the site and depth and width of the designed trench (Larson 1980, 1982). Broadcast and dribbler seeders can be attached to these trenchers, allowing for seeding to take place concurrently (Stevens 1978).

Another piece of equipment in this category is the fireplow, a V-shaped lister share with large disks located on each side of the share (plow) (fig. 29A) (Larson 1980). Where needed, a coulter can be attached in front of the lister share. A moldboard wing may be attached behind either disk allowing for the trench berm to be moved away from the trench edge. Browse seeders or thimble seeders can be connected to the fireplow, allowing for seeding to occur simultaneously (Monsen 1984, 1979; Stevens 1979).

Gougers consist of three to five half-circle blades attached to solid arms that are spring loaded. The blades are raised and lowered automatically, scooping out depressions in a cyclic manner. Seed is broadcast into the depression from a seed box mounted above the blades and arms (Knudson 1977).

Principal Areas of Use—Contour and Rocky Mountain trenchers, fireplows, and gougers are used to construct trenches and scalp areas in a variety of shapes, widths, and depths, depending on the positioning of the disk, plow, or gouger. These implements are used to reduce competition, remove unwanted seed, and create water and snow catchment basins. Scalped areas can be seeded or have grasses, shrubs, forbs, and trees transplanted into them. Monotypic stands of annual and perennials can be improved by removing unwanted seed and vegetation, and at the same time seed desirable species. Shrub density can be reduced and desirable species can be seeded or transplanted into the depressions or scalps. The amount of vegetation and seed removed depends on the width and size of scalps and depressions. Width and depth of scalps or depressions can affect seedling establishment and growth (Stevens 1985a,b). This equipment is well adapted to smooth, nonrocky soils, but it can also be used successfully on uneven, semirocky range sites (Moden and others 1978b; Stevens 1978).

Fire Ignitors

Fire ignitors are used for: (a) vegetation control, (b) fire management, and (c) control of fire. Aerial, handheld, and vehicle-mounted types are available.

Aerial ignitors are connected to or suspended from helicopters. The most widely used is the flying drip torch (helitorch) (fig. 37). The helitorch consists of an oil drum, solenoid valve, electrical fuel pump (gel models), glowplug, and controls. The oil drum holds the gel or gasoline-diesel mix. Fuel flow is by gravity or pump and is controlled by a solenoid. The glowplug ignites the fuel as it leaves the torch. The helicopter pilot controls fuel flow and ignition, and can jettison the complete torch if necessary.

Another aerial ignition system is the ping-pong ball injector (Larson 1980, 1982; Ramberg 1977). Ping-pong balls are loaded with potassium permanganate and when fed through a ball dispenser they are automatically injected with ethylene glycol and dropped. The chemical reaction produced by the two chemicals coming together produces a flame. Ping-pong ball dispensers are mounted on helicopters, and are electrically operated. They can be jettisoned by the pilot, and will dispense up to four ping-pong balls a second. Distance between balls on the ground varies with air speed, altitude, and rate of ejection.

Backpack, handheld, vehicle and trailer-mounted teratorch, and drag-type drip torches are available. These consist of a fuel tank, wand, stem or boom to direct the flame and a fuel ignitor. Fuel is generally a gel, but can be a diesel-gas mix.

Flame throwers, depending on size, are hand operated or mounted on a vehicle or trailer. Pressurized tanks, hose, and a nozzle are the major components of a flame thrower. Fuel can be diesel, kerosene, or liquid propane gas.

Fuse backfire torch or flares are commonly used. Plastic bags or milk carton type containers filled with a gel or diesel-gas sawdust mixtures are placed in areas to be burned and are ignited by a torch or flame thrower.

Principal Area of Use—Ignitors are dispersed aerially from ground rigs or by hand to ignite fires in fire management, slash clean up, and range improvement.

The helitorch and teratorch are used extensively to start and manage prescribed burns, start backfires and burnouts, and make fire lines. The helitorch can be used in otherwise inaccessible areas as well as in extensive accessible areas. Large areas can be ignited in relatively short periods of time with these ignitors, allowing for better fire control and decreased costs.

A number of hand operated and vehicle- or trailer-mounted drip torches, and flame throwers are available. The main drawback to these has been that small crews have difficulty firing large areas in the short time that favorable burning conditions are present. Large crews are generally uneconomical. Small, irregularly shaped burns, backfires, and burnouts are sometimes best managed with hand and vehicle operated equipment.

Herbicide Sprayers

Liquid herbicides are most commonly applied on rangelands by broadcast spraying. Application is by ground rigs, fixed-wing aircrafts, helicopters, and hand sprayers (Ekblad and others 1979; Larson 1980; Vallentine 1989).

There are two types of ground rigs, boom and boomless. Boom sprayers are mounted on tractors, trucks, all terrain vehicles (fig. 38), trailers (fig. 39), or self-propelled chassis. A boom sprayer consists of a

Figure 37—Helitorch used to start a prescribed burn in a mountain big sagebrush community.

Figure 38—Boom sprayer mounted on an all-terrain vehicle.

Figure 39—Rangeland boom sprayer. Booms must be mounted high enough to clear tall shrubs.

tank, pump, pressure gauge, and spring-loaded boom with nozzles spaced along each boom. A boomless sprayer has no booms, but has one nozzle or a cluster of nozzles at one location.

Fixed-wing monoplanes, or biplanes may be equipped with boom sprayers mounted along or near the lower wings. Special equipment required includes cutoff valves, diaphragm check nozzles, and pumps designed to avoid pressure buildup. Helicopters are equipped with boom sprayers up to 40 ft (12 m) long with hydraulic nozzles spaced along the entire length (fig. 40). Helicopter spray units require lightweight tanks, special pumps, and positive shut-off valves. Booms have been specifically designed for helicopter sprayers. Hand-operated sprayers are pump pressurized tanks equipped with a hose and a handle. A cutoff valve is located in the handle.

Primary Area of Use—Boom and boomless ground sprayers can spray only those areas that their transport power unit can traverse. Height of woody vegetation cannot extend above the height of the boom. These sprayers can provide even application of herbicide with little drift. Boom sprayers are superior to boomless on areas where precise application is desired. Boom sprayers have less drift and are less affected by wind. Boomless sprayers are generally less expensive, and less restricted in their areas of use as they are able to travel over rougher terrain and work in larger brush. Boom and boomless sprayers can be used to apply herbicide to selected areas, such as strip spraying followed with broadcast or drill seeding (fig. 41A,B).

Figure 40—Helicopter equipped with a boom sprayer.

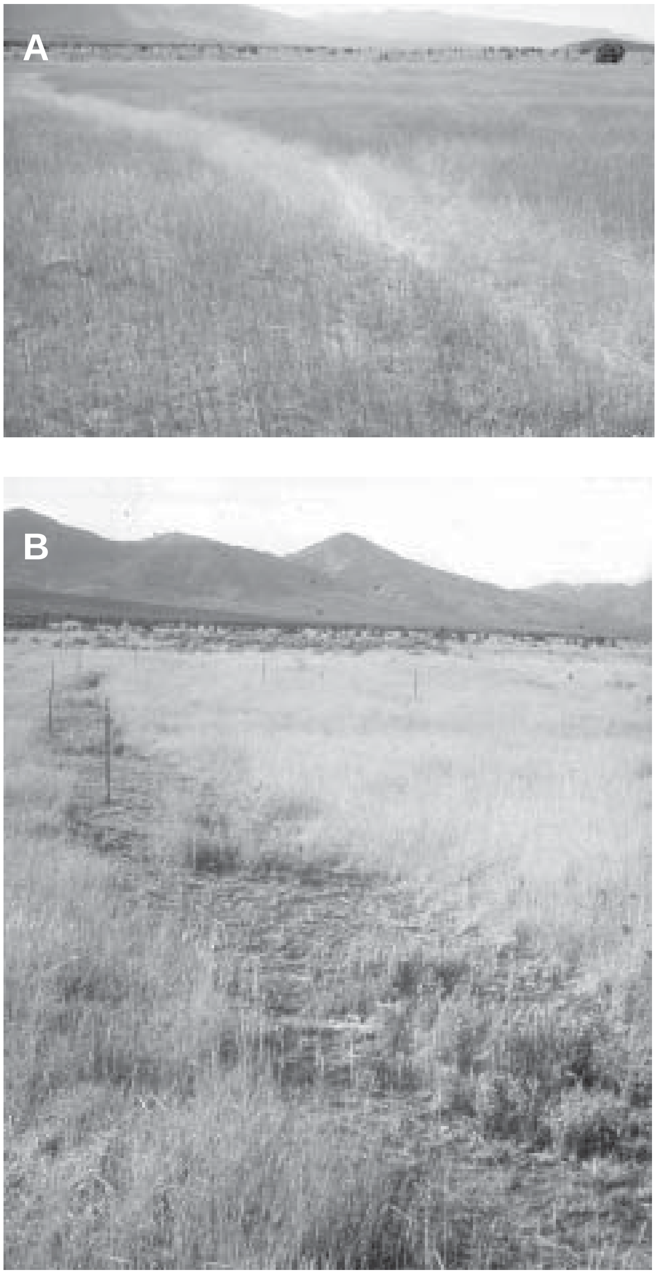


Figure 41—(A) Strip of intermediate wheatgrass sprayed with Roundup in June. (B) Shrubs and forbs established by broadcast seeding in October within the sprayed strip 3 years following seeding.

Figure 42—A helicopter with a boom sprayer spraying mountain big sagebrush on the Manti LaSal National Forest, UT.

Application of herbicide by ground rigs has several advantages over aerial application: small acreages can be sprayed, no landing strip is required (fixed-wing only), there is less drift, application is not restricted by fog or wind, equipment is generally less expensive, and applicators are safer.

Aerial application does have some advantages over ground rigs: application rate (acres per hour) is greater and large areas can be sprayed during short periods of time when conditions are ideal. For this reason, aircraft are commonly used to spray large acreages (fig. 42). Aerial application is also well adapted to spraying wet, rough, steep, and rocky terrain. Cost of application is less, vegetation and soil are not disturbed, and dense, tall brush stands can be treated more effectively.

Steep-slope Scarifier and Seeder

The steep-slope seeder was designed to seed steep slopes and inaccessible sites. It is primarily used to plant roadways, mine sites, and similar disturbances. However, it can be modified to seed range and wildland sites.

The machine consists of a tubular constructed frame with: (1) front- and rear-mounted reversible spring-loaded scarifier tines, (2) soil drags, (3) four spring-loaded press wheels, and (4) two electrically powered rotary seeders or spreaders. The capacity of the seed hoppers is 2 ft^2 (0.57 m^2) (Larson 1980). The machine can be mounted on a telescoping-boom crane or gradall. The seeder is bolted to the end of the crane by a knuckle joint, and can be turned in any direction or angle. The machine can be operated to run horizontally across a slope, or up or down a roadcut or fill surface. Seed and fertilizer are dispensed separately through the two spreaders. The equipment operator is able to start or stop seeding and adjust the seeding rate through electrical lines connected from the seeders to a control box mounted within the cab. The machine can be easily converted to a three-point attachment and towed by a wheel tractor to seed the less steep sites.

Principal Areas of Use—The seeder was initially developed to seed steep roadcuts and fill surfaces where conventional equipment is not able to operate. Steep, inaccessible sites are normally broadcast seeded without any seed coverage, and poor plant establishment usually occurs. The steep-slope scarifier seeder is not only able to operate on uneven terrain, but seeds are planted in the soil.

The front scarifiers or tines loosen the soil. Seed and fertilizer are broadcast directly onto the loosened seedbed. The rear-mounted scarifiers, drags, and press wheels cover the seed and compact the seedbed. The seeder operates on extremely rough surfaces with an abundance of rock or debris. Larson (1980) reports the machine has a production capability of 2 acres (0.8 ha) per hour. Seeding rates can be adjusted to vary between 5 to 60 lb (2.3 to 27.2 kg) per acre (Larson 1980).

The steep-slope seeder is not capable of reducing existing competition, but can be used to seed areas without damage to existing plants. When mounted on a gradall or crane, the machine has limited reach, and can only be operated within the reach of the crane.

John F. Vallentine

Chapter 10

Herbicides for Plant Control

Herbicides can be an effective, necessary, and environmentally sound tool for the control of weeds and brush on rangelands (Young and others 1981b). As a result, chemical control is a widely used means of removing unwanted or noxious plants from range and other pasture lands. Selective plant control by mechanical, biological, fire, or manual means should also be considered but is not always a satisfactory alternative to chemical control.

New herbicides, new formulations, new application techniques, and new uses for herbicides have been developed for rangelands in recent years. Any person who is involved in the development of rangelands must be well versed in the properties and proper use of herbicides. Martinelli and others (1982) recommend that all range managers take advantage of the program for training and certification of pesticide applicators. They conclude that these schools, now being offered in most States with Environmental Protection Agency approval and financing, can be extremely valuable as a refresher program even if one does not plan to apply restricted herbicides. Most States require certification to purchase, handle, and apply many herbicides.

Handbooks and manuals suggested for planning and carrying out plant control programs on Intermountain rangelands, including the use of herbicides, include Bohmont (1983), Klingman and others (1982), Rutherford and Snyder (1983), Weed Science Society of America (1989), and State Agricultural Extension Service and Experiment Station publications.

Potential Results of Herbicide Use

Plant control, including the use of herbicides, requires a carefully planned program. The first step in a plant control program is evaluating: (1) the desirability of resident and potential plant species in the habitat, and (2) at what population levels the various plant species are desired. Desirability must be based on the objectives of land ownership, the multiplicity of range products desired, and the animal species (domestic or wild) that will be favored. Along with deciding which plant species are to be increased or decreased, and by how much, or which will be kept at present levels, consideration must be given to avoiding or reducing damage to desirable, nontarget plant species.

The major objective of herbicide application to rangelands is often to improve animal habitat. Animal habitats must provide food, water, and whatever cover is needed; but each animal species has its own unique habitat preferences and requirements. In general, ideal big game habitat has been equated with: (1) a greater mixture of forage species than is needed for livestock, (2) a mosaic of vegetation types, and (3) greater availability of cover than needed for livestock (Vallentine 1989). Mosaic vegetation can be maintained or created by treating high potential sites and leaving untreated draws, ravines, rough ridges, and shallow, rocky sites. Selective checkerboard treatment of specific sites is generally more effective than aiming for low plant control levels over the entire area.

Morrison and Meslow (1983) concluded that the indirect effects of herbicides on wildlife were far greater than the direct effects. Residues of herbicides in the environment were found to be of low concentration and short lived; herbicide levels in wildlife tissues were low and did not accumulate; and toxic effects on wildlife were deemed incapable of happening if recommended application practices were followed. Indirect effects on habitat modification, however, were considered potentially negative or positive. Even preferred browse species for big game could be increased through herbicide use, but careful planning is required.

Proven uses of herbicides on rangelands include:

1. Selective control of undesirable plants as a sole treatment to favor more desirable forage species, for example, control green rubber rabbitbrush (fig. 1) on foothill sites (Evans and Young 1975a).

Figure 1—Green rubber rabbitbrush sprayed with 2,4-D and Tordon. Crested wheatgrass not affected by herbicide. Herbaceous production doubled after reduction of rabbitbrush competition.

2. Combination treatment with mechanical, fire, or biological methods, for example, burning or mechanical treatment of salt cedar, Gambel oak, black greasewood, with follow-up herbicidal treatment of sprouts.

3. Release of particularly desirable plant species over which undesirable woody or even herbaceous plants have gained dominance, for example, juniper invasion on deep soil benches (Evans and others 1975) or tarweed in mountain meadows.

4. Thinning or removal of trash trees in commercial forests, or both, thereby enhancing herbaceous and browse understory as well as timber production, for example, removal of juniper from ponderosa pine sites.

5. Rejuvenation of tall shrubs and low trees, used as forage by big game, by top killing with light rates of 2,4-D and stimulating new growth from sprouts and seedlings, for example, old growth aspen stands, Gambel oak, mountain maple (Harniss and Bartos 1985).

6. Eradication of poisonous plants on sites suitable for such intensive treatment, for example, tall larkspur on high mountain range and rush skeletonweed (Cronin and Nielsen 1979).

7. Eradication of small infestations of serious plant pests or “environmental contaminants” not previously found locally, for example, spotted knapweed, musk thistle, and others.

8. Total plant kill to meet the needs of chemical seedbed preparation for range seeding or planting (fig. 2), for example, 2,4-D and paraquat on sagebrush-cheatgrass sites.

9. As a post-planting treatment, to enhance establishment by selectively controlling weed competition, for example, dense annual broadleaf weeds or perennial ragweed in new wheatgrass-alfalfa seeding.

Figure 2—Chemical seedbed preparation.

10. Maintenance control or retreatment when applied periodically following primary treatment, for example, periodic suppression of Gambel oak stands.

Herbicidal control has some distinct advantages over other plant control methods, this explains the current widespread use of herbicides, particularly on private lands. These general advantages include:

1. Can be used where mechanical methods are impossible, such as steep, rocky, muddy, or certain timbered sites.
2. Provides a selective means of killing sprouting plants that cannot be effectively killed by top removal only.
3. Provides a rapid control method from the standpoint of both plant response and acreage covered when applied by broadcasting or spraying.
4. Has low labor and fuel requirements.
5. Are generally cheaper, in some cases, than mechanical control methods, but may cost more than prescribed burning.
6. Can be selectively applied in most cases so that damage to desirable plant species can be minimized.
7. Maintains some vegetal and litter cover and does not expose soil to erosion.
8. Safe and reliable when proper safeguards are followed.
9. Can often use regular farm and ranch spray equipment.

Disadvantages of using chemicals to control undesirable range plants exist. Recognizing them may permit minimizing or circumventing them.

1. No chemical control has yet proven effective or practical for all plant species.
2. Herbicides provide a desirable, noncompetitive seedbed for artificial seeding only under certain situations.
3. Costs of control may outweigh expected benefits on lands of low potential.
4. The careless use of chemicals can be hazardous to nontarget plants, to cultivated crops or to other nontarget sites nearby, or may contaminate water supplies.
5. Lack of selectivity may result in killing associated forbs and shrubs.

Chemical Seedbed Preparation ____

Herbicides show promise for chemical site preparation. Seeding or planting can be done shortly after spraying or after a fallow period maintained by herbicides. Seedbed preparation by chemical means, when effectively used, has the following advantages when compared with mechanical methods:

1. Leaves a firm seedbed for better plant establishment.
2. Has good erosion control since the mulch and litter are left in place.
3. Can be used on land that is too steep, rocky, erosive, or wet for mechanical treatment.
4. Does not invert the soil profile, which would be undesirable on shallow, poorly drained, or poorly structured soil.
5. Provides a means of selective plant kill when desirable native forage plants are present.
6. Averts most soil crusting and reduces frost heaving.
7. Conserves soil moisture and nitrogen, similar to mechanical fallow, when used as chemical fallow (Eckert and Evans 1967).
8. Improves moisture penetration and retention as a result of mulch cover on the ground.
9. Allows spraying, drill seeding, transplanting, and fertilization in a single operation while climatic conditions are still optimum (Kay and Owen 1970).
10. Protects grass seedlings by means of the standing vegetation killed by herbicides.
11. Permits seeding an entire field, riparian zone, or watershed having erosive soil, at one time.
12. May be less costly than mechanical seedbed preparation.
13. Does not destroy the soil seedbed of desirable native species.

On the other hand, dead mulch and litter following chemical seedbed preparation may be excessive, or otherwise hinder seeding. However, use of the rangeland drill with its various modifications permits drilling into all but the most extreme sites. Also, herbicide applications may not kill weed seeds resident in the soil unless used as chemical fallow during a growing season. This may require additional herbicide application during the seedling year as a maintenance treatment.

How to Apply

Several methods are available for applying herbicides to undesirable plants. For convenience, these are divided into foliage, stem, and soil application. See Bohmont (1983) for details about various herbicide applications.

I. Foliage application
  A. Foliage spray (selective 2,4-D and related phenoxy herbicides, dalapon, dicamba, paraquat (at low rates), picloram, triclopyr; nonselective amitrole, ASM, diesel oil, glyphosate).
    1. Aerial (airplane or helicopter) (fig. 3).
    2. Ground (hand and power equipment).
      (a) Non directional (mist blowers).
      (b) Directional (boom sprayers; single nozzle sprayers) (fig. 4).
        (1) In row (rowed plants physically protected from spray by shields).
        (2) Strip (chemical seedbed preparation for interseeding) (fig. 4).
  B. Wipe on (rope wicks, rollers, or sponge bars).
  C. Dust (unimportant on range or wildlands).

II. Stem application (individual plant) (2,4-D, hexazinone, picloram, triclopyr) (fig. 5).
  A. Trunk base spray (may be enhanced by use of frills or notches).
  B. Trunk injection.
  C. Cut stump treatment (fig. 6).

III. Soil application (selective; atrazine, dicamba, fenac [partly], monuron, picloram, tebuthiuron [partly], nonselective; bromacil, hexazinone, karbutilate [now tabled]).
  A. Broadcast (spray, granules, or pellets).
  B. Grid ball (spaced placement of pellets).
  C. Individual plant or motte.
    1. Soil injection (liquid).
    2. Soil surface placement (around stem base or spread under canopy).

Figure 3—Helicopter equipped with boom sprayer.

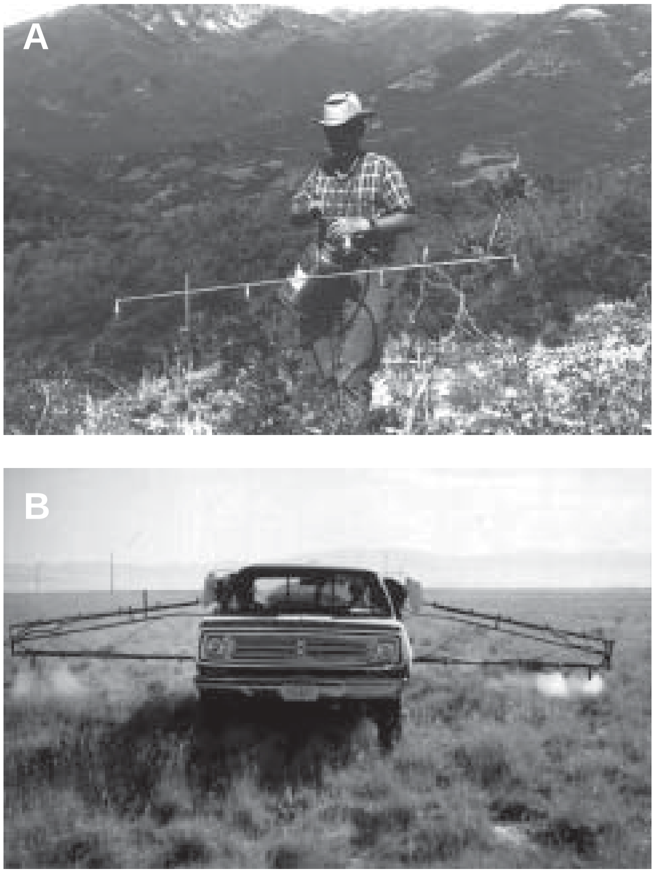


Figure 4—Boom sprayers can be (A) hand held and (B) vehicle mounted. Spraying strips of crested wheatgrass with Roundup to facilitate transplanting desired shrubs.

Broadcast spray application has been the most commonly used method on rangelands. Because an herbicide is applied to desirable as well as undesirable plants on the site when broadcast, selective herbicides are required. Broadcast spray applications can be made either by ground rigs or by aerial application. When herbicides are applied by ground rigs, a spray volume of 10 gal/acre (93.5 L/ha) is common but volume may vary from 5 to 40 gal (46.8 to 374.2 L/ha) depending on need. With aerial application, spray volume can be reduced down to 1 to 3 gal/acre (9.3 to 28.1 L/ha), with ultra low volumes down to 0.50 gal/acre (4.7 L/ha) or even less being satisfactory in some situations.

The comparative advantages of using ground application or aerial application of herbicide sprays are as follows:

Figure 5—Results of basal stem spraying of Gambel oak with Picloram, Triclopyr, and Hexazinone.

Figure 6—One hundred percent kill of salt cedar. Stems cut off and stem ends sprayed with 2,4-D.

- Broadcast Ground Application
  1. Adapted to small acreages.
  2. No landing strip required (pad only required for helicopter).
  3. Less drifting and less subject to fog or wind.
  4. Commercial equipment often not required.
  5. Safer for applicators.
- Aerial Application
  1. Faster coverage.
  2. Adapted to wet, rough or rocky ground, or steep slopes.
  3. Lower cost per acre on most large acreages.
  4. No mechanical disturbance of soil or vegetation.
  5. Better coverage of tall, dense brush, or tree stands.

Although fixed wing aircraft are more commonly used, helicopters are advantageous in some situations (USDA Agricultural Research Service 1976). Helicopters that require no landing strip are interfered with less by trees, snags, and steep terrain, permit slower air speed for application, and have greater maneuverability. However, they are generally less available when needed, have less lifting power in thin, warm air, have less payload capacity (50 to 150 gal [190 to 570 L] compared to 125 to 600 gal [475 to 2,270 L] for fixed wing aircraft), and are more costly per acre on larger projects.

Foliage spray application with ground rigs generally use boom applicators that are as narrow as 4 ft (1.2 m) for hand application to as wide as 100 ft (30.5 m) for self propelled systems. Ground sprayers adapted to range use are discussed by Young and others (1979b). Maxwell and others (1983) describe adapting all-terrain vehicles for herbicide application on difficult-to-reach sites. Boomless ground applicators have been used conveniently in tall brush, along fence rows, or in very rough terrain. Such mist blowers have been used in applying low levels of phenoxy herbicides, using crosswinds of 5 to 12 mph (8 to 19 km/h), thereby permitting strips up to 100 ft (30.5 m) wide to be covered.

Wipe-on applicators have permitted taller, noxious plants to be controlled with nonselective herbicides without damaging low growing desirable plants (Mayeux and Crane 1983; Messersmith and Lym 1981; Moomaw and Martin 1985). Wipe-on applicators have advantages in applying selective herbicides because low volume is required, the total amount of herbicide used is reduced, spray drift is mostly eliminated, and low cost equipment can be used in getting selective control.

Individual plant treatments including wetting sprays, stem application (fig. 6), or soil application may have advantages over broadcast application for spot infestations, for widely scattered plants, on terrain that is too rough for wheeled machinery, or where only a small portion of the plants are to be removed, such as in commercial forests. Individual plant treatment generally allows nonselective herbicides to be used selectively through positive control of spray direction. However, individual plant treatments have a high cost per plant, high labor demand, slow job completion, and are difficult to control when treating plants over 6 ft (1.8 m) high with a foliage application. Hand held boom sprayers or mist blowers provide advantages somewhat intermediate between broadcast application and individual plant treatment.

Soil injection, soil surface placement around the stem base, application in continuous narrow bands on the soil surface or underground, or use of the gridball technique permit nonselective herbicides to be used with significantly reduced herbaceous plant injury. The gridball technique provides for placing pellets in grid fashion, resulting in conical columns of active herbicide in the soil that can intercept the deep roots of woody plants while minimizing intercept by the roots of herbaceous plants.

Where desired, applying soil-active herbicides in granular or pellet form has the advantage of minimizing drift, not being intercepted by foliage, having controlled release, ease of handling and application, premixing; thereby reducing formulation errors, simple application equipment generally, and prolonged soil activity.

What to Apply

The following terminology will be useful in evaluating the characteristics of herbicides:

Herbicide, a chemical that kills plants (syn. phytocide).

Contact, an herbicide that kills only plant parts directly exposed to the chemical and is direction toxic to living cells.

Translocated, an herbicide applied to one part of a plant that is spread throughout the plant where effects are produced (syn. synthetic hormone herbicide, systemic herbicide, or growth regulator).

Selective, an herbicide that kills or damages a particular plant species or group of species with little or no injury to other plant species (are often nonselective at heavy rates).

Nonselective, an herbicide that kills or damages all plant species to which it is applied (general weed killer).

Soil sterilant, an herbicide that kills or damages plants when herbicide is present in the soil. The effect may be temporary or permanent and either selective or nonselective.

The properties of herbicides used or proposed for use on rangelands are given in table 1. General information on clearance and general uses are given for each herbicide. More detailed information on individual herbicides can be found in Berg (1985), Bohmont (1983), Bovey and Young (1980), Spencer (1982), Thomson (1983), and Weed Science Society of America (1989).

The phenoxy herbicides, primarily 2,4-D (and also MCPA and 2,4-DP or dichlorprop in some areas, or 4-DB when damage to legumes is to be avoided) have been the most widely used on rangelands. Silvex and 2,4,5-T, previously widely used in brush control, by regulation can no longer be manufactured or used in the United States or Canada.

New herbicides such as glyphosate, tebuthiuron, hexazinone, and triclopyr are now in widespread use on western rangelands. Other potential range herbicides still in the experimental stages are karbutilate, fosamine, clopyralid, buthidazole, ethidimuron, prodiamine, and metribuzin.

Soil-active herbicides may be selective or nonselective and have either temporary or lasting effects. Herbicides such as dicamba and picloram are effective when applied to either soil or foliage. Atrazine, fenac, 2,3,6-TBA, and tebuthiuron are effective only when applied to the soil. Soil-active only herbicides are generally applied as dry granules or pellets since vegetation will intercept some or most of the spray, but other soil-active herbicides can be applied in either dry or liquid form.

Only a few herbicides have been effectively used, either singly or in combination, on range sites in preparation for seeding or transplanting. Chemical application fallowed by direct seeding into the killed mulch, without further soil treatment, is effective if the herbicide (1) controls a broad spectrum of undesirable plants, (2) dissipates rapidly after weed control is accomplished, and (3) is broken down or leached away by the time seeded species germinate, or is not toxic to seedlings of the seeded species (Eckert and Evans 1967). Chemical fallow during the previous growing season has been more successful in low rainfall areas than spring herbicide treatment and seeding.

The herbicide 2,4-D has been effective in chemical seedbed preparation on those sites where the principal competition has been brush and forbs susceptible to it, such as on big sagebrush or tarweed sites (Hull 1971b; Hull and Cox 1968). Aerial spraying with 2,4-D and drilling with a rangeland drill have been effective for establishing additional perennial grasses on sagebrush-grass and forb-grass sites with a fair understory of perennial grasses. A second herbicide application may be required in the spring of the establishment year if sprouting shrubs such as rabbitbrush are present or a large number of sagebrush seedlings develop.

Picloram can be used in chemical seedbed preparation where rhizomatous forbs and shrubs not killed by 2,4-D are present. Although low chemical residual amount in the soil will not be harmful to grass seedlings, 2 or 3 years must be allowed before forb and shrub species are introduced following picloram application.

On sites dominated by annual grasses, spring application of paraquat and drilling perennial grasses have been effective. Since paraquat is quick acting and leaves no soil residues, planting of perennial forage species can follow immediately (Evans and others 1975). Paraquat has only a temporary effect on perennial grasses and does not kill most broadleaf plants. Where broad leaved weeds and undesirable shrubs are growing with cheatgrass, 2,4-D should be combined with the paraquat application (National Research Council 1968). Band “tilling” with paraquat and drilling down the center of each band has also been effective on annual grass sites (Kay and Owen 1970).

Table 1—Properties of herbicides labelled for use on rangeland or proposed for range use.

Common name (trade name)	Group and type of herbicide	Uses, restrictions LD$_{50}$[a]	Range and pasture uses; comments[b]
Clopyralid (Stinger) Transline) (Reclaim) +2,4-D (Curtail)	Picolinic acid, selective post-emergence herbicide	Cleared for rangelands and pasture, short-lived herbicide.	Kills broadleaf herbaceous weeds, grass seedling.
Dicamba (Banvel) +2,4-D (weedmaster)	Benzoic; selective, translocated, foliage or soil + Phenoxy	Cleared for pasture and range at rates up to 8 lb a.e./acre (9 kg/ha); LD$_{50}$ = 566 to 1,028	Controls difficult plants such as Russian knapweed, Canada thistle, leafy spurge. Also useful in brush control. Persists in soil for up to a few months. Low volatility
2,4-D (several trade names)	Phenoxy; selective translocated, foliage	Pasture and range; LD$_{50}$ = 300 to 1,000	Highly effective as foliage spray on many broadleaf herbaceous plants and some shrubs. Also used in frill cuts. Persists in soil for 1 to 4 weeks. Volatility depends on chemical form
Glyphosate (Roundup)	Aliphatic; nonselective translocated	Range and pasture; broad spectrum herbicide; LD$_{50}$ = 5,000	Used in brush control but also kills desirable grasses and forbs. Used to kill foliage. Undesirable grasses such as foxtail barley or saltgrass. Persists 1 to 3 weeks in soil. May be applied selectively
Oust (Oust	Sulfometuron methyl; translocated by roots and foliage; partly selective, temporary soil sterilant	Rangelands, forestry, and noncroplands	Kills annual grasses at rates between 0.25 to 1.0 oz/acre; can be fall and spring applied. Persists 1 to 2 years. Sensitivity of most native species is not known. Can be used to control and exhaust seed bank of annual weeds. Fall seeding 1 year after treatment appears successful
Paraquat (Paraquat, Granonione)	Bipyridyl; selective to nonselective contact, foliage	Use as spot treatment on noncropland or for pasture or range renovation; LD$_{50}$ = 150	Selectively kills annual grasses by application at 0.25 to 1 lb/acre (0.28 to 1.12 kg/ha); can be applied just prior to range seeding. Rapid acting, nonvolatile. Soil contact inactivates. Has minor effect on broadleaf perennials. Low rate chemically cures but does not kill perennial grasses
Picloram (Tordon) +2,4-D (Grazon P + D)	Picolinic; selective, translocated Phenoxy; selective translocated, foliage	Range and pasture; LD$_{50}$ = 8,200	Effective on leafy spurge, Russian knapweed, low and tall larkspur, whorled milkweed, and also many shrubs, such as rabbitbrush and oaks. Nonvolatile. Rates over 1 lb/acre (1.12 kg/ha) may persist for 2 or 3 years. Often synergic with phenoxy herbicides
Tebuthiuron (Spike)	Substituted urea; partly selective, translocated, soil	Cleared for range use in some states; LD$_{50}$ = 286 to 644	Holds promise for controlling woody plants. Persists up to several months. Spot apply for broadcast as pellets. Selective at 0.5 lb/acre rate or when high rates applied selectively
Triclopyr (Garlon) +2,4-D (Crossbow)	Phenoxy-picolinic; selective, translocated, foliage	Experimental on rangelands; LD$_{50}$ = 713	Shows promise on broadleaf weeds and shrubs including oaks and other root sprouters Also effective in basal spray and trunk injection. Degraded rapidly in soil

---

[a] Registration of herbicides for range and pasture uses and the accompanying restrictions are subject to continual change. Current clearance and restrictions at both State and Federal levels should be checked and complied with. Silvex, Amitrole, Dalapon, Atrazine, Fenatrol, and 2, 4, 5, T have been removed from the market or are no longer approved for use on rangelands in the United States and Canada. LD$_{50}$ taken from Weed Science Society of America (1989). See Woodward (1982) for herbicide tolerance of trout.

[b] Publication directed herbicide control of individual plant species (Bartel and Rittenhouse 1979; Bowes 1976; Britton and Sneva 1981, 1985; Clary and others 1985a, b; Cronin and Nielson 1979; Eckert 1979; Eckert and Evans 1967; Engle and others 1983; Evans and Young 1975a, 1977b, 1985; Evans and others 1975; Hull 1971b; Hull and Cox 1968; Johnsen and Dalen 1984; Marquiss 1973; Miller and others 1980; Mohan 1973; Roeth 1980; Sneva 1972; Thilenius and Brown 1974; Thilenius and others 1974b; Van Epps 1974; Warren 1982; Whitson and Alley 1984; Williams and Cronin 1981; Wilson 1981; Young and Evans 1971, 1976; Young and others 1984c.

Fall application of 0.5 to 1 lb/acre (0.6 to 1.1 kg/ha) of atrazine has effectively controlled cheatgrass during a chemical fallow period (Eckert and Evans 1967; Young and others 1969b). However, at least 1 year must be allowed for dissipation prior to grass seeding. When atrazine is used for chemical fallow, adequate broadleaf control may require spring application of 2,4-D (National Research Council 1968). Integrating 2,4-D or picloram spraying for brush control and atrazine fallow for cheatgrass control has proven effective in Nevada (Evans and Young 1977b).

Dalapon has been more effective than either paraquat or atrazine in killing medusahead (Young and Evans 1971). Since dalapon is slower acting than paraquat and the residual remains longer in the soil, grass seeding should be delayed for at least 6 weeks following dalapon application. Dalapon gives some control of perennial grasses but is ineffective on broad leaved plants.

One of the most promising herbicides for site preparation for range revegetation is glyphosate (trade name, Roundup). When broadcast sprayed or applied in strips, it provides nearly complete kill of all resident vegetation. Since it dissipates rapidly in the soil, seedings can be made within 1 to 3 weeks after glyphosate applications. Although effective in brush and weed control, it has also been effective on foxtail barley and saltgrass.

Oust has remained effective in controlling cheatgrass for 2 years when applied at 1 oz/acre. Satisfactory stands of crested wheatgrass have been established by drill seeding into the treated sites 1 year after fall treatment. Although individual species exhibit different degrees of sensitivity, it appears sites treated at rates up to 1.0 oz/acre can be planted within 180 days following fall treatment.

The compiled herbicidal plant control recommendations published by the respective State agricultural experiment stations and extension services, many of these revised annually, are current and locally adapted. Examples include Alley and others (1978), Chase (1984), Cords and Artz (1976), Dewey (1983b), Duncan and McDaniel (1991), Heikes (1978), Hepworth (1980), or Washington Agricultural Extension Service (1984) or their revisions or replacements. Other compiled sources of individual plant control recommendations include Bovey and Rodney (1977), Hamel (1983), Spencer (1982), and USDA Science and Education Administration (1980).

Herbicide Approval

All pesticides must be registered by the Pesticides Registration Division, Office of Pesticides Programs, Environmental Protection Agency, before entering into interstate or intrastate commerce. The Environmental Protection Agency approves all uses of pesticides including herbicides, regulates instructions on pesticide labels, sets tolerances in animal feeds and human foods, may seize any raw agricultural commodities not complying with these tolerances, and can punish violators using nonregistered pesticides or making unapproved use of registered herbicides.

Herbicides approved for range use are not hazardous to livestock, wildlife, or humans at recommended application methods and rates. Environmental Protection Agency registration of herbicides is intended to insure that they are released for public sale and use only after detailed research and thorough testing. Tolerance levels set for human intake of pesticides include rather large safety factors and are generally set at one percent or less of the highest level causing no adverse effect in the most sensitive animal species; but zero tolerance is mandatory in some cases.

The relative degree of toxicity of the various herbicides to warm-blooded animals has been determined experimentally. The relative degree of toxicity is expressed as the acute oral LD_{50} (the single dosage by mouth that kills 50 percent of the test animals expressed as mg/kg of body weight). The LD_{50} for each herbicide is given in table 1. Toxicity classes are related to LD_{50} levels as follows:

Class	**LD_{50} (mg/kg)**
Highly toxic	50 or less
Moderately toxic	50 to 500
Mildly toxic	500 to 5,000
Nontoxic	Above 5,000

In addition to the Environmental Protection Agency, one lead agency within each State is designated by its governor to participate in pesticide regulation. Individual States may have special registration and use requirements for pesticides. Also, the designated State agency is charged with certifying pesticide applicators. Only certified pesticide applicators are permitted to purchase and use “restricted use” pesticides, including paraquat and picloram, or those on emergency exemption.

In addition to the regular Federal registration of pesticide uses, three special registrations are provided for additional pesticide use approval.

1. *Experimental label*. This special Federal label permits new products, or old products being considered for removal of registration, to be further researched and evaluated before final approval is given.

2. *Emergency exemption*. The Federal administration of the Environmental Protection Agency may exempt any Federal or State agency so requesting unapproved pesticide usage provided that the emergency requires such exemption.

3. *Special state label*. A state may provide registration for additional uses of Federally registered pesticides within the State, if such uses have not previously been denied, disapproved, or cancelled by the Environmental Protection Agency. Final approval of the State

label is given by the Environmental Protection Agency unless such use is known to have definite detrimental effects on humans or the environment.

Evaluating Herbicide Sprays

Preparation of a spray mix involves mixing the commercial product formulated by the manufacturer with the right kind and amount of carrier and adding any additional surfactant needed. The combination of formulation, dilution with the carrier, rate of application, and method of application generally determines whether a recommended herbicide will be highly selective and effective or not. The proper preparation and use of herbicides requires an understanding of the following terms:

Toxicant, the herbicide or chemical agent that causes a toxic effect on plants.

Carrier, the diluent in which the toxicant is mixed to provide greater bulk for more effective application.

Commercial product, the herbicide formulation prepared in liquid form for spray application.

Surfactant (surface active agent), materials used in herbicide formulations to facilitate or accentuate emulsifiability, spreading, wetting, sticking, dispersibility, solubilization, or other surface modifying properties.

Active ingredient, that part of a commercial product or spray mix that directly causes the herbicidal effects.

Acid equivalent (a.e.), the amount of active ingredient expressed in terms of the parent acid or the amount that theoretically can be converted to the parent acid.

The active ingredient of phenoxy herbicides is expressed in terms of acid equivalent. This is a relative term relating esters and salts to the pure acid, a form that is seldom available but may occur in minor amounts mixed with the other chemical forms. The acid equivalent is a more precise measurement than the actual amount of the particular chemical form. However, acid equivalent measures toxicity only indirectly since other factors in the formulation also affect toxicity to plants. For example, the ester chemical forms of 2,4-D are more toxic per unit of acid equivalence (a.e.) than the salt forms or the pure acid. The herbicide label on the commercial product generally provides the amount of toxicant therein in terms of both (1) lb a.e./gal, and (2) percent a.e. (by weight).

Water is the carrier most commonly used today, but the addition of diesel oil to comprise up to 25 percent of the total carrier may increase effectiveness with some woody plants. Water has good driving force through the upper foliage, is easier to work with, and is low cost; but the addition of diesel oil often reduces evaporation of the spray mix, spreads more evenly on the leaf, and penetrates plant cuticles better. Surfactants increase emulsifiability, spreading, sticking, and other desirable surface modifying properties of the spray mix. They are added to the commercial product at the factory, but additional amounts or kinds may be included in specific recommendations. However, excessive use of surfactants may reduce or eliminate normal selectivity of an herbicide.

Herbicide recommendations are generally given in one or more of the following ways:

1. Pounds of active ingredients (or acid equivalent) per acre, or per square rod, for broadcast application.
2. Pounds of active ingredients (or acid equivalent) per 100 gal of mix (a.e.h.g.) for wetting sprays, frill or cutstump application, or plant or soil injection.
3. Weight (grams or ounces) or volume (tablespoons or cups) of commercial product per plant or clump of plants.

The amount of herbicide required to provide adequate control varies with kind and chemical form of herbicide, plant species, and method of application. Herbicide rate recommendations primarily consider optimum toxic effects within legal limits. Higher rates are rarely more effective and may prove detrimental; selective herbicides often become nonselective when applied at excessive rates. However, reducing rates below recommended levels to save money or to be environmentally conscious may sharply reduce kills, particularly when less then ideal conditions are encountered.

Greater selectivity can be realized with herbicides by carefully controlling the application rate, fully considering the relative growth stages of the target and nontarget plant species, using appropriate or even differential application techniques, and using adequate but not excessive amounts of surfactants. When multiple herbicides are required for additive or synergistic effects, or when repeat applications are required for satisfactory kill, the single application of one herbicide but at a higher rate is seldom a satisfactory alternative.

Calculations

The following are examples of calculations frequently used in mixing and applying herbicides[a]:

1. Rate per acre for liquid formulation. If 2 lb a.e. per acre is recommended and a commercial product containing 4 lb a.e. per gallon is purchased, then use the following:

$$\frac{\text{2 lb a.e./acre}}{\text{4 lb a.e./ga. product}} =$$ 0.5 gal (or 4 pt) of product is required per acre. Add enough carrier to give desired volume of spray mix, and apply.

2. Rate per acre for granular form. If 3 lb active per acre is recommended for a commercial product

containing 10 percent active ingredients in granular form then use the following:

$$\frac{\text{3 lb a.e./acre x 100\%}}{\text{10\%}} =$$ 30 lb of granules is required per acre.

3. Rate per gallon for wetting spray. If a “wetting” spray containing 6 lb acid equivalent per 100 gal (a.e.h.g.) is recommended and a commercial product (C.P.) containing 2 lb a.e. per gallon is used, then use the following:

$$\frac{\text{6 lb a.e.h.g. x 256}}{\text{2 lb a.e./gal in C.P. x 100}} =$$ 7.68 T of C.P. is required per gal of spray mix. Apply to plants until wet.

4. Amount per small plot. If a 400 ft^2 plot is to be sprayed at the rate of 3 lb a.e./gal and a commercial product containing 4 lb a.e./gal is used, then use the following:

$$\frac{\text{3 lb a.e./aX 400 ft}^2 \text{ x 256}}{\text{4 lb a.e./gal in C.P. x 43,560}} =$$ l.76 T of C.P. is required. Add enough carrier to give desired amount of spray mix and apply to plot.

5. Amount per field unit. If a l50 acre unit is to be sprayed with 2 lb a.e. of 2,4-D in 10 gal of spray mix per acre, and a commercial product containing 6 lb a.e./gal is used, then the following is needed:

Total spray = 1,500 gal (150 acre x 10 gal/a)
Commercial product = 50 gal (2 lb x 150 acre : 6 lb)
Carrier = 1,450 gal (by subtraction)

When to Apply

The age, stage of growth, and rapidity of growth affect the susceptibility of plants to herbicides. The most effective kill by phenoxy herbicides and most other foliage-applied, translocated herbicides is obtained when carbohydrate production and translocation rate is at the maximum, often near full leaf stage (fig. 7). Since such herbicides are carried with the photosynthate stream throughout the plant, intrinsic plant factors as well as external environmental factors that stimulate growth generally increase plant kill. Maximum growth rate and herbicide kill are associated with ideal soil moisture and fertility, ideal temperature, and adequate light.

Reduced susceptibility periods of desirable species in the plant composition can often be found and followed. For example, 2,4-D should be applied early in the spring for big sagebrush kill, in order to reduce damage to bitterbrush (fig. 8). Spraying at the time of leaf origin in bitterbrush, and before the appearance of distinct twig elongation or flowering, generally causes only slight damage to large bitterbrush plants. Selective application methods permit nonselective herbicides to be used selectively.

Figure 7—Mountain big sagebrush killed with aerial spraying of 2,4-D. Spraying occurred when growth rate, soil moisture, temperature, and light were ideal. With better control of helicopter flight paths there would not have been misses that are evident in the background.

Foliar herbicide application must be timed not only to coincide with ideal plant growth stages, but the best associated environmental and climatic conditions as well. To get the best kill from broadcast spraying of phenoxy herbicides, do not spray:

1. During prolonged drought when low soil moisture retards plant growth.
2. Before most leaves are well developed—exact timing will vary somewhat between different plant species.
3. After leaves have stopped growing rapidly, begin maturing, and develop thickened cuticles.

Figure 8—With proper timing, big sagebrush was killed and antelope bitterbrush was unharmed by aerial spraying of 2,4-D.

---

[a] 1 gal = 4 quarts = 8 pints = 16 cups = 256 tablespoons = 768 teaspoons = 231 inches^3 = 3.785 L.

4. When plant growth has been retarded by late frost, hail, insects, or excessive leaf removal by grazing.
5. When temperature is over 90 °F (32.2 °C) or under 55 °F (12.8 °C). (Temperatures between 70 °F [21.1 °C] and 85 °F [29.4 °C] are best).
6. When wind is above 10 mph (16 km/h) for aerial application or 15 mph (24 km/h) for ground spraying, or when the air movement is being subjected to great turbulence and updrafts.
7. When thunderstorms are approaching. (Rain 4 or 5 hours after spraying will reduce effects very little.)

Soil surface application is less dependent on stage of plant growth than foliage sprays but does require precipitation to dissolve and move the herbicide into the soil. Application just prior to normal rainy season is ideal unless excessive leaching is anticipated then.

Herbicides Can be Effective and Safe

Even though herbicides are among the least hazardous of all pesticides, recommended safeguards in their handling and application must be followed. These routine safeguards include following all directions and restrictions shown on the pesticide label, storing pesticides only in the original containers, properly disposing of excess chemicals, and cleaning spraying equipment after use.

Herbicides now approved for range and pasture use pose no hazard to livestock, wildlife, the applicator, or local inhabitants when properly applied. The Environmental Protection Agency requires temporary removal of livestock following application of the most toxic herbicides, but this is mostly precautionary or directed to dairy cows only. However, livestock should be denied access to spraying equipment, herbicide containers, or herbicide in concentrated form. Herbicides may temporarily increase the palatability of treated plants, and this may increase the hazard from poisonous plants. In some cases the natural poisoning agent in the poisonous plants may be increased also. For these reasons, care must be taken that poisonous plants affected by herbicides are not grazed until they begin to dry and lose their palatability (generally 3 weeks or more after herbicide application).

Proper swath widths are important in preventing skips or overlapping of swaths and in obtaining complete coverage of the foliage in broadcast spray application. Since height above the ground will affect swath width, it should be carefully controlled. Application rates should be checked periodically by proper calibration methods and corrected as needed (Bohmont 1983; Portman 1984; Young and others 1979b). Flagging is essential in aerial application, and some form of ground marking will generally be required with ground application. Many aircraft are now equipped with automatic flaggers that dispense strips of wet, colored paper to mark flight lines reducing or eliminating the need for manual flagging. Gebhardt and others (1985) described a foam marking system for use with boom sprayers operated on the ground.

Herbicide drift is a special problem associated with foliage spray applications, and can be hazardous to susceptible plants downwind unless controlled. The direction, distance, and amount of spray drift that occurs before the herbicide reaches the ground are influenced by several factors. Drift is reduced by increased size of droplets and higher specific gravity of the spray mix, lower evaporation rate, reduced height of release, low velocity of the wind, no vertical air movements, and carefully selected application equipment. Spray drift is a greater problem in aerial application because of the elevated release point and air turbulence generated, but can be serious in ground application as well. Herbicides that volatize after application are again subject to wind movement. Certain ester forms of the phenoxy herbicides are highly volatile while others are not. Low volatile ester or salt forms should be selected for use if susceptible crops or areas to be protected are in the immediate vicinity.

In addition to using herbicide formulations with low volatility and thus drift potential, other means of reducing drift of herbicides include:

1. Using application equipment that will maintain adequate size and uniformity of droplets. Finely atomized spray drops may drift from the target area or evaporate before reaching the foliage. Spray droplets should be large enough to minimize drift hazards and yet be sufficiently small and properly distributed to give good coverage.
2. Reducing height of release, particularly in aerial application.
3. Avoiding spraying on windy days and when vertical air movement is great; favorable conditions are more apt to be found in early morning, late evening, and night.
4. Using water as the carrier since water droplets are heavier and drift less than oil droplets, while being aware that antievaporants may be needed to reduce evaporation in dry atmospheres.
5. Selecting spray days with a slight, continuous wind movement blowing away from susceptible crops or other nontarget areas.
6. Using positive liquid shutoff systems in aerial application and avoiding flights over susceptible crops.
7. Using invert emulsions (water in oil), recognizing however, that special equipment will be required for application because of its thick, nonflowing physical characteristics.
8. Using granular formulations of soil-active herbicides.

Steven G. Whisenant

Chapter 11

Vegetative Manipulation with Prescribed Burning

Introduction

Plant responses to fire differ because of phenological variations at the time of burning, inherently different susceptibilities to heat damage, differing regenerative abilities, and different responses to the postfire environment. Individual plants of the same or different species may have different responses to fire because of local variations in fire temperature or microenvironment. The postfire assemblage of plants may have few species changes, as is often the case after grassland fires, or may be dramatically different in both species composition and structure, following some forest fires. When understood, these differential susceptibilities to fire can be used to manipulate plant communities. Prescribed burning can often be used to enhance one species or assemblage of species while reducing another species or assemblage of species (fig. 1).

Figure 1—Prescribed fire in a spruce-fir-aspen stand. Fire is used to suppress or remove spruce and fir and to release aspen and understory herbs.

Most plants have some tolerance to fire, yet undesirable results can occur. These undesirable results can be minimized if the resource manager has an understanding of fire ecology and prescribes a fire under conditions adequate to accomplish management objectives. Tables 1 and 2 summarize the effects of fire on some grasses and shrubs common to the Intermountain area. These should be used as approximations of the expected results, which are subject to variation.

Prescribed burning can be a useful tool in both big sagebrush and juniper-pinyon communities if burning is carefully prescribed and the area is deferred from livestock grazing for 2 years after treatment (Wright and others 1979).

Fire, improperly used (or wildfires), may have such adverse effects as converting desirable shrub (fig. 2) and perennial grass stands to annual grasses or maintaining annual grass communities. Understanding how fire affects plants is an important step in being able to use fire to accomplish specific management objectives. The effects of fire on plants can be clearly understood only if the modes of action of fire on that community are considered. According to Lloyd (1972) the primary effects of fire on plant communities are: (1) the direct action of heat on plants and soils, (2) changes in the microenvironment, and (3) the redistribution of certain nutrients. The first of these involves breakdown of organic compounds, possible stimuli to dormant organs, and physical, chemical, and biotic changes in the surface soil. The second mode of action affects the microclimate, and the third includes losses of volatile compounds in the smoke and deposition of nonvolatile compounds in the ash. Understanding these three modes of action is helpful in understanding how fire can be used to accomplish management objectives.

Table 1—Summary of fire effects on some grasses of the Intermountain Region[a].

Species	Response to fire	Remarks
Cheatgrass	Undamaged	Reduction in cheatgrass usually results from seed consumption and changes in the microenvironment caused by fire. Recovers in 1 to 2 years
Bluegrass	Slight damage	Slight reductions following late summer and fall burning
Idaho fescue	Slight to severe damage	Greatly damaged by summer burning. Burning in spring or fall, under mild conditions and good soil and water, causes little damage
Indian ricegrass	Slight damage	Tolerant of fire, but may respond slowly to improved conditions
Needlegrass	Moderate to severe damage	Needlegrass are among the least fire resistant bunchgrasses. Large bunchgrasses. Large plants are damaged more than small plants. A 50 percent reduction in basal area is possible
Plains reedgrass	Undamaged	Rhizomatous species that is very tolerant of fire
Bottlebrush squirreltail	Slight damage	One of the most fire resistant bunchgrasses. Often increases for 2 to 3 years after burning. Can be damaged by severe fires in dry years
Wheatgrass	Little or no damage	Bluebunch wheatgrass can be damaged if burning occurs in a dry year. Other wheatgrass, particularly crested wheatgrass are difficult to burn in seeded monocultures
Prairie junegrass	Undamaged	Often increases its density following burning

[a] Adapted and modified from Wright and others (1979).

Table 2—Summary of fire effects on some shrubs of the Intermountain Region[a].

Species	Response to fire	Remarks
Antelope bitterbrush	Variable, slight to severe	Decumbent forms sprout more readily than the columnar forms. Subsequent seedling establishment is higher on more mesic sites. Spring and late fall burning is less damaging than summer burning (Bunting and others 1985)
Sagebrush species	Slight to severe	Black sagebrush and low sagebrush are small and widely spaced. They are rarely burned and may often be used as fire breaks when burning adjacent big sagebrush. Silver sagebrush is capable of sprouting after being burned, and is only slightly damaged. Big sagebrush is killed when burned
Rabbitbrush	Usually enhanced	Vigorous sprouter that often increases following burning
Horsebrush	Stimulated	Vigorous sprouter that may greatly increase following burning
Gambel oak	Stimulated	Vigorous sprouter with rapid regrowth following burning
Snowberry	No lasting damage	Vigorous sprouter that may be enhanced by low severity fires or damaged by high severity fires
Curlleaf mountain mahogany	Variable	Mature, decadent stands, with curlleaf mountain mahogany mostly in excess of 50 years old may be rejuvenated by fire. Also may be beneficial when conifers are out competing mahogany seedlings. Damaging to younger, vigorous stands (Gruell and others 1985)

[a] Adapted and modified from Wright and others (1979).

Heat damage is a function of duration of exposure, environmental temperature, and the initial vegetation temperature (Hare 1961). The quantity of heat required to raise the temperature of living vegetation to the lethal temperature is directly proportional to the difference between the lethal temperature and the initial vegetation temperature. Initial vegetation temperature is a function of air temperature and availability of radiant energy, both are largely regulated by the time of day and season of year. The physiological condition of the protoplasm is an important variable regulating heat effects on plants. As the moisture content of vegetative tissue decreases, its tolerance to heat increases because of the high specific heat of water and the physiological activity of hydrated tissues (Hare 1961).

Figure 2—Wildfire in Wyoming big sagebrush and winterfat communities. Within 2 years following fire, the areas were completely dominated by cheatgrass.

Burning herbaceous plants during periods of active growth generally has adverse impacts on the plant. Conversely, dormant plants are seldom seriously damaged by burning. For example, burning in the spring usually increases warm season herbaceous plants while damaging cool season herbaceous plants (Daubenmire 1968; Wright and Bailey 1982). Burning in the fall usually has the opposite effect.

Plant growth form is a critical factor in the response of plants to heat, with rhizomatous plants having the greatest degree of protection. In general, the deeper the rhizomes are located in the soil, the greater the survival rate from fire (Flinn and Wein 1977). Fire may have either beneficial or detrimental effects on annual plants, depending upon the growth stage, location of the seeds during the fire (Daubenmire 1968), and the resulting microenvironment (Evans and Young 1984). The heat generated by a fire may be sufficiently high to kill seeds in the upper part of the surface litter, or in the inflorescence, but seeds on or under the mineral soil surface often survive (Bentley and Fenner 1958; Daubenmire 1968). Understanding the effects of fire on the various plant life forms is a critical component in prescribing the use of fire to effect desired changes in a plant community.

Season of burning, which greatly influences initial vegetation temperature, tissue hydration, phenology, and position of perennating buds is extremely important in regulating the effects of fire. Within a season, fire intensity increases with increasing fuel, ambient temperature, windspeed, decreasing fuel moisture, and relative humidity. Thus, by carefully selecting the burning time and environmental conditions, a resource manager can control fire intensity and damage to the existing plant community.

Woody plants may be well insulated from extreme temperatures by bark. Fahnestock and Hare (1964) reported longleaf pine bark surface temperatures, during burning, varied from 554 to 1,472 °F (290 to 800 °C) while cambial temperatures varied from 100 to 180 °F (38 to 82 °C). Seedlings of many plants are more susceptible to fire damage than mature plants. Young ponderosa pine and honey mesquite are much more likely to be killed by fire than older plants (Wright and Bailey 1982). Much of this increased protection may be due to the increased bark thickness on older plants.

Considerable research on the effects of litter removal in grassland plant communities has demonstrated the importance of that aspect of grassland fire ecology (Dix 1960; Hulbert 1969; Lloyd 1972; Old 1969). The mechanical removal of dormant, standing herbaceous vegetation, and mulch often accomplishes the same results on perennial plants as burning. Heavy mulch accumulations produce a dominating cover that stifles growth by depriving the plants of space and light (Dix 1960; Old 1969; Scifres and Kelley 1979; Vogl 1974; Whisenant and others 1984). Chemical substances leached from undecomposed plant material may further inhibit growth (Rice 1974).

Postburn responses of grasses in arid and semiarid regions are largely influenced by soil water content after burning. When prescribed fires are followed by a prolonged dry season, the vegetation response is predictably poor. Burning only when soil water content is high is the most reliable way to ensure adequate water for regrowth of plants in regions with unreliable rainfall (Wright 1974).

The importance of postburn changes in soil chemistry has been widely investigated. Most reports from grasslands indicate that nutrient gain from ash is of no detectable significance; any increases in production are a result of litter removal (Hulbert 1969; Lloyd 1971, 1972; Old 1969). In forests, where great volumes of plant material may be consumed, the ash may serve as an important fertilizer (Chandler and others 1983). Soil pH of acidic, weakly buffered forest soils is usually raised following fires that consume great quantities of woody material (Ahlgren and Ahlgren 1960). Most soils of western rangelands are basic, and strongly buffered.

The current uses of prescribed fire on western wildlands may be categorized into four interrelated areas: (1) maintaining existing vegetation, (2) site preparation prior to revegetation, (3) reducing woody plant density, and (4) wildlife habitat improvement.

Maintaining Existing Vegetation

Prescribed fires used for maintenance of existing vegetation are relatively cool fires. They maintain a desirable balance in the vegetation (Scifres 1980) and do not create major changes in the vegetation community. Maintenance fires are usually conducted during relatively cool weather with a higher relative humidity than fires used to create type changes or remove woody debris.

Grass (Christensen 1977; Daubenmire 1968; Lloyd 1971) and browse (DeWitt and Derby 1955; Dills 1970; Lay 1957) appearing after a fire may be attractive to grazing animals and often results in higher weight gains (Anderson and others 1970; Daubenmire 1968). Following prescribed burning, plants are often higher in crude protein, ether extract, nitrogen free extract, digestible energy, phosphorus, nitrogen, and potassium (Daubenmire 1968; DeWitt and Derby 1955; Lay 1957, Lloyd 1971). Most studies report that cattle make greater weight gains on burned than on unburned areas (Anderson and others 1970; Duvall and Whitaker 1964). These increases in nutrient content are often limited to 3 to 4 months after burning. Many of the increases in plant nutritive quality can be explained by the reduced tissue age of plants in recently burned areas (Christensen 1977).

Increases or decreases in forage quality or productivity may be determined by the season of burning. For example, late spring burning of big bluestem grassland in Kansas increased protein content, whereas burning at other seasons decreased it (Aldous 1934). Where fire alters dry matter production per unit of land surface (or per plant), the gains or losses expressed as a percentage of dry matter may be reversed when expressed on a land area basis. Thus, the percentage protein in the shoots of certain Australian grasses was higher after a fire, but the stand of grass was thinned so much that there was much less total protein on a land area basis (Smith and others 1960). In contrast, Christensen (1977) stated that because of increased net production in the burned area, uptake of all nutrients on a unit area basis by plants in the burned area undoubtedly exceeded uptake in unburned areas despite the lack of significant differences in tissue content of certain nutrients.

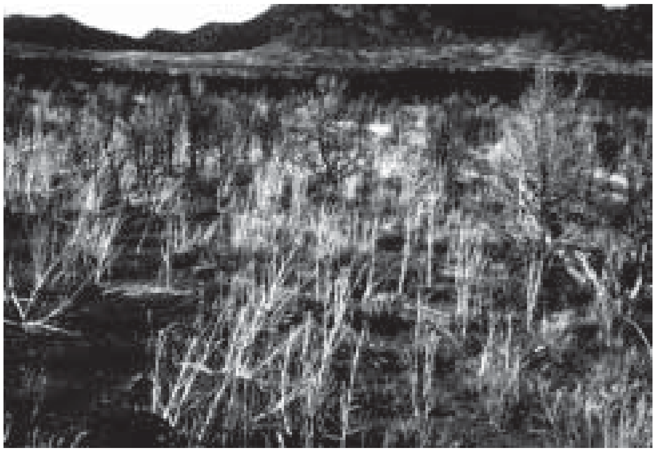


Figure 3—Effect of prescribed fire on small pinyon trees and understory herbs 2 years following fire. This 27-year-old chaining project is primarily on year-round range.

Sites in the early stages of reinvasion by big sagebrush, pinyon (fig. 3), juniper or other shrubs that may be considered undesirable in excessive amounts, are one of the best uses of prescribed burning. Ideally, the burning occurs while there is still sufficient herbaceous fuel available (fig. 4) and the woody plants are small and most susceptible to fire-caused mortality. Seedlings of woody plants are more susceptible to fire damage than mature plants. Small plants of juniper and pinyon species are usually more easily killed by fire, because the foliage is more likely to be ignited by ground fires (fig. 3). Mature pinyon or juniper trees often exhibit a greater distance between the ground and the lowest foliage, particularly when plants are heavily foraged, or high-lined, by big game animals. Fire in the herbaceous layer may pass under mature pinyon or juniper trees without igniting the canopy.

Site Preparation Prior to Revegetation

Prescribed burning may have several potential uses in the revegetation of western wildlands. Herbicide treatments or chaining may create debris that interfere with activities of livestock, wildlife, or planting equipment. Fire may be used to reduce this woody debris (fig. 5). The effectiveness of fire in debris removal varies with environmental conditions and the amount and distribution of fuel. Burning conditions favorable for debris removal are more hazardous than burning conditions used for maintenance burning. Ignition and consumption of woody debris requires hotter, drier environmental conditions. Certain detrimental effects on desirable species may also be associated with this intensity of burning. The potential damage to desirable species should always be carefully weighed against the expected benefits from burning to consume woody debris.

Competition from herbaceous weeds is one of the most important causes of seeding failures and the degeneration of established seedings. Direct seeding efforts may be damaged by competition from annual grasses. Cheatgrass has invaded big sagebrush communities in much of the Western United States (Evans and Young 1975b). Cheatgrass is highly competitive with perennial grasses and once established, may continue to dominate the site (Young and Evans 1973). Daubenmire (1968) stated there was no conclusive evidence that cheatgrass will relinquish an area to indigenous species once it becomes established

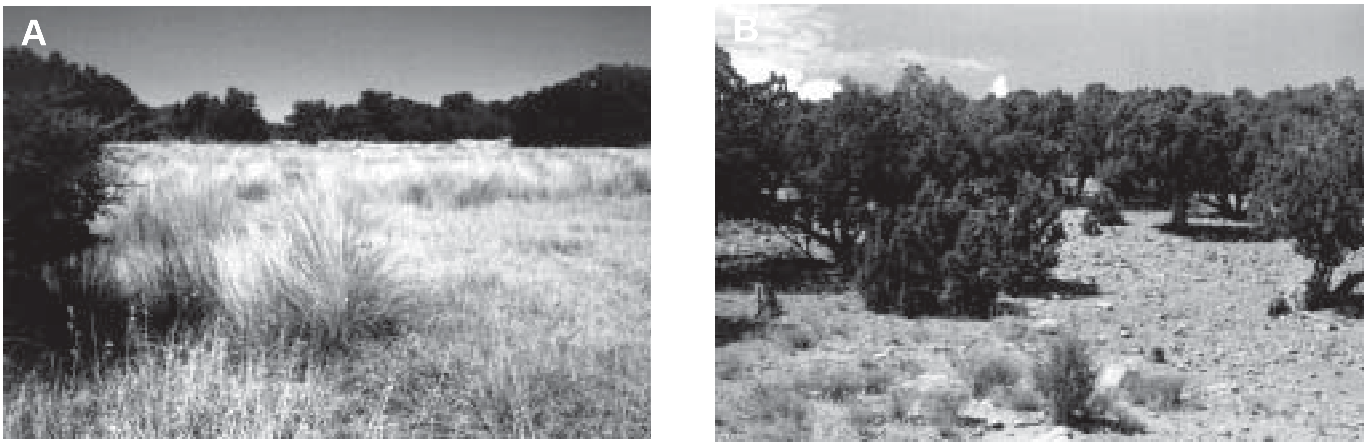


Figure 4—(A) Sufficient fuel has to be available to successfully burn juniper-pinyon stands. (B) Fire cannot be started or continued when understory fuel is lacking.

Figure 5—Prescribed fire being used to reduce woody debris on a chained juniper-pinyon area used by cattle, elk, and mule deer.

(fig. 6). The highly competitive nature of cheatgrass makes establishment of desirable perennial grasses very difficult. In a Nevada study, growth of perennial grass seedlings was dependent upon cheatgrass control (Evans and others 1970). Without cheatgrass control, soil water was depleted prior to establishment of perennial grasses.

Fire has been used with varying degrees of success in big sagebrush-cheatgrass communities to prepare the area for seeding to perennial grasses. It has not been very successful where cheatgrass is dominant (Wright and others 1979). Procedures developed for rehabilitating cheatgrass-dominated rangeland following wildfires may also be used following prescribed burning. Areas dominated by cheatgrass may be treated with atrazine or plowed and seeded to aid establishment of an adequate stand of perennial grasses (Eckert and Evans 1967; Eckert and others 1974).

Fire may be used to convert juniper-pinyon communities to a more desirable mixture of woody and herbaceous plants (fig. 3). Simply removing the trees does not ensure that the resulting vegetation mixture will be dominated by more desirable herbaceous and woody plants. Removing woody plants often results in increased cheatgrass densities. The vegetation resulting from disturbing western juniper woodlands may be considered as a greater environmental degradation than tree invasion if sustained forage production is used as the evaluation criteria (Young and others 1985). They discussed obstacles encountered in attempting to revegetate western juniper-dominated rangelands. The aerial standing crop of the trees often reaches 187 tons per acre (419 metric tons per ha). This represents a great sink of nutrients that are unavailable for plant growth and can become an impediment to seeding equipment. A flush of annual weeds usually occurs following tree removal, which may reduce establishment of seeded species. Some type of weed control is recommended following tree removal, with herbicides providing the most potential (Young and others 1985).

Big sagebrush-cheatgrass communities (fig. 7) can be successfully seeded following burning if the fire is hot enough to consume both sagebrush plants and cheatgrass seeds in the standing inflorescence (Young and others 1976b). Density and ground cover of cheatgrass may be drastically reduced the first year after fire but increase dramatically the second year. In one study there were less than 0.9 plants per ft^2 (10 plants per m^2) the first year after fire, nearly 740 plants per ft^2 (8,000 plants per m^2) the second year, and more than 1,490 plants per ft^2 (16,000 plants per m^2) the third year (Young and Evans 1978b). Ground cover of cheatgrass was about 2 percent the first year, 12 percent the second, and 14 percent the third year after burning.

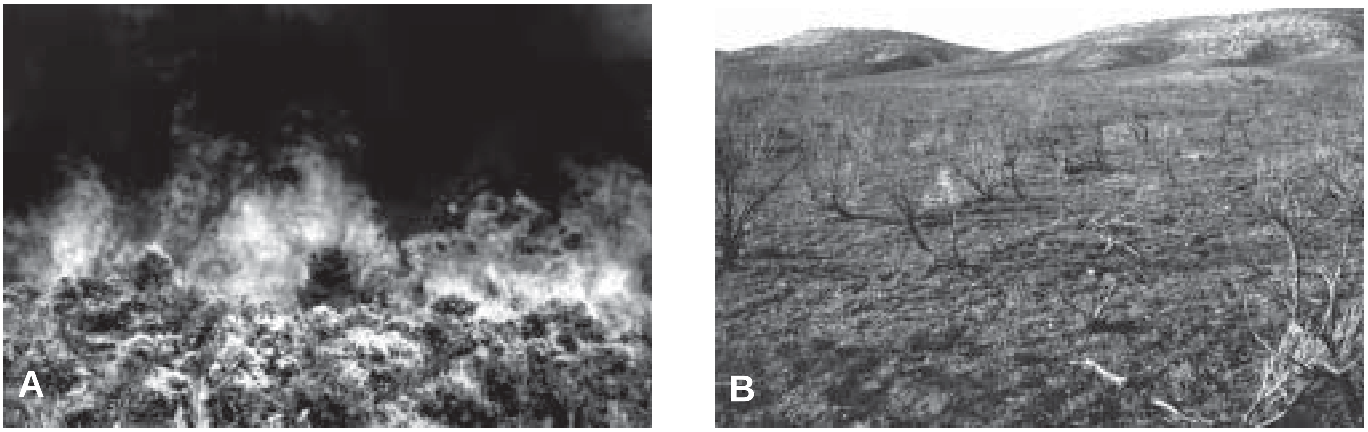


Figure 6—Fire in a big sagebrush-perennial grass-cheatgrass community (A) provided the established perennial grasses the opportunity to once again become dominant (B).

Figure 7—Big sagebrush community with sufficient understory to burn. Seeding of desirable perennial species should occur following the burn.

Much of the postburn area provides a nutrient-rich environment, allowing full expression of downy brome's growth potential (Young and Evans 1978b). Even though much of the cheatgrass seed is destroyed by fire, some survive and develop into large vigorous plants with many tillers and seeds produced per plant. Young and Evans (1978b) found cheatgrass seed production per plant in an unburned area varied from less than 10 to 250 per plant while in a burned area it varied from 960 to almost 6,000 per plant. They attributed this response to reduced intraspecific competition resulting, from lower plant density. Hassan and West (1986) found that even though fire reduced cheatgrass seed pools by half, the seed pool increased within 1 year to twice the level on unburned areas. If much cheatgrass seed remains, the area may be chemically fallowed (Eckert and Evans 1967), or the cheatgrass seedlings plowed prior to seeding perennial grasses.

After fire there is a dramatic reduction in diversity of annual plants. Wildfires are a major agent for increases in cheatgrass, which is well suited to postburn conditions because of its reproductive and competitive abilities (Evans and Young 1984). Rehabilitation of big sagebrush-cheatgrass rangeland following wildfires has resulted in the conversion of large areas from annual grass to perennial grass dominance (fig. 6). Wildfires in this vegetation type may be either extremely detrimental or beneficial, depending on rehabilitation efforts. The advantages obtained by burning must be realized during the first year following the fire.

An accumulation of plant litter on the soil surface is an important requirement for establishment of cheatgrass in the arid Intermountain area (Evans and Young 1970). Plant litter on the soil surface moderates the microenvironmental parameters of air temperature and available water in the surface soil. This creates a seedbed environment within the physiological requirements for cheatgrass seed germination and seedling growth. The microenvironment of a bare soil seedbed does not permit germination and establishment of cheatgrass in Nevada (Evans and Young 1970). However, there is some evidence, but little data, to indicate that plant litter on the soil surface is less critical for cheatgrass seedling success in more mesic regions of the Western United States.

Planning revegetation efforts requires that potential cheatgrass competition levels be predicted. Using a bioassay technique, Young and others (1976b), determined the density of viable cheatgrass seeds relative to postfire seedbed conditions. By determining the relative cover of ash and unburned organic matter after fire, an estimate of the potential cheatgrass reinfestation can be determined. Bioassays from the area to be rehabilitated may be conducted by placing samples of unburned organic matter and ash in small cups and covering with vermiculite (Young and others 1969a). Cheatgrass seedlings from the samples are counted for 8 weeks and calculated on a number per m^2 basis. As few as 4.0 seedlings per ft^2 (43 cheatgrass seedlings per m^2) moderately reduced establishment of crested wheatgrass seedlings and 64.0 seedlings per ft^2 (688 cheatgrass seedlings per m^2) prevented perennial grass seedling establishment in a greenhouse (Evans 1961).

Effects of Fire on Woody Plants

Management goals for sagebrush wildlands vary, but conservation of the basic natural resources, soil and vegetation, is usually one of the primary considerations. Blaisdell and others (1982) stated that in general, there is too much sagebrush and other low value shrubs, too many annuals, and not enough perennial grasses and forbs. Under these conditions, the most common vegetation management goal is to reduce sagebrush and increase perennial grasses and forbs.

Grazing management may be used to improve the vegetation if deterioration has not progressed too far. Unfortunately, the aggressive, long lived nature of sagebrush often requires some form of direct control followed by revegetation with perennial, herbaceous species to restore the area to a satisfactory condition (Blaisdell and others 1982). It is wise, however, to consider the desirable attributes of sagebrush, in proper amounts, when planning control measures. Sagebrush is a part of many native plant communities and has many benefits when not overly abundant. Regardless of the control measure used, proper grazing management should always be part of the long-term management plan.

Figure 8—Release of understory herbs and resprouting of aspen following prescribed burn.

Figure 9—Response of understory grasses and forbs following burning of lodgepole pine.

Forage that is unavailable to the browsing animal is of little value to them. Many woody plants obtain a height that places all the yearly leaf and shoot production out of reach of most browsing animals. Aspen and bitterbrush are just two of the plants capable of reaching that height. When plants resprout following top removal, the opportunity exists to increase forage availability with fire. Fire may stimulate suckering or resprouting of some species; placing the majority of annual browse production within reach of most animals. When aspen is clearcut, burned, or otherwise disturbed, resprout (sucker) density may be in the tens of thousands per acre (fig. 8) (Jones 1975). Maximum densities are reached the first year and begin to decline after that (Jones and Trujillo 1975). Forage production in aspen and conifer (fig. 9) communities is greatly increased following burning (Bartos and Mueggler 1979; Jones 1975).

Juniper and pinyon species have invaded many sagebrush/grass and grass communities during the past 80 years and have also increased their density over much of their range. The highly competitive nature of these trees has proven detrimental to some of the more desirable woody and herbaceous species. Several studies have attributed this increased density to overgrazing and reductions in fire frequency, which have enabled these fire intolerant species to increase both their range and density (Blackburn and Tueller 1970; Johnsen 1962).

In the sagebrush and juniper-pinyon communities the primary use of prescribed burning has been to reduce competition between the excessive woody plant cover and the more desirable plant species (fig. 10). Burning these communities often increases productivity, quality, and palatability of herbaceous plants and may have long lasting effects on the vegetative composition. Evans and Young (1978) stated that establishment of perennial grasses was an important factor in delaying the reinvasion of big sagebrush and low rabbitbrush.

Bitterbrush exhibits a less predictable response to fire. Several factors are undoubtedly responsible for this variability; not the least of which is the difference between wildfires, which often occur during the hottest period of the year, and prescribed fires that are often set during cooler weather. Wildfires usually occur during the summer, when carbohydrate reserves are low (Menke and Trlica 1981). Wildfires have reportedly destroyed bitterbrush on large areas (Hormay 1943) and "permanently eradicated" it on many sites in the Great Basin (Billings 1952). Bitterbrush resprouted frequently, but inversely with fire intensity following fires in eastern Idaho (Blaisdell 1950, 1953). Resprouting was limited following wildfires in Washington (Daubenmire 1970) and California (Nord 1965). Other research that included prescribed fires, concluded that burning in the spring was less

Figure 10—Increase of native grasses, forbs, and palatable shrubs following wildfire in a juniper-pinyon community.

damaging than burning at other times (Blaisdell and Mueggler 1956).

Genetic traits account for some of the variable response of bitterbrush to fire (Bunting and others 1985; Clark and others 1982; Giunta and others 1978). Decumbent forms resprout more frequently than erect forms of bitterbrush, particularly following spring burns (Bunting and others 1985; Clark and others 1982). Clark and others (1982) stated that bitterbrush does not sprout abundantly after fire. However, fire creates litter-free sites necessary for germination of rodent-cached seed (Sherman and Chilcote 1972). Bunting and others (1985) studied bitterbrush response, 3 to 10 years after burning, following both prescribed fires and wildfires at 56 locations in Idaho and Montana. They found seedling establishment rates were greatly influenced by soil water content; more mesic sites had higher bitterbrush establishment rates. Since most bitterbrush reproduction is from seed (Daubenmire and Daubenmire 1968; West 1968) rather than vegetatively, burning may enhance reproduction in a few situations (Clark and others 1982).

Use of Fire to Improve Wildlife Habitat

Leopold (1933) defined game management as "…the art of making land produce sustained annual crops of wild game for recreational use." Burger (1979) defined wildlife management as "…a blending of science and art, aimed at achieving sound human goals for wildlife resources by working with habitats, wildlife populations, and people." Others definitions exist, but like these, virtually all of them place some emphasis on managing the land as habitat. Management of habitats and wildlife populations are closely linked (Scotter 1980). Wildlife habitat is a constantly changing entity that cannot be preserved unchanged. It consists principally of vegetation, and as such is subject to change through succession.

Fire serves as a primary agent of successional setback in many communities. In moist environments, marginal burning conditions reduce fire frequency (Wright and Bailey 1982). A coincidence of fuel buildup, extreme burning conditions, and ignition eventually result in intense fires that may burn large areas. Even under these circumstances, there are areas within the fire's boundaries which, because of aspect, additional moisture, type or amount of vegetation, do not burn or burn incompletely. Along the edges of most fires there is mixing of burned and unburned areas. "Fingers" and pockets of unburned or incompletely burned habitat remain in and around the burned areas (fig. 11).

Figure 11—Fire can occur in pockets or fingers, thus increasing community diversity and edge areas.

Improved fire protection has contributed to the decreased quality of some wildlife habitat by aiding succession to plant communities with low capacities to support certain species of animals (particularly big game animals) (Scotter 1980). Prior to human's intervention, wildfires regularly burned large areas. Much of the postfire vegetation provided favorable forage for livestock and certain game species, especially deer and elk (Lyon 1966b). For example, in the Northern Region of the U.S. Forest Service, which includes portions of Idaho, Montana, and Wyoming, the area burned by wildfire declined from an annual average of 249,000 acres (101,000 ha) at the turn of the century to less than 4,942 acres (2,000 ha) in the early 1960's (Pengelly 1966). This resulted in an increase in the amount of mature forests at the expense of the grass or shrub subclimax vegetation. These succession patterns are common to much of Western North America, and have reduced the quality and extent of large herbivore habitat (Scotter 1980).

Prescribed burning is a promising tool for wildlife habitat improvement. It has been used to enhance habitat diversity, and to improve forage quality and quantity (fig. 1, 9, 10, 11) Severson and Medina (1983) stated "…prescribed burning can be used to improve or create wildlife habitat by creating diversity and edge and by improving the quantity and quality of food. Diversity and edge enhancement is generally accomplished by eliminating overstory vegetation, trees and shrubs, in prearranged patterns that create optimum cover/forage ratios. Benefits to food resources can be realized by eliminating undesirable plants, removing dense, rank, and/or overmature growth to stimulate crown or root sprouting, and increasing the nutritive value."

Fire, like any other management tool, is not a panacea. The misapplication of fire can have devastating effects on wildlife habitat (fig. 12). Understanding the

Figure 12—Misuse and uncontrolled use of fire can result in losses of critical wildlife habitat. This fire destroyed prime sage-grouse and mule deer habitat.

influence of fire on plant succession and the relationships between animal habitat requirements and plant succession will enable resource managers to make informed decisions.

Successional Relationships Between Plants and Animals

Many animals are associated with one or more of the successional stages or plant communities. Bailey (1984) classified animals into three categories that describe the relationships between their habitat requirements and plant succession. He considered animals as either climax-adapted (Class I), adapted to early successional stages (Class II), or adapted to a mixture of successional stages (Class III). By understanding these relationships the resource manager can often use fire to retard or set back succession to a vegetative type more compatible with management objectives.

Animals have different degrees of versatility in the number of plant communities and successional stages that they can use for feeding and reproduction. Populations of climax-adapted species (Class I) may be adversely affected by habitat disturbances, such as fire. Bailey (1984) listed the woodland caribou, spruce grouse, snowshoe hare, and pileated woodpecker as examples of climax-adapted species. These types of animals are poorly equipped to adapt to habitat changes and are best managed by protecting their habitat.

Class II species are typified by the bobwhite quail, cottontail rabbit, and Swainson's thrush (Bailey 1984). Periodic habitat disturbances, such as fire, maintain plant successional stages most favorable to Class II species.

Animals that can adapt to a mixture of successional stages (Class III species) are less affected by abrupt habitat changes. Bailey (1984) considered ruffed grouse, whitetailed deer, and mule deer to be good examples of Class III species; which may require disturbance or protection, depending on which habitat component is limiting.

Thomas (1979) developed a versatility index (V) that can be used to rate individual animal species, or all the species of an area. The V score for each species is derived by determining the total number of plant communities and the total number of successional stages to which the species shows primary orientation for feeding and reproduction: $V = (Cr + Sr) + (Cf + Sf)$ where V is the versatility score, Cr is the number of communities used by the species for reproduction, Sr is the number of successional stages used for reproduction, Cf is the number of communities used for feeding, and Sf is the number of stages used for feeding (Thomas 1979). The versatility index is a tool that allows wildlife habitat managers to estimate how many, and which wildlife species are likely to benefit or be harmed by prescribed fire in a specific area.

Wildlife habitats should be identified in such a way that they can be considered simultaneously with other land management activities. This can be accomplished by equating plant communities and successional stages with habitats for wildlife (Thomas 1979). Associating individual wildlife species or groups of species with plant communities and stages of plant succession allows the wildlife manager to translate range and forest inventories into wildlife habitat information (Whisenant 1986a).

Prescribed burning has been successfully used to increase willow abundance for moose habitat improvement. Geyer's willow is a subclimax species, highly preferred by moose, which is replaced by spruce through succession. Prescribed burning has been used in western Wyoming to prevent succession to spruce, and to stimulate willow regeneration (Weiss 1983). The resulting increase in amount of willow was followed by increased moose use of the burned areas.

Cover Requirements

Scotter (1980) asserted that habitat components such as type and amount of cover may be equally as important as quantity and quality of food.

The primary function of cover is to provide escape routes and hiding places from predators, in addition to shelter from weather (Black and others 1976; Severson and Medina 1983; Thomas 1979; Thomas and others 1976). Hiding cover provides the security that makes an animal's use of the area possible, and thermal cover helps the animal maintain body temperatures within tolerable limits.

Requirements for hiding cover vary throughout the year. Leopold (1933) listed five kinds of cover for birds: winter cover, refuge cover, loafing cover, nesting, and roosting cover. There is much overlap between these kinds of cover; one location may serve as adequate winter, refuge, and nesting or loafing cover. Rarely are cover requirements for a particular species completely understood. Careful consideration of these requirements with respect to the location and species in question will help to alleviate many of the potential problems.

For example, hiding cover for elk has been defined as the vegetation capable of hiding 90 percent of an elk from the view of a person at 200 ft (61.0 m) or less (Black and others 1976; Thomas 1979). The amount of vegetation required to do this varies between vegetation type and location. Elk use of cover is significantly reduced beyond 900 ft (274.3 m) from an opening (Reynolds 1966). Hiding cover that meets the requirements for elk will be more than adequate for deer (Black and others 1976).

For elk management, an optimum ratio of 40 percent cover to 60 percent foraging area has been recommended (Black and others 1976; Thomas 1979). This suggestion was based on how elk used cover and openings in relation to edges. The 60 percent forage area included all openings and forested areas that did not qualify as cover.

Thomas and others (1976) defined thermal cover for elk as a stand of coniferous trees in excess of 40 ft (12.2 m) tall with a canopy cover in excess of 75 percent. Multilayered vegetation provides better thermal cover than single layered vegetation. At least 30 acres (12.1 ha) are required for adequate shelter from the wind, and areas larger than 60 acres (24.2 ha) are not used efficiently. Others have suggested that elk thermal cover requirements are more variable. Consistently used elk thermal cover in south-central Wyoming summer ranges are less than 5 acres (2.0 ha) in size and only 150 ft (45.7 m) from openings (Ward 1976). Thermal cover for deer has been defined (on summer and spring fall range) as trees or shrubs, at least sapling size (Black and others 1976). Deer thermal cover has an optimum size of 2 to 5 acres (0.8 to 2.0 ha) with a minimum width of 300 ft (91.4 m). Unfortunately, research into deer and elk cover requirements have rarely considered winter ranges that undoubtedly must be very important (Severson and Medina 1983).

Pronghorn antelope are associated with open country, and little research attention has been given to their thermal cover requirements. However, pronghorns are reported to make use of wind velocity barriers such as creek and river banks, road fills and dikes, and the lee sides of sagebrush (Yoakum 1980). Pronghorns have also been observed taking summer shelter under isolated trees in otherwise open valleys. Until more detailed information is available, resource managers must make subjective judgements about the adequacy of pronghorn thermal cover.

Burning may alter an animal’s ability to enter an area. In forests, movements of large animals into an area may be reduced or eliminated if large numbers of fallen trees restrict movement.

Kelsall (1968) believed the tangle of dead trees on burned areas explained the observations of Banfield (1954) that barren ground caribou avoided burned forests. Gates (1968) showed that deer used burned and debris free areas more frequently than those that contained unburned logging slash. Research did not rule out the possibility that deer preferred the food on the burned areas. Where downed timber restricts movement of large ungulates into an area, the burning plan should attempt to increase animal access into as many new areas as possible or practical.

Another concept closely allied with cover is vegetation edges, which are the places where plant communities or successional stages come together (Thomas 1979). A discussion of the importance of areas of vegetation edge is aided by an understanding of two important concepts, dispersion and interspersion (Thomas 1979). The law of dispersion states “the potential density of game...requiring two or more types is, within ordinary limits, proportional to the sum of the type peripheries” (Leopold 1933). The law of interspersion states that “the number of species requiring two or more types of habitat depends on the degree of interspersion of numerous blocks of such types” (Severson and Medina 1983).

Small or patchy fires that create a mosaic of vegetation types and statures in previously homogenous vegetation are usually beneficial to most species. These types of fires not only increase the number of species present but often increase the number of individual animals. Biswell (1952) recommended small burns of 5 to 10 acres (2.0 to 4.0 ha) in a checkerboard pattern to open up dense chamise brushland for blacktailed deer, game birds, and small mammals in California. This type of burning program increased deer abundance, weight, weaning percentage, and wintering ability compared to deer from unburned areas or on large uniform burns. This improved deer performance was explained by enhanced nutritive value of plants growing in the openings.

Often it is not the quantity of the habitat components that determines animal numbers or health, but rather the degree of interspersion, or spatial relationship to other requirements (Dasmann 1964). It is the complexity of habitat requirements that leads to the recognition of the “edge effect.” More edge between particular types results in greater densities of animals associated with that edge. Increasing the interspersion of types will increase the edge requirements of various animals as well as the use of diversity indices to quantify the edge (Severson and Medina 1983; Thomas 1979; Yoakum and others 1980).

Food Requirements

Nutrient contents of plants often follow a predictable annual cycle. Nutritional values are highest early in the growing season, usually decline following flowering, and are lowest during dormant periods. Most herbivores thrive as long as they can consume the young tender shoots, leaves, and buds. Nutritional difficulties occur when they are forced to eat old, coarse vegetation.

Fire can be used to remove old litter and standing vegetation from an area. This often has the effect of improving diet quality of large herbivores by reducing consumption of old coarse growth and increasing consumption of young plant parts.

The concept of tolerance ranges for all environmental factors should always be considered in any habitat analysis and improvement scheme. Dasmann (1964) aptly stated the correct approach when he wrote “the game manager, in attempts to improve habitat, must continually search through the range of potential limiting factors seeking one that can practically and economically by remedied. Habitat research and management have sometimes been defined as attempts to discover limiting factors and then to remove each in turn until the maximum feasible production of wildlife is obtained.” Unfortunately, it is not always simple to determine what is limiting wildlife populations.

Riparian Considerations

Fire can have many impacts on stream habitats. Of primary importance are changes in soil erosion, water flow, nutrient loading, and water temperature. All of these commonly increase following a fire and may be detrimental to aquatic organisms. A reduction in streamside vegetation often results from burning and is a contributing factor to many of the detrimental impacts. Sediment input to streams may reduce the area suitable for spawning or smother fish eggs with fine materials (Cordone 1961). Increased water flow may damage eggs by increasing gravel movement (Lyon and others 1978). Removal of streamside vegetation often increases streambank erosion, reduces the available streamside habitat, and increases water temperatures. Increased water temperature increases oxygen demand and fish disease (Lyon and others 1978). Increased nutrient loading often occurs after a fire and may be beneficial by increasing stream productivity (Lyon and others 1978). Adverse stream-related impacts can be lessened by leaving a buffer of vegetation around streams.

Competitive Interactions Between Wildlife Species

Fire may alter the competitive interactions between animals; with the result of one species increasing at the expense of another. An interesting study of how fire can alter the competitive relationships between ungulates was conducted in Banff and Jasper National Parks of Alberta, Canada (Flook 1964). Before the fire, mule deer, moose, and bighorn sheep were relatively common, and elk were relatively uncommon. Each of these species lived in separate habitats and interactions were relatively rare. Widespread fires encouraged grassland and shrubland that benefited the elk. The elk moved into many new areas and competed vigorously with mule deer for food and cover and with bighorn sheep and moose for food. As a consequence of habitat changes brought on by fire, and competition from elk, moose, bighorn sheep, and mule deer declined in numbers (Flook 1964).

Evaluating the effects of fire or any other management practice, on multiple wildlife species becomes quite complex. Thomas (1979) devised a matrix type approach to analyzing potential impacts of management practices on all forest species in the Blue Mountains of Oregon. This required an understanding of the habitat requirements of the wildlife species, the requirements filled by the present vegetative community, and the requirements filled by the post burn vegetation.

Manipulating Wildlife Habitat With Fire

The first step in planning a habitat manipulation program must be to clarify the objectives. Is management for species diversity the overriding consideration? If so, the habitat should be developed for maximum diversity of communities, successional stages, and ages of plants. If a single animal species is to be given priority, then habitat manipulation should be planned with that species in mind, with less concern for requirements of other species. Are recreational and aesthetic considerations of overriding importance in the area? If so, the vegetation manipulation plan will require a much different approach. Often multiple use objectives require consideration of all species and uses. However, certain smaller areas may be selected as having the greatest potential for a particular use and can be managed primarily for that use. These are some of the questions that must be addressed early in the planning stages.

Severson and Medina (1983) stated that wildlife habitat managers have four facets of vegetation manipulation to consider when designing habitat modifications: (1) the amount of hiding and thermal cover necessary to fulfill the animals’ needs, (2) the amount of area needed for food production, (3) the optimum arrangement (interspersion) of various cover and food producing areas to realize, and (4) the optimum amount of edge. When considering these four facets of vegetative manipulation the habitat manager must seek to find the limiting factor(s) of the population(s) in question. Adequate information is seldom available on all the possible limiting factors. As a result, the habitat manager should acquire more information, or proceed by improving the quality of the “probable limiting factors” in the habitat. General reviews and discussions of habitat improvement techniques can be found in Thomas (1979), Yoakum and others 1980, and Severson and Medina (1983).

Successful habitat management must be based on a thorough understanding of the fact that the vegetation on a given site does not remain the same from year to year if left alone (Leopold 1933). Each successional change is characterized by a certain assemblage of plant species that have different kinds and amounts of cover and food. Succession can be hastened by planting climax species, protection from grazing, and fire. Even with this help, accelerating the pace of succession may be very slow. Succession can be rapidly set back through the use of prescribed burning (fig. 13). The challenge to the habitat manager is to ensure that this change in plant succession is consistent with management objectives.

Several kinds of changes in the plant community are possible and should be considered in a habitat manipulation program. Fire can be used to change plant abundance, availability, dispersion, nutritive value, and species composition. Community dispersion, interspersion, and edge can also be altered with fire. Judicious use of fire can often produce the desired mix of these attributes in a plant community (fig. 14).

Figure 13—Selective spot burning in a mixed spruce and aspen community. Prescribed burning was used to set back succession on a prime elk summering area.

Figure 14—Juniper-pinyon being selectively burned for the benefit of Rocky Mountain bighorn sheep. (A) Area in foreground is a 3-year-old burn, and (B) Bighorn sheep on a 3-year-old juniper-pinyon burn.

Selectivity is required to produce the desired plant community with prescribed burning. Three types of selectivity can be used to effect the desired changes in plant communities: (1) selectivity of fire intensity, (2) species selectivity, and (3) area selectivity. Of these three types of selectivity, fire intensity is of overriding importance; understanding each is necessary to realize the potential of fire in habitat manipulation.

Fire intensity (described by fireline intensity) is the amount of heat released per unit of time per length of fire front. Fire severity incorporates both upward and downward heat fluxes and is an expression of the effect of fire on the ecosystem (Brown 1985a). It relates plant mortality to the extent of organic matter loss. Selectivity of fire intensity is obtained by selecting the proper mix of environmental conditions to achieve the fire intensity necessary to effect the desired change in the habitat. Burning under relatively cool, humid conditions results in fire with reduced severity that may not consume the ground litter. Conversely, burning under hot, dry, and windy conditions results in a more severe fire capable of removing vegetation and organic matter to the mineral soil. The differences between these two kinds of fires have profound influences on the resulting vegetation.

Postfire aspen sucker density is influenced by fire intensity and fire severity (Brown 1985a). Aspen sucker response to three levels of fire severity have been described by Brown (1985a) based on studies by Horton and Hopkins (1965) and Bartos and Mueggler (1981):

1. Low fire intensity and low ground char results in partial mortality of vegetation. Less than 50 to 60 percent of aspen trees are top-killed, and litter and upper part of soil duff is consumed. Suckering response is patchy and sparse.
2. Moderate to high fire intensity with moderate ground char top-kills nearly all of the aspen. Some patches of soil duff and charred material remain. Suckering is prolific.
3. Moderate to high fire intensity with high ground char top-kills nearly all of the aspen. Forest floor is reduced to ash and exposed mineral soil. Substantial suckering results.

Species selectivity is the ability to change the plant species composition of an area to meet the desired management objectives. Fire intensity, life form, and phenology all influence the differential mortality or stimulation of plants following fire. Plant species response to fire differs because of phenological variations at the time of burning, inherent susceptibilities to heat damage, regenerative abilities, and responses to the postfire environment. Individual plants may have different responses to fire because of local variations in fire temperature or microenvironment. The postfire assemblage of plants may have few species changes, as is often the case after grassland fires, or may be dramatically different in both species composition and structure, which occurs following some forest fires.

The precise path of plant succession, or the results of fire on a certain community depends on many interacting factors and may, therefore, be difficult to predict. It is the plant community, and the successional stages of it, that are of primary concern to the wildlife habitat manager and should be understood prior to any prescribed burning operation. Fortunately, there is sufficient information available on fire effects in many communities to allow several generalizations.

Each step in succession may last only a few months or as long as several centuries. Succession can be hastened by planting climax species, protection from abusive grazing, and from fire. The process of succession from one vegetation type to another can be very slow, even with helpful management. Succession can be set back by many kinds of disturbances; the most common of which are overgrazing by domestic livestock, cutting vegetation for hay or timber, plowing the soil, and burning.

Grasslands are usually well adapted to recurring fire regimes and are not drastically changed by fire. An increase in forbs is a common occurrence. Early successional animals such as bobwhite quail are often favored by these changes (Leopold 1933; Stoddard 1931). Woody plants vary considerably in their response to fire. Communities of woody plants without the ability to resprout following top removal, such as big sagebrush and Utah juniper, are often destroyed by fire. In contrast, communities with aggressive resprouters such as mesquite, willow, aspen, or Gambel oak retain similar species compositions but the aboveground portions of the communities may be drastically reduced in height while the stem density increases.

Area selectivity is the ability to burn certain areas, or a percentage of an area. This is a critical factor in determining the amount of dispersion, interspersion, and edge in the post-burn community. Area selectivity can be obtained by burning a series of small areas (fig. 14) or by burning at a time and place where the fire will not burn continuously.

Burning Techniques

Firebreak Considerations

Adequate firebreak construction is essential to the development of a successful prescribed burn. Firebreaks may consist of any area, whether natural or human-made, which successfully contains the fire under consideration. Natural firebreaks may be rivers, rock bluffs (fig. 15), or areas with insufficient vegetation to carry the fire. Human-made firebreaks may be roads (fig. 16), plowed fields, or areas constructed specifically to stop a prescribed fire.

Natural firebreaks provide a significant cost advantage when available, but specially developed firebreaks are routinely used in prescribed burning. These usually consist of a combination of mechanically removing vegetation down to the mineral soil for a width

Figure 15—Use of a river and rocky hillside as natural fire breaks in a prescribed burn.

Figure 16—Human-made firebreak in a juniper-pinyon prescribed burn.

of 8 to 12 ft (2.4 to 3.7 m) and burning the vegetation in a strip around the area to be burned. Burning firebreaks usually occur under relatively mild conditions. Depending on the situation, this may mean burning the firebreak several months in advance or preparing the firebreak the morning of the main fire.

Burning in grassland fuels usually requires only a 100 ft (30.5 m) firebreak (fig. 17). However, burning in shrubby vegetation, particularly where the shrubs contain volatile oils, requires a much wider firebreak (fig. 18). The following burning prescriptions include suggested fireline widths, however, there is no substitute for experience and careful consideration of the unique features of each individual burning situation. For detailed information on fireline preparation, firing techniques, and the application of prescribed burning, refer to the excellent reviews on those subjects (Emrick and Adams 1977; Fischer 1978; Martin and Dell 1978; Mobley and others 1978; Schroeder and Buck 1970; Wright 1974; Wright and Bailey 1982).

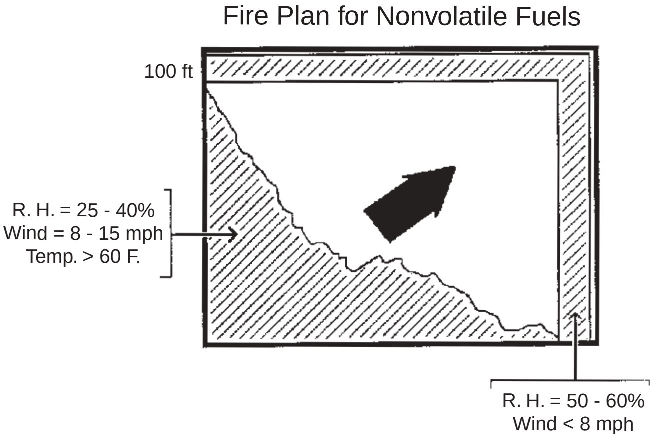


Figure 17—Fire plan for nonvolatile fuels.

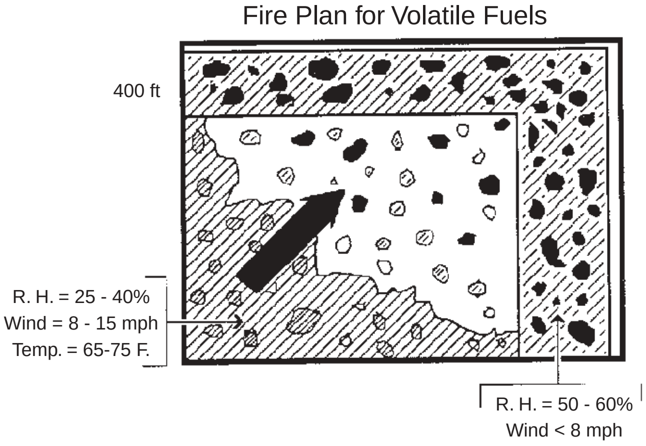


Figure 18—Fire plan for volatile fuels.

Sagebrush Communities

Larger sagebrush types (fig. 12) often provide fuel sufficient to carry a fire. Sites dominated by dwarf species seldom support enough fuel to carry a fire.

Big Sagebrush-Grass

According to Beardall and Sylvester (1976), a minimum of 600 to 700 lb per acre (673 to 785 kg per ha) of herbaceous fuel is required to burn sagebrush grass communities. Where the fire is to be carried with herbaceous fuels, livestock grazing should be restricted during the growing season prior to the burn. This should help provide adequate fuel to carry the fire. Pechanec and Stewart (1944) determined that 20 percent cover should be the minimum amount of sagebrush to consider burning. Wright and others (1979) recommended early spring or late summer burning, when soil moisture is usually present down to 12 to 19 inches (30.5 to 48.3 cm). Soil moisture is less critical when burning in the fall.

The following instructions for burning sagebrush-grass range were suggested by Wright and others (1979) and Wright and Bailey (1982):

1. Prepare a fireline of 10 to 12 ft (3.0 to 3.7 m) width around the entire area to be burned. This fireline should expose the mineral soil.
2. Burn a 250 ft (76.2 m) blackline on the downwind side, when weather conditions are mild. Air temperature should be 60 to 70 °F (15.6 to 21.1 °C), relative humidity 25 to 40 percent, and windspeed 6 to 10 mi per h (9.7 to 16.0 km per h). These environmental conditions are most common in the early morning hours during the summer.
3. Burn the remaining area in the afternoon as air temperature reaches the maximum and relative humidity approaches its minimum. Recommended

environmental conditions are air temperature of 75 to 80 °F (23.9 to 26.7 °C), relative humidity 15 to 20 percent, and windspeed 8 to 15 mi per h (12.9 to 23.9 km per h).

Dense Stands of Big Sagebrush

Dense stands of big sagebrush surrounded by low sagebrush may be burned during hot, dry, windy days with no firelines (Beardall and Sylvester 1976). They suggested burning these areas in early spring when relative humidity is below 60 percent, windspeed is above 8 mi per h (12.9 km per h), and when there is more than 600 to 700 lb per acre (673 to 785 kg per ha) of fine fuel.

A technique for burning very dense stands of big sagebrush that does not require fireline preparation was developed by Neuenschwander (1980). This technique involves winter burning, with snow present, and is restricted to areas with greater than 50 percent sagebrush cover and a distance between plants of less than 50 percent of the average sagebrush height. With those restrictions, fire carried through sagebrush canopies when effective windspeed was above 5 mi per h (8.0 km per h) and the winter ignition index was greater than 29. The winter ignition index is determined using the following equation:

$$Y_1 = 96.64 - 91.20\ (X_1) - 1.1\ (X_2)$$

$$r^2 = 0.811$$

Where Y_1 = ignition index
X_1 = fine fuel moisture content of canopy (percent)
X_2 = relative humidity (percent)
and $Y_1 > 0+$

Under those conditions, only small areas burned. Winter sagebrush burning might be impractical in most areas because of stand limitations and the relatively few days with proper burning conditions (Neuenschwander 1980). However, where feasible, winter broadcast burning is inexpensive, and completely safe when snow is present. It requires no fireline construction or fire crews and can be used to create vegetation mosaics beneficial to both wildlife and livestock.

Cheatgrass Communities

Burning cheatgrass ranges is relatively easy if a continuous cover of dry cheatgrass is present. The critical aspect in burning this community is postfire management. Establishment of perennial grass species is very important. Fireline construction can easily be done with the wetline technique described by Martin and others (1977). Fires can be backed away from a single wetline or allowed to burn between two wetlines. Martin and others (1982) suggested the following prescription for burning cheatgrass ranges: (1) burn after grasses have dried out and when soil surface litter is dry enough for the fire to consume cheatgrass seeds in the soil surface litter, (2) use backfires to create a blackline of 30 to 100 ft (9.1 to 30.5 m) on the downwind sides, and (3) burn with headfire when air temperature is 56 to 84 °F (13.3 to 28.9 °C), relative humidity is 20 to 45 percent, and windspeed is 0 to 10 mi per h (0 to 16.1 km per h).

Juniper-Pinyon

Prescribed burning in the juniper-pinyon zone (fig. 3, 11, and 14) is primarily used to reduce tree and shrub cover, allowing recovery of herbaceous species, or as a site preparation procedure for seeding efforts. The following guidelines are useful in planning and conducting prescribed fires in juniper-pinyon types.

Closed Stands of Juniper and Pinyon—Stands of juniper and pinyon with little or no herbaceous plants are difficult to burn. The areas become more difficult to burn as the percentage of juniper increases and pinyon decreases. With large fire lines, stands with over 300 trees per acre (741 or more per hectare) can be burned on hot, windy days (Blackburn and Bruner 1975; Truesdell 1969). These areas may require winds in excess of 35 mi per h (56.4 km per h) to carry a fire. The hazards of an escaped fire prevent most resource managers from burning under these conditions. However, in unusual situations where excellent natural fire breaks were present, prescribed fires have been successfully conducted under those conditions (Truesdell 1969). The following prescription is recommended (Wright and Bailey 1982) for burning closed stands of juniper-pinyon: (1) prepare a 10 ft (3.0 m) fire line around the area to be burned. On the downwind side, 500 ft (152.4 m) in from the outside boundary, construct a similar fireline parallel to the first. The downwind strips can be chained and windrowed; (2) windrows are to be burned in early spring or summer when vegetation of adjacent areas is still green. This burning should occur with an air temperature of 60 to 75 °F (15.6 to 23.9 °C), relative humidity of 20 to 35 percent, and windspeed of 0 to 10 mi per h (0 to 16.1 km per h); (3) the main burn area is prepared in the spring by dozing strips 20 to 50 ft (6.1 to 15.2 m) wide every 0.25 mi (0.4 km) and pushing the debris against the windward side of the standing trees. These fuels should be allowed to cure for 2 to 3 months; and (4) conduct the main burn in the summer with an air temperature of 80 to 95 °F (26.7 to 35.0 °C), relative humidity less than 10 percent, and windspeed greater than 8 mi per h (12.9 km per h). The fire intensity is built up in the windrows and carries through the adjacent standing trees.

Davis (1976) suggested chaining as an alternative method of preparing firelines in closed juniper-pinyon stands. The firelines would be chained in the winter, and in the spring when adjacent unchained areas had moderate conditions and green vegetation, the chained areas would be burned. Bryant and others (1983) stated that recently chained or dozed juniper (less than 100 days) can be safely burned if herbaceous fuel is less than 445 lb per acre (499 kg per ha), windspeed is less than 6 mi per h (9.7 km per h), relative humidity is above 45 percent, and air temperature is less than 86 °F (30.0 °C). The best fireline width is not known, but Wright and others (1979) suggested 300 ft (91.4 m) if little fine fuel is present in the surrounding area.

Pure stands of juniper are difficult to burn without a pretreatment that increases flammability or continuity. These areas require firelines and hot, dry, windy conditions. The distance between windrows may need to be reduced to only 250 ft (76.2 m). The difficulty in broadcast burning these areas may require large fire crews to ignite the scattered piles and windrows. Flammability may be increased by mechanical treatments or possibly with herbicide treatments on the area, or parts of the area, to be burned. The fuel continuity may be increased by one-way chaining the area with a relatively light chain. This treatment uproots very few trees but moves them to a fairly horizontal posture. This greatly reduces or eliminates the distance between trees and enables the fire to spread much easier.

More recent research into techniques of burning mature Ashe juniper in Texas with crown fires has added more information and suggestions (Bryant and others 1983). They studied the effect of dozed and windrowed juniper as an aid to igniting adjacent standing trees. Dozed trees left where they fell were ineffective in igniting a crown fire in the adjacent standing trees. Windrowed plots produced the best result for igniting the adjacent crowns when canopy cover exceeded 35 percent; windspeed exceeded 10 mi per h (16.1 km per h); air temperature was 73 to 91 °F (22.8 to 32.8 °C); relative humidity was 20 to 35 percent; and juniper leaf water content was 58 to 60 percent. Crown fires stopped when the distance between juniper trees exceeded 26 ft (7.9 m). Burning into less dense areas and using livestock to reduce fine fuel loads of fire lines was also effective (Bryant and others 1983). This method is limited to times and places with high winds, hot temperatures, and dense juniper stands, and has not been tested on juniper-pinyon communities of the Intermountain area. Nevertheless, it should be of considerable importance when it can be used.

Open Stands of Juniper-Pinyon With Grass Understory—In these communities, the fine fuel is used to carry fire from tree to tree (fig. 4). This requires 600 to 700 lb per acre (673 to 785 kg per ha) of fine fuel if it is uniformly distributed (Wright and others 1979). This method is restricted to areas with small trees (fig. 3). Trees larger than 4 ft (1.2 m) will rarely be killed unless the fine fuel load is sufficient to ignite the tree canopies.

Prescriptions for burning open juniper-pinyon stands containing a grass understory are similar to those for grasslands. However, additional precautions should be taken to reduce the potential for spotting. Information from Jameson (1962) and Dwyer and Peiper (1967) was used to prepare the following prescriptions: (1) prepare a 10 to 12 ft (3.0 to 3.7 m) wide fireline around the area to be burned. Use strip headfires to prepare a 100 ft (30.5 m) blackline on the downwind sides (Wright and others 1979). This is best done in the morning or early evening during spring and (2) ignite main fire with an air temperature of 70 to 74 °F (21.1 to 23.3 °C), relative humidity of 20 to 40 percent, and a windspeed of 10 to 20 mi per h (16.1 to 32.2 km per h) (Dwyer and Pieper 1967; Jameson 1962).

Martin (1978) studied western juniper mortality following fire under four sets of environmental conditions. All the sites studied had sufficient herbaceous fuel or sagebrush cover to carry the fire through the juniper stands. He subsequently suggested the following prescription for burning: (1) prepare a 200 ft (61.0 m) fireline on the downwind side of the area to be burned. Use backfires and short strip headfires to burn the fireline and (2) ignite the main headfire with an air temperature of 65 to 80 °F (18.3 to 27.8 °C), relative humidity of 17 to 23 percent, and a windspeed of 5 to 12 mi per h (8.0 to 19.3 km per h).

Mixed Juniper-Pinyon—Bruner and Klebenow (1979) reported a prescription for burning dense, mixed Utah juniper single leaf pinyon stands in Nevada without the use of firelines. They developed a simple index to aid in determining where and when these burns should be attempted. This index consists of total tree and shrub cover, air temperature, and maximum windspeed. The index is as follows:

INDEX = tree and shrub cover (percent)
+ air temperature (°F)
+ maximum windspeed (mi per h)

where, shrub and tree cover = 45 to 60 percent, air temperature = 60 to 75 °F (15.6 to 23.9 °C), windspeed = 5 to 25 mi per h (8.0 to 40.2 km per h), and relative humidity is less than 25 percent. The index must equal or exceed 110 for a fire to carry and kill large pinyon and juniper trees. At values less than 125, reignition may be necessary; above 130, conditions are too hazardous to burn.

This method is safe, economical, and useful for the areas in which it was designed. This prescription was developed on a series of fires that carried upslope into ravines. Ignition was aided by the upslope, thick stand of juniper-pinyon, and the high percentage of pinyon (greater than 90 percent) in the vegetation. Firelines were not required because of the sparse vegetation outside of the ravines. Most of the burns were small, ranging from 5 to 60 acres (2.0 to 24.3 ha).

Aspen

Aspen forests have generally been considered difficult to burn (fig. 1, 8, and 13). Fuel loads and flammabilities of these communities vary greatly. Careful selection of locations where fuels are sufficiently flammable to offer a high probability of success is critical in aspen communities. Fortunately, some quantitative guidelines have been developed for burning in aspen communities. Brown (1985a) states that at least 80 percent aspen top kill was necessary to achieve effective suckering following burning. He also stated that flame lengths averaging 1.3 ft (0.4 m) were a minimum flame size for sustained spread and for consistent aspen top kill.

Flammability of aspen and aspen-conifer communities varies with leaf litter abundance, downed woody material, herbaceous vegetation (table 3), shrubs, conifer reproduction, slope, grazing intensity, fuel water content, crown closure, and pocket gopher activity (Brown 1985a). Aspen communities can be separated into five fuel classes (table 4) with respect to potential for prescribed burning (Brown 1985a).

Table 3—Vegetation classification of aspen fuels and flammability[a].

	Vegetation and fuel characteristics			
Characteristics	**Aspen shrub**	**Aspen tall forb**	**Aspen low forb**	**Mixed shrub**
Overstory species occupying 50 percent or more of canopy	Aspen	Aspen	Aspen	Conifers
Shrub coverage (percent)	>30	<30	<30	>30
Indicator species for community type	*Prunus*	*Bromus*	*Ranunculus*	*Prunus*
	Amelanchier	*Heracleum*	*Mahonia*	*Shepherdia*
	Shepherdia	*Ligusticum*	*Arnica*	*Spiraea*
	Symphoricarpos	*Spiraea*	*Astragalus*	*Amelanchier*
	Artemisia	*Calamagrostis*	*Thalictrum*	*Symphoricarpos*
	Juniperus	*Rudbeckia*	*Geranium*	
	Pachistima	*Wyethia*	*Poa*	

[a] Adapted from Brown (1985a).

Table 4—Probabilities of successfully applying prescribed fire in aspen forests according to vegetation fuel classes and the influence of grazing and quantities of downed woody material[a].

	Vegetation, fuel class				
Condition	**Aspen shrub**	**Aspen tall forb**	**Aspen low forb**	**Mixed shrub**	**Mixed forb**
Ungrazed, light downed wood	Good	Fair	Poor	Good	Fair
Ungrazed, heavy downed wood	Good	Fair	Poor	Good	Good
Grazed, light downed wood	Fair	Poor	Poor	Fair	Fair
Grazed, heavy downed wood	Good	Poor	Poor	Good	Fair

[a] Adapted from Brown (1985a).

The probability of successful burning of the aspen and aspen-conifer communities can be better predicted when grazing and the amount of woody fuel are considered. Using the probability of successful burning information (table 4) developed by Brown (1985a) allows concentration on sites with the greatest likelihood of success. These probabilities can be greatly modified by factors such as aspect, slope, fuel continuity, and fuel water content.

Once a potential site is selected, fuel water content should be carefully considered. The best indirect indicator of live fuel water content is time of year (Brown 1985a). In most aspen communities, the snowpacks do not completely melt until the spring greenup. Summers are usually dry in the Rocky Mountain aspen region, and fuels dry through late summer and fall (DeByle 1985b). As fall approaches, the probability of a major precipitation event increases (DeByle 1985b). The most reliable time to burn aspen communities is often after live vegetation is cured, and prior to fall precipitation.

Live Aspen—Burning live aspen forests usually requires relative humidity below 35 percent. Wright and Bailey (1982) stated that acceptable burning conditions and a proven prescription for aspen parklands in Alberta are: (1) relative humidity of 15 to 30 percent; temperature 65 to 80 °F (18.3 to 26.7 °C); 4 to 15 mi per h (6.4 to 24.1 km per h) windspeed; at least 14 days since the snow melted in adjacent grassland or 3 drying days since the last rain; and a surface duff water content of less than 20 percent; (2) prepare a 500 ft (152.4 m) fireline on the leeside and a 100 ft (30.5 m) fireline on the remaining sides; and (3) strip headfires are the best ignition method. When burning in aspen parklands, where groves of trees are surrounded by grassland, the grassland can be burned to provide a fireline for the aspen fire.

Dead Aspen—Aspen forests can be killed with an herbicide and burned 2 years later under fairly moderate conditions (Wright and Bailey 1982). Under these conditions, burning should not occur when relative humidity is less than 35 percent because the dead aspen bark becomes a dangerous firebrand. Wright and Bailey (1982) recommended the following prescription for burning dead aspen forests: (1) relative humidity of 35 to 50 percent; temperature 40 to 75 °F (4.4 to 23.9 °C); 2 to 12 mi per h (3.2 to 19.3 km per h) windspeed; at least 10 days since the snow melted or three drying days since the last rain; and a surface duff water content of less than 20 percent; (2) prepare a 400 ft (121.9 m) fireline on the leeside and a 100 ft (30.5 m) fireline on the remaining sides; and (3) strip headfires are the best ignition method if a person can walk around the perimeter of aspen groves. In a continuous forest, perimeter firing is recommended because strip headfiring is too dangerous in a dead forest.

When a dead aspen forest is totally surrounded by live aspen forest, a 1 m (3.3 m) fireline can be constructed around the perimeter of the dead forest. Relative humidity should be 40 to 50 percent (Wright and Bailey 1982). More detailed information on prescribed burning of aspen communities can be found in Brown (1985a).

Management After Burning

The success of any wildland rehabilitation project is largely determined by postfire management (Young and others 1985). Judicious application of management practices based on the unique attributes of the resource with consideration for additional concerns created by burning are the key to successful wildland rehabilitation. The recommendations made by Pechanec and Stewart in 1944 are still appropriate for managing western rangeland after burning. They stated: (1) protection of burned areas from trailing by livestock during the first fall at least; (2) protection of burned areas from grazing for one full year; (3) light grazing for the second year, and thereafter no heavier than the range can support permanently; (4) the same grazing management for burned and reseeded areas as for areas not in need of reseeding; (5) for areas with more than half the understory in cheatgrass, special protection against recurrent accidental fires; and (6) for accidentally burned areas, at least as good management after burning as that demanded for the best results from planned burning.

Stephen B. Monsen
Richard Stevens

Chapter 12

Seedbed Preparation and Seeding Practices

Selection and Use of Adapted Species

Selection and use of seeds of different species must be carefully considered in range and wildland improvement projects. The selection of species to be planted in any restoration program usually takes place after the decision has been made to restore or rehabilitate an area, and the objectives of the project have been determined. However, availability of seed and planting stock can delay and alter seeding programs. Seeding and planting involves an introduction of seeds and plants to a site that alters existing plant communities and influences successional processes. Most seeding projects are conducted only once, and the plant communities that ultimately develop are dependent upon the initial success of the plantings. In contrast to natural seedings that normally produce only a few new seedlings each year and may or may not alter plant composition, artificial seedings, if successful, create a dramatic and immediate change in community composition.

Figure 1—Planting adapted and compatible species in mixtures is essential in any restoration project.

Successful site improvement projects are based on the selection of adapted plant materials (Stevens 1981). There is no substitute (manipulation, management) for proper species selection (fig. 1). The factor that most often leads to project failure is the use of unadapted species. Seeded species must be able to establish and maintain themselves, whether growing alone or in mixtures with native or introduced species, often under various management systems. Some primary factors that influence species establishment are: (1) germination attributes, (2) initial establishment traits, (3) growth rates, (4) compatibility, (5) seedling tolerances, (6) persistence, and (7) grazing impacts. These and other characteristics are ranked by species in tables found in chapter 18. Some species are very site specific, whereas many others have a wide range of adaptation (Ferguson 1983; Hassell and others 1983). Following proper selection, seeds and plants must be planted using techniques and practices that provide them every possible advantage to establish. New plantings should be protected to insure perpetuation of the developing community.

Guides to Species and Ecotype Selection

Numerous factors can be used to identify species that are adapted to a planting site. Native species are normally reintroduced in many plantings. If native species have been eliminated and sites are infested with weeds, it may be difficult to determine the most adapted species to seed. If seedings are designed to alter or change the composition of the existing plant communities, the selection process can become more complex. Following are a number of guides that can be used in selecting adapted species.

Species Compatibility and Planting Objectives

Introduced grasses, including crested wheatgrass, pubescent wheatgrass, intermediate wheatgrass, smooth brome, orchardgrass, Kentucky bluegrass, and Russian wildrye, have been able to withstand adverse climatic conditions, fires, and severe grazing, and yet provide excellent forage (Cook 1966; Plummer and others 1968; Ross and others 1966). Plantings of crested wheatgrass have remained productive for over 45 years on foothill ranges in Utah (Vallentine 1989). Hard fescue, pubescent wheatgrass, and timothy are also adapted to many sites. The excellent survival, forage attributes, and ground cover values of these and other introductions have prompted their use.

This universal use of introduced perennial grasses for most range, watershed, and wildland seedings has created some serious problems (Bentley 1967). The establishment and persistence attributes of many introduced grasses have resulted in the elimination and decrease of desirable native species. Crested wheatgrass and pubescent wheatgrass formed almost closed communities 6 years after seeding on Utah foothill ranges (Cook 1966). Intermediate wheatgrass establishes more slowly, but is able to restrict growth of oakbrush and maintain nearly complete dominance of the understory (Plummer and Stewart 1944; Plummer and others 1968). Smooth brome slowly increases in dominance, and forms nearly a complete sod on many ranges, restricting native grasses and broadleaf herbs. Plantings of crested wheatgrass have slowly gained dominance in many pinyon-juniper seedings, restricting the recovery of natives (Davis 1987; Stevens 1987b; Walker and others 1995). Monsen and Shaw (1983c) reported that both intermediate and crested wheatgrass seeded as an understory with antelope bitterbrush prevented natural recruitment of shrub seedlings.

Davis (1987) found no negative seedling establishment interactions when crested, intermediate and tall wheatgrasses, smooth brome, orchardgrass, Russian wildrye, sainfoin, hard fescue, cicer milkvetch, alfalfa, yellow sweetclover, and small burnet were seeded together on a pinyon-juniper site in Utah. This study indicates these species, all introductions, are adapted to similar environments and are compatible as seedlings. However, Stevens (1987b), and Walker and others (1994), reported that where similar species were seeded on a central Utah pinyon-juniper site the cover of native perennial grasses decreased from 50 percent to about 30 percent as the introduced species attained maturity.

Incompatibility of introduced perennial grasses with native species, particularly shrubs and broadleaf herbs, reduces the desirability of seeding these grasses as a principal portion of a seed mixture if restoration of native communities is a goal. Where shrubs and other natives are desired, the use of introductions must be carefully regulated. Although introductions have excellent traits, they should be used for special situations. Studies currently in progress indicate that seeding introduced grasses at low rates may enhance the recovery and presence of native species (Davis 1987). Most long-term ecological studies, however, indicate that many introductions slowly gain dominance, and low seeding rates simply tend to delay the process.

Various introduced grasses are currently the most useful species for controlling weeds that infest and occupy extensive rangelands (Plummer and others 1970b; Vallentine 1989; Young and others 1984c). Introduced perennial grasses are considered better able to control cheatgrass, medusahead, halogeton, and many summer annual weeds than releases or wildland collections of most native species currently being planted. Native species and undisturbed communities can control weeds, but various introductions have been most successful when seeded on weed infested sites. Until the problems associated with weeds can be better addressed, and the availability of adapted native plant materials increases, the use of some introduced grasses will probably be relied upon.

Few native species have been developed for seeding most western rangelands, particularly the arid regions occupied by salt desert shrub communities. Consequently, introduced grasses have dominated the seed mixtures of many range and wildland rehabilitation programs. Many important shrublands and herblands have been converted to introduced grass-dominated communities. Some seedings have been justified because of the lack of native seed (McKell 1975), and problems associated with the establishment of natives (Vallentine 1989). In many situations these problems have been corrected. The use of appropriate native species can be attained through better planning, buying, and stockpiling of seeds.

Species that are seeded together must be compatible as young, developing plants or certain individuals will succeed and others will fail (Samuel and DePuit 1987). The amount of seed sown will affect the degree of competition, and the number and composition of seedlings that survive. Seedlings of some native broadleaf herbs and shrubs are less aggressive and succumb to competition from more rapidly developing species (Hubbard 1957; Stevens and others 1985c). Not all native species are slow growing, and many can be used as rapidly developing plants. Seeding heavy rates of the slower developing species will not offset losses from competition. Seeding slower growing species in rows separate from fast-growing herbs will result in the most favorable stands.

Drill seeding causes species in a mixture to be placed in potentially competitive situations. Seeds in a mixture that are broadcast planted are not placed in as close contact with each other as occurs with drilling, and are usually less likely to succumb to competition.

The species used must also be compatible with each other and with existing species that occur on the planting site. Few plantings are conducted on areas void of other plants. It is important to recognize that existing species can help as well as suppress new seedlings. In many situations, the presence of overstory plants improves seedbed conditions, entraps soil moisture, and protects seedlings from frost (fig. 2). Existing stands of Gambel oak, quaking aspen, antelope bitterbrush, and numerous other species enhance the establishment of understory seeded species unless the density of the overstory is excessive.

Many species improve soil fertility by fixation of nitrogen, and other species benefit by this association. Both legumes and nonleguminous species are able to increase soil nitrogen, and can be used to improve vigor and growth of associated plants. In some situations, various nonnitrogen-fixing species appear to enhance the growth of associated plants. Plants of Utah sweetvetch and Sandberg bluegrass are often seeded with other species because they appear to improve stand density of associated species.

Seeding a compatible mixture is often necessary to moderate seedbed conditions, and aid in the establishment of species that otherwise may not be able to establish alone. Many large, expansive burns in semiarid ranges are subjected to winds that dry the seedbed and remove snowcover. Big sagebrush and other small-seeded species do not establish very well on dry, barren surfaces. To establish these species, it is often necessary to establish a cover or nurse crop.

Figure 2—The presence of overstory plants can improve the establishment of seedlings.

Plant Community Indicators

Most areas selected for restoration or rehabilitation have been seriously altered, and usually support only remnant numbers of native species (fig. 3). Weeds have often invaded, and dominate the areas. Less disturbed and comparable areas usually exist nearby and can be inventoried to determine the original composition of the native communities. Remnant plants are important indices to use in determining the native vegetation. Considerable information is available to assist in classification of seral status, habitat types, and disturbed areas (Blaisdell and others 1982; Daubenmire 1970; Franklin and Dyrness 1969; Hironaka and others 1979).

The presence of remnant native species can be used to identify the major plant associations that once were present. The occurrence of less abundant species cannot always be determined by the presence of one or two remnant species, but the principal plant associations can be identified. Major plant communities that occur in the Intermountain Region are described in chapter 2. Species adapted to these communities are listed with guides for seeding mixtures.

Plants that have been successfully used in range and wildlife habitat rehabilitation programs have been chronicled for most major plant communities that occur in the West (Hafenrichter and others 1968; Horton 1989; Plummer and others 1968; Sampson and Jespersen 1963; Schopmeyer 1974b; Thornburg 1982). Most native plant communities have been classified and grouped with specific soil types, climatic conditions, and aspect. The classification system developed by Hironaka and others (1979) identifies site differences and relationships of different plant types that occur within the big sagebrush communities. This and other classification systems can be used to determine the potential of individual sites to support different plant species. The presence and distribution of different plant communities that occur throughout a proposed project area can be mapped and used to develop species mixtures.

Some severely disturbed sites may not be capable of supporting the original native species, and substitute species may be needed.

Climatic Conditions as a Guide

The amount of precipitation an area receives, and the season or periods when moisture is available, influence seed germination, seedling establishment, and persistence (Frasier and others 1987; Jordan 1983). Seasonal and annual precipitation are very unpredictable in arid regions, and planting sites may not receive sufficient moisture to facilitate seedling establishment every year (Bleak and others 1965). Once established, plants can usually persist during dry years, but reproduction is often delayed until periods of favorable moisture. Attempting to foretell years when artificial revegetation will be successful is quite difficult.

Figure 3—Native species recovering with proper management and lack of competition from neighboring species.

Sites receiving in excess of 11 inches (280 mm) of annual precipitation can be successfully planted in most years. Many sites in the 9 to 10 inch (230 to 250 mm) zone are seeded, but success is less likely (Cook 1966; Plummer and others 1968; Reynolds and Martin 1968).

Many introduced grasses have been used in rehabilitation projects because of their establishment attributes. Most are able to establish under dry, unfavorable climatic conditions, and are well adapted to a broad range of sites (Hughes and others 1962). Standard crested and fairway crested wheatgrass have been the most reliable species to establish on sites receiving 8 to 10 inches (200 to 300 mm) of moisture (Hull and Klomp 1966; Shown and others 1969). Consequently, introductions have gained considerable popularity, and frequently are relied upon when planting droughty sites.

Selection and breeding programs continue to provide native and introduced species with improved establishment traits. For example, improvements in seedling vigor of Russian wildrye and forage kochia have been reported by Asay and others (1985), McArthur and others (1990a), and Monsen and Turnipseed (1990). Additionally, selections of Sandberg bluegrass, Indian ricegrass, bottlebrush squirreltail, and Lewis flax with excellent establishment attributes have also been developed and can better establish under arid situations. Erratic stands of some native species often develop partly because of poor seed quality and germination characteristics. However, improvements in seed collection, cleaning, and storage now provide a greater number of native species adapted to arid sites.

It is not advisable to use species or ecotypes on sites that are more arid than the collection site from which the seed was obtained. Ecotypes of antelope bitterbrush, fourwing saltbush, and many other species, have failed when seeded on sites that are more arid than the native collection location (fig. 4). Although some ecotypes have become established, they will most likely succumb to adverse climatic conditions. Moving ecotypes of fourwing saltbush, Indian ricegrass, and gooseberryleaf globemallow from warmer climates to more frigid environments has not been successful. In most cases, movement of plant materials from southern desert communities to northern regions is not advised. Some exceptions do occur, as a few southern collections of winterfat, desert bitterbrush, Nevada ephedra, and Apache plume have persisted following establishment in colder northern environments.

Many rangelands receiving less than 8 to 10 inches (200 to 250 mm) of annual rainfall are infested with cheatgrass and other weeds. Various native and introduced species have been seeded in an attempt to control the weeds. Selections of big sagebrush, rubber rabbitbrush, bottlebrush squirreltail, western wheatgrass, and other species have been seeded to control weeds and initiate successional changes in the plant community (Romo and Eddleman 1988; Young and Evans 1986a). In some situations the ecotypes that were seeded exhibit aggressive establishment capabilities, but are not fully adapted to the arid sites. They may establish well, but fail to reproduce and ultimately succumb. Considerable efforts have been made to eliminate weeds and create favorable seedbeds in arid regions to aid seedling establishment (Ogden and Matthews 1959). These practices increase planting success, but do not ensure survival of the planted species. The serious infestation of annual weeds on arid rangelands continues to promote seeding of marginally adapted species and ecotypes. This situation will likely continue. However, it is inadvisable to use marginally adapted species or ecotypes in any area.

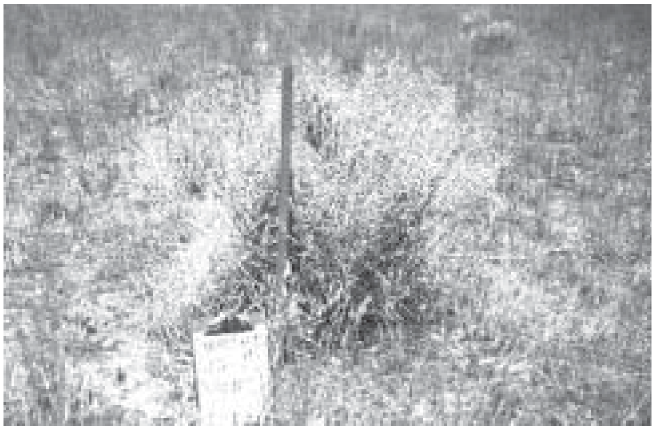


Figure 4—Death of maladapted New Mexico fourwing saltbush seeded in southern Idaho.

Soils and Parent Materials as a Guide

In general, planting sites consist of a mosaic of variable soil types that support an array of plant communities. Plants that are adapted to the different soil types and physical conditions should be sown. Seeding species mixtures has been the most practical approach to establish diverse communities (fig. 1).

Both native and introduced species have evolved on specific soils. Some ecotypes are not adapted to a wide range of soil conditions. When using native species, it is advisable to obtain seed from soils similar to the planting location. For example, antelope bitterbrush collections grown on acidic soils in central Idaho are not adapted to the basic soils of the Great Basin (Plummer and others 1968). Selections of fourwing saltbush, Indian ricegrass, Russian wildrye, and alfalfa have also been reported to differ in adaptability to soil conditions (Hassell and Baker 1985; Heinrichs 1963; Lawrence 1979; Stutz 1983). Nearly all native species consist of an assembly of different populations that have evolved under different environmental conditions. Certain ecotypes will grow over a wide range of sites. However, the range of adaptability of most native species has not been well documented. Consequently, it is advisable to plant species and sources on sites similar to their origin. It is particularly important to use plant materials acquired from specific soil types when seeding areas with unique soils or parent materials. For example, seeding fourwing saltbush on sandy, deep, well-drained soils should be done using seed produced on bushes growing on a similar site. On soils that have uniquely different soil textures, pH levels, drainage conditions, and fertility, specific ecotypes should be used.

Woodward and others (1984), working in Utah, found that dicotyledons (broadleaf herbs) tend to take up divalent ions more efficiently than monocotyledons (grasses), but monocots take up more monovalent cations than dicots. Also, the root cation-exchange capacity values for dicots were significantly larger than for monocots. The characteristic of root cation-exchange capacity helps to explain the differential distribution of grasslands and shrublands in common climatic zones. Differences in root cation-exchange capacity result in intense competition between monocots and dicots for certain minerals. This suggests that plants that are similar in root cation-exchange capacity coexist best. However, seeding grasses on soils deficient in magnesium but with adequate potassium would not be recommended, as it is unlikely that grasses would persist on these soils. In extensive areas where soils differing in mineral content exist, the use of adapted species is necessary.

Soils from the desert communities typically contain high levels of salts and have high pH levels. Few plants are adapted to these sites and only well-adapted species should be used. Attempts to convert these shrublands to grasses have not been successful. However, some grasses such as Russian wildrye and tall wheatgrass have proven adapted to specific sites and have been seeded to provide additional forage.

Planting introduced species and their varieties requires careful consideration of plant growth requirements. It is important that adapted species are planted, and marginally adapted substitutes are not planted. Also, it is unwise to convert unique plant communities to other species and growth forms following a major disturbance such as a wildfire.

Soil conditions directly affect seedbed features, which in turn influence planting success. Sites may be capable of supporting certain plant communities, but once the original vegetation has been removed or destroyed, the suitability of the site is altered. Native species that have evolved on the site may not be able to reestablish due to unstable soil conditions. It is not always correct to assume that native species can be easily established. For example, saline and alkaline soils, common in many valley bottoms, present unusual problems in preparing and maintaining a suitable seedbed. These soils absorb water slowly, are usually sticky when wet, and crust when dry (Pearson 1960). High levels of salt can cause physiological drought (Bernstein 1958). If vegetation is removed from these sites, they are extremely difficult to revegetate. Seedbed preparation methods often degrade soil structure. If soils are plowed, tilled, and left exposed, heavy crusting will occur and can prevent seedling emergence. Although these soils are capable of supporting a specific group of species, modifications to the area can reduce the success of artificial revegetation.

Disturbances on riparian sites also illustrate areas where disruption of the soils can alter the suitability of the site for establishing desired species. Disturbance of the vegetation can significantly affect soils and seedbed conditions, restricting the ability of certain species to establish (Platts and others 1987). These sites are usually flooded in the spring for long enough periods to damage the seedbeds. Also, many disturbed sites are subjected to siltation or erosion, creating unstable seedbeds.

Soil conditions directly influence species adaptiveness by affecting seedling establishment. Soils that are exposed to fires or heavy grazing are often altered (Eckert and others 1987). Changes in soil structure, presence of organic matter, standing crops and litter significantly affect the seedbed. Big sagebrush and winterfat have been difficult to establish on large open areas disturbed by fire due to disruption of the soil surface (Monsen and Pellant 1989).

Species Origin

Native Species—In general, native species have been more difficult to establish in large project plantings than selected introductions. Kilcher and Looman (1983) conclude that the factors limiting the use of natives are: (1) the lack of seed of local origin; (2) the variability in seed germination; (3) the physical difficulty in processing and seeding some native species; (4) unreliable emergence and establishment; (5) susceptibility to winter injury, especially with seed harvested outside the immediate area; (6) limited ability to compete with weeds during establishment; (7) low seed yields; and (8) comparatively high cost of seed. In most situations the limitations listed by these authors have and are being overcome, and the culture and use of native plants continue to increase in importance.

Recent plant selection programs have provided a wide complement of species for restoration or revegetation. Important advances have resulted in: (1) a larger number of native shrubs, broadleaf herbs, and grasses for artificial revegetation; (2) identification of specific ecotypes having important features and the determination of their areas of adaptation; (3) improvement of planting practices and seeding techniques; and (4) availability of better quality native seeds.

Native species can be recommended and used on range, watershed, and wildland sites with more confidence than in the past (see Section VII). Many important native shrub and forb species, ecotypes, and populations have been identified and can be recommended for planting. Notable advances have been made with some shrubs including big sagebrush, black sagebrush, fourwing saltbush, rubber and low rabbitbrush, Stansbury cliffrose, curlleaf mountain mahogany, Martin ceanothus, antelope bitterbrush, winterfat, skunkbush sumac, and green ephedra. Antelope bitterbrush has received the most attention (Ferguson 1983), but seed collection and sales from specific ecotypes of big sagebrush, rubber rabbitbrush, and fourwing saltbush are also quite important (Monsen and Stevens 1987; Shaw and Monsen 1990).

Considerable genetic variability exists in most native species, and selections have been used to enhance germination and establishment attributes, growth rates, growth habits, forage production, and quality (USDA Soil Conservation Service 1989). Currently, ecotypes of many important species can be recommended for seeding specific locations with different climatic and edaphic conditions. Programs have also been employed to propagate and increase ecotypes with important traits.

Figure 5—Site of origin for Lassen antelope bitterbrush.

Hybridization between varieties, ecotypes, and taxa have been used to enhance specific attributes of a number of woody species. Selection programs have been employed to promote features of fourwing saltbush, big sagebrush, antelope bitterbrush (fig. 5), low and rubber rabbitbrush, Stansbury cliffrose, curlleaf mountain and true mountain mahogany, and black sagebrush (McArthur and Welch 1986; Shaw and Monsen 1990; Tiedemann and Johnson 1983; Tiedemann and others 1984b). The importance of maintaining ecotypes with a broad genetic base has been recognized by Stutz (1985). Genetic diversity has been investigated through planting a number of populations or ecotypes at a problem site, and allowing natural selection to occur. This procedure has not been widely used, but represents an important consideration in planting native species over a wide range of sites.

New techniques for culturing many plants have significantly aided in their use. Regional seed companies now market seeds of a number of native species. In addition, seed vendors have developed more reliable collection, processing, and storage techniques to aid in providing a more stable supply of native seeds. Various wildland collection sites are now managed to produce seeds of different ecotypes. Consequently, seeds of a wider array of native species and a better and wider selection of species, advanced cultivars, and ecotypes are available for planting. The increased availability of seed has significantly reduced costs, and continued reductions can be expected. More reliable seed germination tests have been developed and standardized by seed laboratories (Stevens and Meyer 1990). Seed purity and germination standards have been developed to aid in seed marketing (Allen and others 1987; Kitchen and others 1989).

Seed Dormancy—Seeds of many native species collected from wildland sites germinate erratically depending upon year of collection, seed origin, and stratification treatments (Kitchen 1988; Silvertown 1984; Stevens and others 1981a). Seeds of many native species have embryo dormancy or impermeable seedcoats or both (Moore 1963; Schopmeyer 1974b). These features may delay and regulate germination and plant establishment (Meyer 1990). Seed dormancy is normally an advantage and aids in natural establishment of the species (Meyer and others 1990b). Dormancy may prevent seeds from germinating during periods when the chance of survival is low. Seeds of many species are not conditioned to germinate the first year after development, but persist, creating a seedbank from which new seedlings may occur over a number of years. Sporadic germination hinders development of uniform stands. Seeds of sumac, snowberry, Woods rose, and hawthorn, are difficult to germinate even if pretreated for extended periods. Seeds of other species are less difficult to germinate, but require quite different pretreatments to promote uniform germination. Unless adequately stratified, certain seedlots germinate so erratically that satisfactory stands generally fail to establish.

Seed dormancy obstacles in a number of native species have been overcome through selection and planting at appropriate seasons. Selections of ‘Bighorn’ sumac, ‘Montane’ mountain mahogany, ‘Rincon’ fourwing saltbush, and ‘Cedar’ Palmer penstemon have been developed, in part, for their favorable germination attributes (McArthur and others 1982). In addition, seeds from certain native collection sites are selectively harvested and sold because of favorable germination features. Land managers may not be aware of individual differences in germinability of all seedlots, but seeds can and should be tested to assure use of germinable sources. In addition, records should be maintained to document sources used in successful seedings.

Rate of germination is also an important attribute for planting success. The length of time required for seeds to germinate appears important to the establishment of species under arid situations.

Drought Tolerance—The success achieved in seeding arid, semiarid, and subalpine sites is most often dependent upon soil moisture conditions at the time of seedling emergence. Quite often soil moisture is only moderately favorable, and seedling survival is dependent upon the drought tolerance and physiological growth of seedlings (fig. 6). Considerable emphasis has been directed to the selection and use of drought-tolerant strains and ecotypes as many plantings are conducted in semiarid communities (Asay and Johnson 1980; Johnson and others 1982). Differences

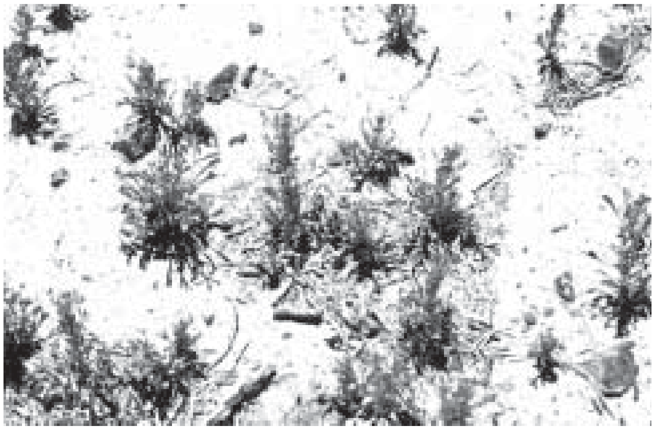


Figure 6—Big sagebrush seedlings. Drought tolerant and rapid rate of top and root growth is required for establishment in arid areas.

in seedling tolerance to drought varies significantly among collections, strains, and cultivars (Ford 1988; Wright and Brauen 1971).

If drought problems are anticipated, planting techniques should be used that help conserve moisture and assure protection of the less tolerant species. Establishment problems cannot be entirely rectified simply by planting the most adapted ecotypes. Seedlings of some species are especially sensitive to drought. Land managers should be aware of this and assure the creation of suitable seedbeds.

In the Intermountain area, drought frequently causes extensive dieoff of many plants (Harper and others 1990; Wallace and Nelson 1990). However, native species that have evolved under these circumstances express considerable tolerance of arid conditions. Selections of western wheatgrass and winterfat commonly used in wildland seedings are able to persist through periods of extended drought. Western wheatgrass, Sandberg bluegrass, purple three-awn, Idaho fescue, and bluebunch wheatgrass survived and increased during the drought periods of 1986-1989 in central Utah, when density of cheatgrass was significantly reduced. Certain introduced species, including Russian wildrye, also express excellent drought tolerance, and can be relied upon for seeding arid sites (Asay and Knowles 1985b).

Species seeded in arid sites must be adapted to periods of low moisture. Substitute species that are marginally adapted should not be used.

Growth Rates

Range and wildland seedings are currently based upon the use of species that have demonstrated the ability to establish and attain a reasonable stand in a relatively short time. In most seeding projects, species with rapid development are planted to furnish needed cover and forage (Davis and Harper 1990). Species that are capable of growing rapidly and can attain a mature stature in a short time are recommended in most seeding projects (Monsen and Turnipseed 1990). Plants with the ability to establish and grow quickly generally are better able to compete with weeds and survive periods of drought. Species that grow more slowly should be seeded separately from more aggressive species.

Species growth rate is important in maintaining plant composition and perpetuation of established stands. Seedling recruitment is required to perpetuate many species, and new seedlings must be able to compete with established plants. Species that are able to reproduce when growing with other plants usually are the ones that ultimately survive. Introducing aggressive and dominating plants to a composition of natives may not allow regeneration of the natives, and would not be recommended.

Cold Tolerance—Cold tolerance and resilience to frost generally are desired features of most plant species selected for revegetation in the Intermountain West. Cold tolerance is particularly important in young plants as seedlings usually emerge in early spring. Many young seedings are weakened or killed by spring frosts. Species with sensitive seedlings cannot be arbitrarily deleted from all seedings, but more cold-tolerant ecotypes should be seeded in areas where frost is a major problem. Seed sources of big sagebrush, winterfat, fourwing saltbush, and alfalfa are known to be highly sensitive to frost, and the most adapted ecotypes should be planted (Plummer and others 1968). Species with obvious intolerance to cold should be sown in late spring, if possible, to lessen losses from early spring frosts.

Palatability—Palatability and resilience to grazing are important features that can influence seedling establishment. Unmanaged grazing has frequently eliminated the more desirable species from mixed seedings. Unfortunately, only species having similar palatability traits are planted in some projects to limit problems associated with grazing management. Although this is a solution to grazing problems, the most appropriate species needed for other resources may not be planted.

New seedings normally attract concentrated use by many animals. Small mammals, insects, rodents, and often large game animals selectively graze small seedlings (Evans and others 1983). Young seedlings are extremely sensitive to heavy and repeated grazing. Livestock use can be regulated to protect new plantings. Wildlife populations are not as easily controlled, but reduction in animal numbers may be necessary to protect new plantings. Protection from heavy use must be provided until seedings are well established.

Some species require 2 to 7 years to fully establish and attain a stature that is able to persist with moderate use (Davis and Harper 1990; Monsen and Shaw 1983a). Less desirable ecotypes of certain shrubs and forbs can be sown to discourage grazing, but this may not be in line with the rehabilitation goals. In some situations, more resilient, but palatable, species might be sown to attract grazing and defer use from less resilient species. Seedings of alfalfa (fig. 1), yellow sweetclover, small burnet, orchardgrass, and mountain rye have been useful in providing desirable herbage from new plantings. It is most important that, whenever possible, areas seeded should be of sufficient size to dissipate grazing and lessen animal use. This may not be practical in all situations, especially on sites where wildfires or related disturbances determine the acreages to be seeded.

Animal use of emerging seedlings and young plants usually is not a problem on sites that support a remnant stand of native species. Remnant plants normally recover quickly following treatment. As these plants recover and produce new growth they attract use and aid in dispersing grazing pressure.

Persistence—Species that are able to persist under varied and often adverse climatic conditions, competition, and management impacts should be planted. Attempting to maintain a noncompatible composition of plants is ill-advised. Seeding aggressive, introduced understory herbs into many native communities has frequently resulted in the loss of most native species, coupled with a progressive increase of the seeded herb. The changes in plant composition may occur slowly, requiring many years to stabilize. Most problems have occurred when introduced species make up the major part of seed mixture. Although some introductions can enhance native communities, it is important that a natural balance in species composition is attained.

Value of Maintaining a Broad Genetic Base—In some situations, plants with desirable attributes are planted exclusively. Some strains have been developed through breeding or selection processes that may narrow the genetic base of the species, and eliminate other adaptive traits. Maintenance of a broad genetic base is recommended when seeding native species. Extensive dieoff of plantings attributable to the use of narrowly developed strains has not been widely detected. However, planting of a single seedlot or ecotype over a broad range of sites has often resulted in discernible patterns of success and failure. It should not be assumed that strains or selections with certain favorable traits are universally adapted to all sites. Plantings should not be confined to the use of seed from one very restricted population, or from only a limited number of individuals.

Seeds of many native species are often gathered from small, confined areas where soil moisture or other conditions favor seed production. Considerable amounts of seed are often collected from favorable sites, yet may not include the diverse attributes of the broader population.

Native species grown under cultivation may also have been propagated from seed of a few individuals. Seed that is commercially sold is normally collected or reared from bushes that are high seed producers and are easily harvested. These features may not represent the most desirable traits necessary to assure survival of the species.

Land managers cannot regulate or maintain direct control over the collection and sale of all seeds, but attention should be given to the origin of the seed acquired, and conditions at the rearing locations.

Adaptability of Released Cultivars—All plant cultivars have been developed for specific planting conditions. All have particular attributes or features that differ from the norm and encourage their use (USDA Soil Conservation Service 1989b). The selection and development of 'Rincon' fourwing saltbush was instigated, in part, because of the small utricles and early, uniform germination attributes. Stand establishment of 'Rincon' is usually more predictable than for other ecotypes (Monsen and McArthur 1985). However, it is not advisable to seed this cultivar on sites where it is not adapted. Also, it is obvious that cultivars are not universally superior in all traits to all other selections or collections of a species. Seedings should not be restricted to released cultivars, but seed sources should be determined on a case-by-case basis. Planting of 'Rincon' fourwing saltbush on low arid sites has not been successful, and the ecotype has not proven as well adapted to these areas as native ecotypes. Similar results have been recorded when Lassen antelope bitterbrush and 'Hatch' winterfat were planted on sites to which they are not adapted.

All cultivars have been carefully evaluated and their performance can be predicted. The quality of certified seed is usually good. However, each cultivar should be examined and used for the purpose for which it was developed. (See discussion of individual species and their cultivars in chapters 18-23.)

Seeding Mixtures or Single Species

Wildland restoration projects are usually conducted to reestablish native plant communities. This is not always possible as seeds or planting stock of many species are unavailable, and knowledge or techniques required for planting some species is lacking. Also, costs currently limit certain planting measures. However, advances in methodology continue to permit use of a greater complex of native species. As techniques are further developed, complete reestablishment of native plant communities may be possible.

Not all revegetation work is designed to reestablish native plants. In many range plantings introduced species are primarily used to increase forage yield and quality, and to accommodate management practices. In these situations, only a limited number of introduced species may be used.

Rehabilitation programs that are designed to provide livestock forage, watershed, and wildlife values have, to date, included a preponderance of introduced grass and broadleaf herbs. Introduced species are more readily available, seedlings establish more successfully, and forage values are better understood.

In most range seedings the trend has been to seed single species or simple mixtures. Revegetation efforts to satisfy wildlife, watershed, and reclamation needs include a wider array of species, and rely upon the restoration of native plants. In general, the advantages reported for seeding a single species or a limited number of plants apply primarily to the use of introduced forage grasses, and do not apply to seeding other species. Hughes and others (1962), Hull and Holmgren (1964), and McIlvain and Shoop (1960) reported that single species or simple mixtures are more easily managed if species with similar palatability, growth response, and grazing tolerance are used. However, native rangelands consist of a complex array of species that have persisted with natural use. Communities are only upset when seriously mismanaged.

Harris and Dobrowolski (1986) concluded that species mixtures in range seedings planted in northeast Washington are unstable, and that monospecific populations of suitable species, selected to fit seasonal grazing, should be seeded separately. Plantings should be fenced and used separately in a managed grazing system. Their studies reported that hard fescue eventually dominated most planted mixtures. Cook (1966), Currie and Smith (1970), Hull (1971a), and Vallentine (1989) concluded that the relative palatability of the species used determines the future of species in a mixture. Grazing animals tend to concentrate use on more palatable species, eventually reducing or killing them. Regulating the grazing season and period of use has not prevented the selective loss of more palatable species. Cook (1966) also concludes that seeding mixtures to furnish palatable species throughout the grazing season generally failed because all of the species cannot be maintained.

These conclusions are based on the assembly of forage grasses planted primarily for grazing by cattle. The implications are not directly applicable to wildlife or multiple uses. In addition, the results have questionable application to range seedings where different species are planted. Van Epps and McKell (1977) found that interseeding shrubs with grasses on semiarid ranges improved the quality of forage consumed by livestock, particularly in the fall and winter (fig. 7). Gade and Provenza (1986) found that sheep grazing on shrub and grass pastures in central Utah increased their forage intake by 36 percent and the forage consumed contained about 35 percent more crude protein than when the sheep grazed crested wheatgrass alone. The response of species when seeded in mixtures is directly related to grazing pressure and livestock management. Revegetation of most wildland occurs on sites having a variety of aspects, soils, and moisture conditions; mixed seedings are necessary to populate the area (Plummer and others 1968). Rechenthin and others (1965) reported that native rangelands in good condition are best seeded to native species at approximately the same ratio as found in the native community.

Regardless of the problems inherent in the use of mixtures, it is apparent that combinations of species should be seeded. Balancing the use of introduced and native plants must be considered on a case-by-case basis. As additional information is gathered, more precise species mixtures will, undoubtedly, be developed. Following are some specific considerations for selecting and using species mixtures, or using a single or a limited numbers of species.

Advantages of Planting Mixtures

Maintenance of Diverse Plant Communities—Most seedings are conducted on sites that have diverse microclimates, with varied soil and moisture conditions (Gifford 1975). Different plant communities appear, and different species are used to restore

Figure 7—Big sagebrush interseeded into crested wheatgrass to increase forage quality and quantity for livestock and big game.

various plant communities. Soil temperatures, fertility, and aspect differ among microsites, and different plant species are adapted to the various microsite conditions. Therefore, a number of species are needed to adequately populate the entire area.

Many areas have been dramatically abused, and some native species have been eliminated. Neither existing plants nor a seedbank remain to repopulate the site. Consequently, plant communities must be reconstructed by seeding or planting.

Encouraging Successional Changes—Most plant communities are created through successional changes (Eckert and others 1987). Although some species and communities can be established directly by seeding, natural shifts in species density and composition occur. Seedings of crested wheatgrass and intermediate wheatgrass establish quickly and persist for extended periods. In contrast, plantings of timothy and mountain brome establish quickly, but weaken after a number of years and may be invaded and replaced by other species. Seedings of Wyeth eriogonum, Lewis flax, and Pacific aster establish moderately well, but gain in importance even amid considerable competition. Many native shrubs establish slowly, but after attaining maturity may dominate the site.

Planting species that may restrict natural successional processes is not advised. Also, misuse of planting sites can disrupt successional changes. Desired changes can be adversely affected if weedy species are not removed or reduced at the time of planting, and desired species are unable to establish. The composition of species that initially establish following seeding sets the stage for future changes in species composition. Although restoration plantings are designed to restore entire communities, the proper assembly of species and seeding rates are not known. Plantings are currently being conducted using the most desired species expecting natural succession will ultimately result in a natural grouping of species.

Improves Weed Control—Seeding a mixture of species usually improves the control of undesirable weeds. Many individual species are extremely aggressive, and if planted alone can quickly control weedy plants (Torell and Erickson 1967). However, mixtures normally enhance weed control over diverse sites.

If plantings are designed to control annual weeds, early growing species usually must be planted (Foster and McKay 1962). Certain summer annuals are not entirely controlled by early spring species. Plants that establish and grow during late spring and early summer are more competitive with these weeds.

Seeded species must be able to restrict seedling establishment of weedy plants, and must be able to reduce or prevent spread by vegetative reproduction. Many perennial weeds may not be quickly eliminated by competition from seeded species, but their density and spread can be contained.

Reduces Risks of Establishment—Seeding a number of species together helps to ensure the establishment of a desirable stand. Many species, including Canada bluegrass, small burnet, slender wheatgrass, bottlebrush squirreltail, and crested wheatgrass have excellent establishment attributes. Consequently, any one of these species can be seeded alone. Few species establish as well as these plants, and seeding combinations increases the chance of success. Climatic conditions are often so erratic that seeding a single species over a wide variety of sites may result in poor stand establishment.

Mixtures should not be indiscriminately assembled, but a desirable number of species should be sown. Although weak stands may appear, mixed plantings generally improve over time.

Satisfy Multiple Uses—Use of a number of species provides the vegetative base necessary to support a variety of resource needs (Cook 1962). Revegetation and restoration efforts may be designed to enhance watershed, wildlife, or aesthetic conditions. In most situations, a single species is not able to provide such diverse needs. Even when the objective is to furnish forage for livestock, multiple species mixtures should be used. Seeding with multiple species provides longer periods when succulent forage is available (table 1). Land uses often change, and forage and cover requirements also change. Revegetation and restoration goals should not be limited to immediate uses, but should take into consideration future needs. Once a seeding is established, it becomes expensive and difficult to change.

Watershed and ground cover—Planting combinations of species having different growth habits furnishes a storied array of species that usually provides better ground cover throughout the entire year (USDA Soil Conservation Service 1954). Shrubs and trees with an upright stature entrap snow and delay snowmelt and runoff. Herbaceous plants normally furnish dense ground cover. Mixtures also contribute to a variety of plant litter, which provides soil protection and site stability.

Wildlife habitat—Game and nongame habitat consists of a variety of forage and cover plants. Species should be planted that can furnish seasonal cover as well as nutritious herbage at different seasons. Not all plantings will be designed to furnish a mixture of resources, but each planting site contributes to the overall needs of wildlife. Consequently, it is important to assure that all aspects of wildlife habitat are enhanced by rehabilitation measures. Sites that provide seasonal wildlife habitat should be seeded to assure animal needs are satisfied.

Table 1—Duration of succulence for selected grasses, forbs, and shrubs.

	Periods of succulence			
Species	**Mar-May**	**Jun-Aug**	**Sep-Nov**	**Dec-Feb**
Grasses				
Brome, smooth	xxxxxxxxxxxxxxxxx[a]		0000[b]	
Fescue, hard sheep	xxxxxxxxxxxxxxxxx		00	
Fescue, red	xxxxxxxxxxxxxxxxx00000000000			
Orchardgrass	xxxxxxxxxxxxxxxxxxxxxxxx		0000000000	
Ricegrass, Indian	xxxxxxxxxxxxxxxxxxx		00000000	
Rye, mountain	xxxxxxxxxxx		00000000	
Timothy	xxxxxxxxxxxxxxxxxxxx		000000000	
Wheatgrass, bluebunch	xxxxxxxxxxxx		00000	
Wheatgrass, crested	xxxxxxxxxxxx		0000000	
Wheatgrass, standard crested	xxxxxxxxxxxx		00000	
Wheatgrass intermediate	xxxxxxxxxxx		000000000000	
Wheatgrass, pubescent	xxxxxxxxxx		00000000	
Wheatgrass, tall	xxxxxxxxx		0000000	
Wildrye, Great basin	xxxxxxxxxxxx		000000	
Wildrye, Russian	xxxxxxxxxxxxxxxxxxxxxxxx0000000000000000000			
Forbs				
Alfalfa	000000xxxxxxxxxxxx000000000000000000000000000000000			
Balsamroot, arrowleaf	xxxxxxxxxxx			
Burnet, small	000000xxxxxxxxxxxxxxxxxxxxxxxxxxxx0000000000000000000000000			
Flax, Lewis	00000xxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000000000000000000			
Geranium	xxxxxxxxxxxxxxxxxxxxxxxxxx000000000			
Globemallow	xxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000			
Goldeneye, showy	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx000000			
Milkvetch, cicer	000000xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000			
Penstemon, Palmer	0000xxxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000000000000000000			
Penstemon, Rocky Mountain				
Sainfoin	0000xxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000			
Sweetvetch, Utah	xxxxxxxxxxxxxxxxxxxx0000000000000000000000000000			
Shrubs:				
Bitterbrush, antelope	00000xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000			
Cliffrose, stansbury	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Ephedra, green	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Mountain mahogany, curlleaf	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Mountain mahogany, true	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Rabbitbrush, rubber	00000xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx00000000000000000000			
Sagebrush, big	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Sagebrush, black	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Saltbush, fourwing	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Shadscale	xxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Serviceberry, Saskatoon		xxxxxxxxxxxxxxxxxxxxxxxxxx		
Winterfat	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			

[a] XXXX = Most leaves and seed stalks are green.
[b] 0000 = Only basal or overwintering leaves remain green.

Certain sites may offer limited wildlife benefits, and less diverse plantings will suffice. However, few sites are void of some form of wildlife, and species mixtures are usually necessary.

Forage production and quality—Grazing animals seek diversity. Forage resources are generally improved by selection of species mixtures. Certain sites may not support many species and a single species may be sown to ensure persistence of an adapted cover. However, mixed plantings usually provide more herbage, and seasonal production is greatly enhanced (Gade and Provenza 1986; Hughes and others 1962). Mixed plantings also improve forage quality (Gomm 1964; Van Epps and McKell 1977). For example, planting shrubs with herbs enhances both winter and summer forage conditions. Where possible, mixtures should be used to extend the season of use, increase herbage yields, and improve seasonal quality of forage.

Aesthetics—Nearly all rehabilitation efforts affect the appearance of the area treated for extended periods. Planting species that are compatible with adjacent undisturbed sites is recommended. It is usually necessary to seed mixtures to reestablish a significant density and distribution of species that will blend with adjacent areas.

Little research has been done on the use of revegetation to improve aesthetics. Planting native communities is usually regarded as the best method to reestablish natural appearance. However, some sites and circumstances do not facilitate reestablishment of natives. Thus, plant communities must be reconstructed using species that closely resemble the natives.

Adding species to a mixture to assure improvement of aesthetics may reduce forage production or lessen other resources. However, in most seedings forage species usually dominate, and aesthetic values are not fully considered—a practice that should be corrected.

Factors Suggesting Use of a Single Species

Certain plantings favor the use of one or only a few species. Normally, single-species plantings are restricted to specific sites, soil conditions, or to satisfy specific resource needs. In some situations, only a few species may be capable of growing on the planting site (McArthur and others 1987b). Soil or climatic conditions may limit the number of adapted species (Blaisdell and Holmgren 1984). Planning a broad complex of species on these sites is usually a waste of seed and effort.

Sites that could support a number of species are frequently seeded to only a few, but this should be done only after careful consideration of all circumstances. Some factors do influence the decision to plant only a few species. Following are some reasons for limiting the number of species used.

Ease of Planting—Seeding a single or only a few species is usually much easier than planting a complex mixture. If only two or three species with similar seed size, germination, and establishment attributes are sown, planting techniques are simple (Vallentine 1989). Planting methods that are available and can be used often determine the species used. The use of a number of seeding practices is often rejected as being too complex and difficult. In many cases only one seeding practice (drilling, broadcasting, interseeding) is selected and employed. Species that cannot be included in a common mixture and planted in one operation are thus eliminated from the revegetation plan. Although planting one or two species may be quite simple, it is important that the species selected and procedures used are not dictated by convenience.

Planting Costs—Selection of site preparation and revegetation methods used on wildland sites are often restricted by the costs involved. Using a number of species may require using two or three planting practices. It is costly to treat small areas with one piece of equipment, and then use different equipment on adjacent sites. A project must often be quite large, and resources values high, to justify using a number of revegetation practices.

Aid in Seedling Establishment—Not all species can be established satisfactorily when seeded in mixtures (Horton 1989). Certain species of shrubs are particularly sensitive to competition from broadleaf herbs and grasses. These shrubs should be seeded alone or with a limited amount of understory herbs. Also, the presence of weedy plants often reduces establishment of seeded species, and only the most competitive plants can be sown in some situations (Jordan 1983).

Shrub-Herb Plantings ____________

Species Compatibility

Most wildlife habitat improvement projects and restoration plantings differ from the typical livestock range improvement programs since a wider number of species having different growth forms are planted. Generally, most projects include a mixture of woody and herbaceous species. In contrast, range seedings emphasize the use of a limited number of herbaceous plants, principally grasses. Most species of grasses used in range and wildlife plantings establish well and develop rapidly. These traits are beneficial, and encourage the use of these plants. However, aggressive growth habits of many seeded herbs may create problems if slower developing species are also planted.

The problem is further complicated when seedings are conducted on steep, rocky, or inaccessible terrain where site preparation and seeding practices are limited.

Mixed plant communities occupy most wildland sites. Plant composition of these sites undoubtedly developed through various stages of plant succession. Natural changes in plant communities are not fully understood, and attempts to duplicate successional changes through artificial restoration are not always successful.

Seedling Status—The primary factor influencing species compatibility is the degree of competition exerted upon small, developing seedlings. If seedlings or young transplants are able to establish, their presence is most likely assured. However, if competition restricts or limits survival, plant density and composition are critically affected. Few species have been carefully evaluated to determine their compatibility with other commonly seeded plants. However, guidelines related to the establishment attributes and competitive traits of some species have been developed, and the ratings and evaluations are provided (table 2; also, tables in chapter 17). Matching the most compatible species together is essential for the success of mixed plantings. Species that are able to establish well and compete in mixtures are generally the most widely recommended species used. Seed mixtures recommended for various plant communities are presented in chapter 17. These recommended mixtures have been developed based upon compatibility among species during stages of community development.

Some species of grasses, including Indian ricegrass, and western wheatgrass establish slowly and are less competitive with seedlings of other species. Their presence, or addition to seed mixtures, better assures the establishment of associated species than if more aggressive grass species are sown.

Competition in Mature Communities—Natural regeneration and change in species composition occur after plants gain maturity. Many species are long-lived, but natural reproductive or vegetative spread are essential to their survival. New seedlings must be able to establish and survive amid competition within mature communities (fig. 8). The entry and survival of new seedlings are often dependent upon disturbances caused by rodents, climatic events, and fires. These disturbances may "open up" small areas and favor seedling establishment.

Seedling establishment of some species may benefit from the presence of associated plants. Competition may limit natural seedling recruitment, even though some seedlings are able to establish in most years. During years of favorable conditions, seedling survival may be quite high. Monsen and Shaw (1983c) found throughout a 40-year period that natural reproduction of antelope bitterbrush occurred regularly on sites supporting an understory of native grasses and broadleaf herbs. A sufficient number of shrub seedlings established to maintain stand density. Monsen and Pellant (1989) reported that the presence of Sandberg bluegrass significantly improved the natural reproduction of winterfat on sites with a preponderance of cheatgrass.

The seedbed and soil surface conditions created by existing plants frequently benefit seedling establishment. Soil microsites beneath the crowns of undisturbed big sagebrush shrubs are favorable to seed entrapment and establishment of small seedlings (Eckert and others 1987). The overstory canopy and litter provided by Gambel oak, quaking aspen, and Rocky Mountain maple enhance seedbed conditions for understory herbs (Plummer and others 1968).

Species that are highly ranked in regard to natural spread are plants that can increase in density amid mature plant communities (tables 2; also, tables in chapter 17). Plants with unusual ability to spread are not restricted to species normally growing under the most favorable climatic conditions. Seedlings of Apache plume, and black sagebrush are able to spread quite well in somewhat arid environments.

Natural reproduction and changes in species composition are related to climatic conditions, and seedling establishment may occur quite erratically. Seedling establishment is not always confined to years or seasonal periods of high moisture. From 1988 to 1990 considerable increases in density of perennial grasses occurred in southern Idaho and central Utah on sites previously dominated by cheatgrass. This increase occurred during years of drought when annual weeds were unable to establish and produce seed crops.

Benefits of shrub-herb associations—In situations where shrubs and herbs normally occur together, there are benefits in maintaining these associations. Species that have evolved together undoubtedly benefit by the relationship, or are sufficiently compatible to survive. In addition to the benefits derived from favorable seedbeds provided by associated plants, mixed communities also influence other factors related to perpetuation of a seeded community. The presence of compatible understory herbs frequently prevents the invasion of weeds that can upset natural regeneration processes. Understory plants of Idaho fescue, purple three-awn, bluebunch wheatgrass, Thurber needlegrass, and western wheatgrass are capable of preventing the invasion of annual grasses and summer annual broadleaf weeds. Maintaining a healthy understory of perennial herbs has been essential to the natural reproduction of stands of antelope bitterbrush, big sagebrush, Stansbury cliffrose, winterfat (fig. 9), and curlleaf mountain mahogany.

Table 2—Seeding requirements and seedling characteristics of some major species.

Species	Date of seeding[a]	Method of seeding[b]	Depth of seeding[c]	Compatability with other species[d]	Seedling vigor[e]	Seedling growth rate[f]
Grasses						
Bluegrass, Sandberg	F-S	A-B	A	5	4	4
Brome, mountain	F-S	A-B	B	5	5	5
Brome, smooth	F-S	A-B	B	4	4	3
Canarygrass, reed	F-S	A-B	B	4	2	4
Dropseed, sand	F-S	A-B	C	2	3	4
Fescue, hard sheep	F-S	A-B	B	3	3	3
Needlegrass, green	F-S	A-B	B	3	3	3
Oatgrass, tall	F-S	A-B	B	4	4	4
Orchardgrass	F-S	A-B	B	4	4	4
Ricegrass, Indian	F	A-B	D	3	3	3
Rye, mountain	F-S	A-B	B	5	5	5
Squirreltail, bottlebrush	F-S	A-B	B	4	5	4
Timothy	F-S	A-B	B	4	4	4
Wheatgrass, bluebunch	F-S	A-B	B	2	2	3
Wheatgrass, crested	F-S	A-B	B	2	2	3
Wheatgrass, standard crested	F-S	A-B	B	5	5	4
Wheatgrass, intermediate	F-S	A-B	B	5	5	5
Wheatgrass, pubescent	F-S	A-B	B	4	5	4
Wheatgrass, western	F-S	A-B	B-C	3	3	3
Wheatgrass, tall	F-S	A-B	B-C	3	4	4
Wildrye, Great Basin	F	A-B	B	2	2	2
Wildrye, Russian	F-S	A-B	B	3	2	2
Forbs						
Alfalfa	F-S	A-B-C-D	B	4	4	5
Aster, blueleaf	F-S	A[g]-B-C-D	A	4	4	4
Balsamroot, arrowleaf	F	A-B-C-D	B-C	2	3	1
Burnet, small	F-S	A-B-C-D	B	4	5	5
Crownvetch	F	A-B-C-D	B	3	3	3
Flax, Lewis	F-S	A-B-C-D	A-B	5	4	4
Globemallow	F	A-B-C-D	B	3	3	3
Goldeneye, showy	F-S	A-B-C-D	A-B	4	2	2
Lupine	F	A-C-D	B-C	3	4	4
Milkvetch, cicer	F	A-B-C-D	A-B	4	4	3
Penstemon, Palmer	F	A-B-C-D	A-B	5	4	3
Penstemon, Rocky Mountain	F	A-B-C-D	A-B	4	4	3
Sainfoin	F-S	A-B-C-D	B-C	4	4	3
Sweetclover, yellow	F-S	A-B-C-D	A-B	5	5	5
Sweetvetch, Utah	F	A-B-C-D	B	3	2	3
Shrubs						
Bitterbrush, antelope	F	B-C-D	B-C	4	5	4
Chokecherry	F	B-C-D	B-C	2	2	2
Cliffrose, Stansbury	F	B-C-D	B-C	3	3	2
Currant, golden	F	A-B-C-D	A-B	5	3	5
Elderberry, blue	F	B-C-D	A-B	2	2	3
Ephedra, green	F	B-C-D	B	3	2	2
Greasewood, black	F	B-C-D	B	2	3	2
Kochia, forage	F-S	A-B-C-D	A	5	5	3
Mountain mahogany, curlleaf	F	B-C-D	B	3	3	3
Mountain mahogany, true	F	B-C-D	B	3	3	3
Oak, Gambel	F	C-D	C	1	2	2
Rabbitbrush, low	F-S	A-B[g]-C[h]-D[h]	A	5	5	4
Rabbitbrush, rubber	F-S	A-B[g]-C[h]-D[h]	A	5	5	4
Sagebrush, basin big	F-S	A-B[g]-C[h]-D[h]	A	3	4	4
Sagebrush, black	F-S	A-B[g]-C[h]-D[h]	A	3	5	4
Sagebrush, mountain big	F-S	A-B[g]-C[h]-D[h]	A	4	5	4
Sagebrush, Wyoming big	F-S	A-B[g]-C[h]-D[h]	A	3	4	4
Saltbush, fourwing	F	A-B-C-D	A-B	3	4	4
Shadscale	F	B-C-D	B	2	2	2
Serviceberry, Saskatoon	F	C-D	B	3	3	3
Sumac, skunkbush	F	C-D	B	2	2	2
Winterfat	F-S	A-B[g]-C[h]-D[h]	A	4	5	3

[a] F = fall to winter; S = early spring.

[b] A = aerial or ground broadcast; B = drill; C = surface compact seeding; D = browse interseeder.

[c] A = surface to 0.12 inch (3.0 mm) deep; B = 0.12 to 0.25 inch (1.6 to 6.4 mm) deep; C = 0.25 to 0.75 inch (6.4 to 19 mm) deep; D = greater than 0.75 inch (19 mm) deep.

[d] 1 to 5 with 5 being highly compatible.

[e] 1 to 5 with 5 having high seedling vigor.

[f] 1 to 5 with 5 having the highest rate of growth.

[g] If cleaned to 60 percent or greater purity.

[h] If cleaned to 30 percent of purity.

Figure 8—Natural recovery of native species. New seedlings must be able to survive amid competition from established plants.

Value of legumes in species mixtures—Legumes have been widely used as agricultural crops and in cultivated pastures. The addition of legumes to grass seedings has resulted in an increase in herbage production and an improvement in forage quality (Gomm 1964; Hughes and others 1962). Legumes supply soil nitrogen that can be used by associated plants (Derscheid and Rumbaugh 1970; Holland and others 1969; Nutman 1976). For these reasons legumes have been actively promoted for range and wildlife plantings.

Many introduced and native legumes have been evaluated for rangeland and disturbed land plantings. Legumes do occur in most native communities, and should be planted in restoration projects. They may be important in the recovery of native communities, but are more commonly used to provide forage or restore harsh mine sites or related disturbances.

Species of alfalfa, including common alfalfa and sicklepod alfalfa, have been the most successful broadleaf herbs for range and wildland seedings (Dahl and others 1967; Kilcher and Heinrichs 1966b; Lawrence and Ratzlaff 1985). Alfalfa is primarily used for its forage value. Nitrogen fixation has been observed to benefit associated plants, but rangeland varieties have not been developed for this characteristic. Few other species are comparable to alfalfa for establishment traits and forage value (Lorenz and others 1982). Most strains are adapted to sites receiving at least 12 to 14 inches (305 to 355 mm) of annual moisture. Once established, alfalfa survives periods of drought and considerable grazing (Rosenstock and others 1989).

Figure 9—Aerial seeded winterfat stand and considerable natural spread that followed.

Root-proliferating or rhizomatous cultivars have proven well adapted to semiarid regions (Berdahl and others 1986). The most successful cultivars include: ‘Nomad’; ‘Rambler’; ‘Rhizoma’; ‘Sevelra’; ‘Teton’; ‘Travois’; ‘Roamer’; ‘Drylander’; ‘Spreader II’; and ‘Kane’ (Lorenz and others 1982). Strains with spreading root systems are able to recover from root damage caused by gophers. ‘Nomad’, ‘Rambler’, and ‘Ladak’ have been the most widely used strains throughout the Intermountain Region. ‘Ladak’ has preformed extremely well in pinyon-juniper, mountain brush, and big sagebrush sites in Utah. It is not considered a decumbent form, yet it withstands grazing and persists much better than cultivated field varieties (Heinrichs 1975). Berdahl and others (1986) concluded that the slow regrowth after grazing, and dormancy during long dry and cold periods are traits that contribute to the survival of dryland types.

Alfalfa provides excellent forage to all classes of grazing animals and is widely planted to provide high quality, palatable forage (Rumbaugh 1983). It has been planted in the foothills to draw big game animals away from cultivated farms and residential areas and is particularly well adapted to seeding with grasses. It establishes well, but seedlings are vulnerable to spring frost. Alfalfa is also very compatible with native herbs and grasses. It has usually been seeded in mixtures at rates up to 2 lb per acre (2.25 kg/ha). More recently, seeding rates of 2 to 5 lb per acre (2.25 to 5.63 kg/ha) have been used, with the amount of grass seed in the mixture being decreased significantly. In some earlier seedings, alfalfa was sown at 0.25 lb per acre (0.25 kg/ha). At this low seeding rate the plants were excessively grazed. Increasing the seeding rate to 2 to 4 lb per acre (2.25 to 4.5 kg/ha) significantly increases the density and forage production, and reduces concentrated grazing. Using alfalfa at these higher rates has not restricted the recovery of native herbs and shrubs. In fact production has been increased by higher seeding rates.

Kilcher and others (1966) concluded that on dryland sites in the northern Great Plains, seeding more than one grass with alfalfa had little advantage; however, reliance on one or two species for most range or wildland plantings is not advisable. Alfalfa has been eliminated by selective grazing when seeded in mixtures with grass and grazed with livestock. Use of alfalfa in range and wildlife planting in the Intermountain Region has improved yields, and with proper management the legume has persisted even under heavy use by game, livestock, rodents, and insects (Rosenstock and others 1989).

Other exotics, including cicer milkvetch, crownvetch, birdsfoot trefoil, and sainfoin have improved grass plantings, but their areas of adaptation are more limited than alfalfa (Hafenrichter and others 1968; Heinrichs 1975; Nichols and Johnson 1969; Plummer and others 1968; Townsend and others 1975; Wilton and others 1978).

Kneebone (1959) concluded through extensive trials that native legumes offer little promise for range use. However, considerable use has been made of Utah sweetvetch in range and wildland seedings (Ford 1988). Establishment features have been improved, and nitrogen fixation and areas of adaptability have also been evaluated and selections developed with superior attributes (Redente and Reeves 1981). The release 'Timp' is now available.

Seeding some native legumes has resulted in improvement of stand density, vigor, and forage production of associated species (Dahl and others 1967; Johnson and others 1983). In addition to Utah sweetvetch, plantings of silky lupine have been successful. Excessive animal use has not occurred with either of these two forbs, and they have demonstrated excellent longevity. Other native legumes are very important but have not been widely planted.

Considerable progress in development of other native forbs has resulted in the wide use of Lewis flax, Palmer penstemon, globemallow, showy goldeneye, sweetanise, arrowleaf balsamroot, Rocky Mountain penstemon, nineleaf lomatium, and Pacific aster. Contrary to earlier reports (Heinrichs 1975; Kneebone 1959; Vallentine 1989) native herbs have been found to have excellent forage characteristics. Many selections cure well and provide useful year-around herbage. In general, these species are easily established and current revegetation projects can be seeded with the appropriate herbs.

Some nonleguminous plants, including various shrubs, are associated with nitrogen-fixing organisms and improve soil fertility (Becking 1977; Hoeppel and Wollum 1971; Klemmedson 1979; Nelson 1983; Rose and Youngberg 1981). The list includes various species of alder, buckbrush, cliffrose, elaeagnus, and buffaloberry. Various woody legumes fix nitrogen, and understory species benefit from association with these shrubs (Becking 1970; Bermudez-DeCastro and others 1977). Including these species in range and wildlife plantings improves stand establishment and long-term productivity.

Seeding Rate

Sufficient seed should be used to assure the development of a good stand, yet at the same time prevent the waste of seed. Use of excessive seed amounts is needless and expensive. It can result in considerable seedling competition within and among seeded species, and can lead to high seedling mortality and even seeding failures. On the other hand, skimpy seeding may jeopardize establishment of good stands or individual species. This is not economically wise when considerable money has been spent to prepare the site. Hull and Holmgren (1964) listed three disadvantages of low seeding rates: (1) a longer period is required for the seeding to reach maximum productivity; (2) thin stands are more subject to invasion by undesirable species; and (3) robust and unpalatable plants tend to develop, plant distribution is irregular, and subsequent use is uneven.

Seeding rate can be influenced by species included in the mixtures, seed size (table 3), purity, viability, type and condition of seedbed, method of seeding, amount of competing vegetation present at time of seeding, and project objectives. Ease of establishment varies greatly among species. Number of seedlings established from a given number of seeds can be greater for fairway crested wheatgrass, alfalfa, small burnet, and smooth brome than for cicer milkvetch, Russian wildrye, western wheatgrass, and arrowleaf balsamroot.

Seed Quality

The amount of seed sown is influenced by the quality of seed to be planted. Seeds of many species are grown under cultivation, and acceptable seed purity and germination standards have been established. Both State and Federal seed certification standards have been established to assure that viable, high quality seed is sold and planted. Seed is certified on a State-by-State basis, and administered by an agency organization such as the Crop Improvement Association, the State Department of Agriculture, or the Agriculture Extension Service (chapter 27).

Various strains and varieties of individual species that have superior attributes have been developed through selection and breeding programs. These items may be released for sale as named cultivars. Numerous cultivars are currently available for range and wildlife plantings. Seed that is produced and sold as certified seed has been produced under specific field conditions to insure genetic purity, and has been cleaned and processed to meet minimum standards of germination, purity, and the absence of weed seeds. Certified seeds are grown, processed, and sold under supervision of State regulatory agencies. They are bagged and labeled with identifiable tags and sealed to prevent the bags from being opened unofficially. The tags provide information of State certification, crop variety name, and the grower's lot number. The certified seed must also include a label showing germination, date tested, weed seeds, and so forth. Seed certification and labeling laws have worked well to assure the availability of high quality seed.

Considerable amounts of noncertified seed are also grown and sold, but are not likely to be a genetically pure line, variety, or cultivar. Noncertified seed should also be tested and labeled to indicate the germination and purity of the seedlot. In addition, seed should meet standards related to the presence of noxious weed seeds. Noncertified seed is referred to as "commercial" or "common" seed and is often advertised as meeting certified seed standards. However, seed that has not been certified will probably not be genetically identical to a certified variety.

Harvesting and sale of native species has grown rapidly in recent years, creating a new series of problems related to seed quality standards and verification of seed origin. Seed quality standards are being constantly updated to standardize seed laboratory testing, and provide uniformity in the procedures and techniques used to determine seed germination, viability, and purity.

Table 3—Number of seeds per pound for selected grasses, forbs, and shrubs as compared to number of seeds per pound in fairway crested wheatgrass.

Species	Number of seed per lb	Pounds of seed required to equal the number of seeds in one pound of fairway crested wheatgrass
	100 percent purity	
Grasses		
Bluegrass, Kentucky	1,525,000	0.21
Brome, mountain	135,600	2.46
Brome, smooth	106,000	3.00
Fescue, hard sheep	633,500	0.50
Orchardgrass, 'Paiute'	600,000	0.53
Ricegrass, Indian	188,300	1.70
Wheatgrass, fairway crested	319,600	1.00
Wheatgrass, intermediate	88,100	3.63
Wheatgrass, pubescent	102,800	3.11
Wheatgrass, standard crested	192,800	1.66
Wildrye, Great Basin	130,700	2.45
Wildrye, Russian	210,000	1.52
Forbs		
Alfalfa	213,800	1.49
Balsamroot, arrowleaf	55,200	5.79
Burnet, small	55,100	5.80
Flax, Lewis	278,300	1.15
Milkvetch, cicer	113,700	2.81
Penstemon, Palmer	609,700	0.52
Sainfoin	26,300	12.15
Sweetclover, yellow	258,600	1.24
Shrubs		
Bitterbrush, antelope	20,800	15.36
Cliffrose	64,600	4.95
Kochia, forage	520,000	0.61
Mountain mahogany, birchleaf	55,000	5.80
Mountain mahogany, true	59,000	5.42
Rabbitbrush, whitestem rubber	693,020	0.46
Sagebrush, basin big	2,576,000	0.12
Sagebrush, mountain big	1,924,000	0.16
Sagebrush, Wyoming big	2,466,000	0.13
Saltbush, fourwing	55,400	5.78
Winterfat	112,300	2.85

To assure that seeds from specific wildland locations are harvested and sold, regulatory agencies have established a seed certification program to inspect and verify the origin and sale of source-identified collections. This program complements the more traditional seed certification process (Young and others 1995).

Seeds of native species will vary a great deal in quality among collection sites and among years of collection (Toole 1940, 1941). Seed quality is affected by climatic conditions, insects, previous browsing, the timing of seed harvest, methods of collection, seed cleaning, and storage conditions. Seeds that ripen irregularly such as many berry crops are often harvested before the seeds have fully matured. Seeds of antelope bitterbrush, arrowleaf balsamroot, and Martin ceanothus are often damaged by insects (Ferguson and others 1963; Schopmeyer 1974b), and seedlots must be carefully inspected to assure that viable seeds are planted. The cleaning processes used to clean fruits of mountain mahogany, rabbitbrush, lomatium, and winterfat may damage the seed. Removing seed appendages from rabbitbrush or winterfat can reduce seedling establishment success (Simpson 1952; Stevens and others 1986). Seeds of fourwing saltbush, redstem ceanothus, and various other species are subject to insect damage during periods of storage.

To maintain viability, seeds should be stored under cool, dry conditions (Stein and others 1974). Some seeds, particularly forage kochia, must be dried to a specific moisture content of about 7 percent or seed viability declines rapidly.

Seed germination percentages do not always reveal quality of the seed. Seeds may germinate normally, but seedlings may not grow satisfactorily. Erratic performance of the seedlings may result from being damaged during cleaning, or because seeds were harvested before they were mature. Good seedling vigor is essential to survival of young plants. Tests are not currently available to fully discern the potential vigor of the seedlings. In general, larger seeds within a seedlot usually produce the most vigorous seedlings, germinate and emerge sooner, and often have higher germination (Green and Hansen 1969). However, attempting to separate and seed only large seeds is not considered a practical procedure for field plantings. It is important to select and use seeds from collection sites or varieties that consistently express good seedling vigor and germination features.

Seedlots often contain a high percentage of inert material. Seedlots of sagebrush, rabbitbrush, winterfat, aster, needlegrass, alder, and many other species cannot be easily cleaned to a high purity. Such species are normally processed by screening, chopping, or related treatments to condition the material to pass through most conventional seeders. Thus, seedlots are frequently sold and used that have only 10 to 20 percent purity. Seeds of these and other small-seeded species would have to be diluted with an inert carrier to facilitate seeding if the seed was cleaned to a purity approaching 40 percent.

Seed acquired from wildland collection sites should be submitted to certified seed laboratories for germination and purity tests. All seeds should be properly labeled with germination and purity percentages, date tested, and location of collection. As possible, information related to the conditions of the collection site should be made available by the vendor.

Seeding rates should be based upon the amount of pure live seed (PLS) (table 4) within the seedlot. Percent PLS is determined by:

$$\text{PLS} = \frac{\text{percent Germination x percent Purity}}{100}$$

Selling seed on a PLS basis is much more practical than attempting to market bulk seedlots. Seed germination of individual seedlots is an important factor, and seedlots with unusually low percentages should be avoided. Seedlots with high germination percentages and low purity may still produce excellent healthy seedlings.

Table 4—Computing seeding rates and number of seeds sown.

Species	Mixture	PLS[a] desired	PLS of bulk seed	Bulk seed needed	Seeds per pound (PLS)	Seeds sown
	Percent	*lb/acre*	*Percent*	*lb/acre*	*No.*	*No./ft^2*
Bluebunch wheatgrass	23	3.0	85	3.45	142,640	9.8
Western wheatgrass	19	2.5	72	2.95	115,000	6.6
Idaho fescue	15	2.0	88	2.24	497,370	22.8
Needlegrass	15	2.0	81	2.38	94,895	4.4
Arrowleaf balsamroot	15	2.0	85	2.30	55,245	2.5
Eaton penstemon	12	1.5	94	1.59	351,085	12.0
Mountain big sagebrush	2	0.2	.20	0.36	1,924,000	8.8
Total	100			15.27		66.9

[a] Pure live seed.

The condition of the seedlot is important to consider. Seedlots that contain considerable debris that will not flow through a seeder should be avoided. Extraneous material may be small enough to pass through a seeding mechanism, but too light in weight to flow under its own weight. Adding a carrier may be necessary to facilitate seeding. Seed cleaning processes may cut small stems and sticks into particles having rough and ragged ends. These small particles become clogged in the seedbox, drop tubes, and small gates of a seeder. Seed processing and cleaning should remove stems, weed seeds, leaves, and other debris that interfere with seeding, reduce bulk and handling, absorbs moisture, or causes heating in storage. Most seeds can be processed to facilitate seeding. Only a few lightweight, fluffy seedlots present unusual problems.

Determining Seeding Rates

Seeding rates for range and wildlife plantings have generally evolved through experience gained from seeding agronomic grasses. Studies in New Mexico by Springfield (1965), and in Idaho by Mueggler and Blaisdell (1955) reported that seeding crested wheatgrass at rates ranging from 2 to 6 lb per acre (2.3 to 6.8 kg/ha) produced nearly the same plant density, herbage yield, and plant sizes 5 to 6 years after seeding. However, this grass establishes very easily and seeding other perennial grasses at slightly higher rates varying between 5 to 12 lb per acre (5.6 to 13.5 kg/ha) has been recommended (Cook and others 1967; Hull and Holmgren 1964; Hull and Klomp 1967; Keller 1979; McGinnies 1960b; Plummer and others 1955; Reynolds and Springfield 1953).

Usually 8 to 16 lb per acre (9 to 18 kg/ha) for a total mixture is suggested for seeding game ranges to a diverse mixture of species. Actual volume depends on the individual sites and whether seeds are drilled or broadcast. As additional species are added to a seed mixture, the total weight of the mixture may or may not increase. If additional species of grasses are added to a mixture, the total amount sown is usually not increased. This is accomplished by reducing the amount of seed of each species in the mixture. If additional species of broadleaf forbs are added to a mixture, the total amount sown may or may not increase depending upon the other species in the mixture and the competitive problems that may occur. Sufficient seed of each species should be added to assure uniform and adequate distribution during planting.

As seeds of additional species are added to a mixture, the amounts of other species may often be reduced. However, the reduction is not necessarily proportional to the amounts added. Number of seeds per pound varies greatly between species (table 3). When seeds of a number of species are planted, usually more than one method of seeding is used. Some seeds may be broadcast sown, and others drilled or planted in separate furrows.

Total seed used is based upon the number of live seeds applied per square foot. Numbers vary somewhat, but approximately 20 live seeds per square foot (211 seeds/m^2) is recommended (Bryan and McMurphy 1968; Rechenthin and others 1965).

Light seeding rates normally require longer periods for complete stands to develop, whereas moderate rates produce a full stand in a shorter period (Mueggler and Blaisdell 1955). However, when weeds are not a problem, light seeding rates result in better recovery of native plants and a better chance for all species sown to establish. Higher seeding rates control weeds better (Hull and Klomp 1967), which is desirable since poor initial stands may not develop dominance if weeds exist (Launchbaugh and Owensby 1970). Hull and Holmgren (1964) concluded that irregular plant distribution and uneven grazing results from thin seedings. Hyder and Sneva (1963) reported that planting wheatgrass in rows not over 12 inches (30 cm) wide increased the proportion of vegetative shoots and palatability. Irregular plant spacings have been observed to be more conducive to the establishment of a greater number of species than close, uniform, row plantings.

When seeding grasses for range or pasture purposes, planting approximately 20 seeds per ft^2 (211/m^2) is an appropriate standard. However, species that establish and spread quickly by tillering, rhizome expansion, or natural seeding may be seeded at rates as low as 6 seeds per ft^2 (60/m^2) (Hughes and others 1962). Increasing the seeding rate for slower developing species and species producing weaker seedlings is appropriate (Launchbaugh and Owensby 1970).

Confining seeding rates to 20 seeds per ft^2 (211/m^2) for many seed mixtures is not always appropriate. Seed mixtures that contain small seeds of big sagebrush, Canada bluegrass, western yarrow, Pacific aster, or various species of penstemon will normally contain more than 20 seeds per ft^2 (211/m^2). These species have between 1 to 3 million seeds per lb (2.2 to 6.5 million/kg). Seeding just 1 pound of seed containing 2 million seeds per lb would result in nearly 46 seeds per ft^2 (485/m^2). It is often impractical to reduce seeding rates below 0.5 lb per acre (0.56 kg/ha) just to maintain a 20 seed per ft^2 (211/m^2) standard. It is difficult to uniformly spread very small amounts of seed in large-scale projects. Small amounts can be sown if a carrier is added to provide the volume necessary to handle and distribute the material. Adding small amounts of seed of certain species to a mixture with other species also provides a means of mixing, handling and dispensing the material.

Seeding rates should be based upon plant density and distribution patterns desired. When a number of species are sown, the distribution and density achieved are based upon survival of the seedlings. Usually a greater density of grasses and broadleaf herbs is desired than shrubs when mixed seedings are conducted. Often only one shrub may be required for each 100 sq ft (9.2/m^2), amounting to approximately 435 plants per acre (1,074/ha). The percent success of seed sown is often influenced by the species and amount of seed sown. Richardson and others (1986) reported that slightly more than 2,200 plants of mountain big sagebrush, 2,788 rubber rabbitbrush, and 1,040 antelope bitterbrush established per acre (5,436, 6,889, and 2,570/ha) when seeded as a mixture at 4 lb per acre (4.5 kg/ha) in southern Idaho. Shrub numbers dropped to 81 plants of mountain big sagebrush, 116 rubber rabbitbrush, and no antelope bitterbrush plants per acre (200, 287, 0/ha) when perennial grasses were seeded at 12 lb per acre (13.5 kg/ha) with the shrubs. Increasing the seeding rate of the shrubs to 20 lb per acre (22.5 kg/ha) and grass to 18 lb per acre (20.3 kg/ha) resulted in increased establishment of sagebrush and rabbitbrush seedlings, but no antelope bitterbrush seedlings survived.

Mueggler and Blaisdell (1955) reported that when crested wheatgrass was seeded alone, exceptionally heavy seeding rates did not cause stand failure from excessive competition among seedlings. Similar results have been obtained when individual native grasses and herbs are seeded as single species. However, when mixtures are seeded, increasing the seeding rate of individual species affects the survival of others sown. When aggressive grasses are seeded with broadleaf forbs or shrubs, the seeding rate of the grasses should not exceed 2 to 4 lb PLS per acre (2.25 to 4.5 kg/ha). Certain circumstances may alter this amount, but grass seed should be limited to assure survival of other species.

The seeding rate of alfalfa when sown with grasses in irrigated and nonirrigated pastures has usually been between 0.5 and 2 lb (PLS) per acre (0.56 to 2.25 kg/ha) (Allred 1966; Kilcher and Heinrichs 1968; Rumbaugh and others 1965). Seeding rangelands with as much as 5 lb per acre alfalfa (5.6 kg/ha) has resulted in excellent stands. Seeding rates of other broadleaf herbs are quite different from alfalfa. Small-seeded species such as western yarrow, Pacific aster, and Lewis flax can be seeded at much lower rates. However, higher rates are required to attain similar results for large-seeded species such as Utah sweetvetch, arrowleaf balsamroot, or silky lupine.

Results from seeding a single species indicate that increasing the seeding rate usually increases the number of seedlings that emerge, but reduces the number of plants established per 100 seeds sown (Cook and others 1967; Launchbaugh and Owensby 1970; McGinnies 1960b; Vallentine 1971). When mixtures are seeded, increasing the seeding rate will normally result in an increase in number of seedlings that emerge, but seedlings of certain species will survive better than others. For example, increasing the amount of Lewis flax, sulfur eriogonum, and alfalfa seeds sown usually results in a proportional increase in plants that establish and survive. In contrast, increases are less apparent for arrowleaf balsamroot and gooseberryleaf globemallow.

Determining Seeding Rates Based Upon Methods of Seeding—The amount of seed sown also depends, in part, on the planting methods and equipment used. Certain practices are more efficient than others. Approximately 50 to 75 percent more seed has been recommended when broadcast seeding is used compared with drilling (Cook 1966; Plummer and others 1955). However, evaluations of numerous aerial broadcasting and anchor chaining projects of pinyon-juniper sites in Utah have shown that an increase of about 20 percent is necessary for development of satisfactory stands. Aerial seeding usually distributes seeds very uniformly, and chaining provides adequate coverage. Unless broadcast seeds are covered or incorporated in the soil many do not germinate or become established. Broadcast seeding is not advisable unless some method of seed coverage is used. Increasing the seeding rate will not substitute for poor planting techniques. Drilling usually results in more uniform placement of the seed in the soil than broadcasting followed by harrowing or chaining. Seeds of certain species, particularly small seeds, establish better from shallow or surface placement, and broadcast planting followed by light harrowing provides an ideal seedbed for smaller seeds (table 5).

Seeding rates for mixed seedings can usually be reduced if the seedbox is partitioned into separate compartments, and seeds of similar sizes are grouped and seeded in separate rows from seeds with different sizes or shapes (Wiedemann 1975). If this is done, the seeding rates can be more precisely metered and more uniform distribution is also achieved. If planting depths can be separately adjusted for each furrow seeder, better seed placement will result and a higher percentage of the seed will establish. Various seeders, including drills and imprint planters, have multiple seedboxes and can simultaneously plant seeds of different species in separate rows and at different rates and depths.

Seeding grasses, broadleaf herbs, or shrub seeds in alternate or separate rows increases the chance of success as seedling competition is reduced (Hafenrichter and others 1968; Plummer and others 1968). Species mixtures seeded in alternate rows maintain their original composition better than when mixed in each row (Gomm 1964; McWilliams 1955). Seeding in alternate or separate rows also allows greater

Table 5—Pounds of seed per acre[a] required to seed one, five, and 10 seeds per linear foot (0.3 m) (drilled) or square foot (0.01 m^2) (broadcast).

	Number of seeds per linear foot		
Species	**One seed**	**Five seeds**	**Ten seeds**
	- - - - *lb Seed/Acre* - - - -		
Grasses			
Brome, smooth	0.32	1.6	3.2
Dropseed, sand	0.008	0.04	0.08
Fescue, hard sheep	0.08	0.40	0.8
Needlegrass, green	0.27	1.35	2.7
Orchardgrass	0.09	0.45	0.9
Ricegrass, Indian	0.27	1.35	2.7
Rye, mountain	0.77	3.85	7.7
Timothy	0.03	0.15	0.3
Wheatgrass, bluebunch	0.30	1.5	0.3
Wheatgrass, fairway crested	0.14	0.7	1.4
Wheatgrass, intermediate	0.50	2.5	5.0
Wheatgrass, pubescent	0.50	2.50	5.0
Wheatgrass, Siberian	0.20	1.0	2.0
Wheatgrass, slender	0.33	1.65	3.3
Wheatgrass, standard crested	0.23	1.15	2.3
Wheatgrass, tall	0.56	2.8	5.6
Wheatgrass, western	0.38	1.9	3.8
Wildrye, Great Basin	0.33	1.65	3.3
Wildrye, Russian	0.25	1.25	2.5
Forbs			
Alfalfa	0.20	1.0	2.0
Balsamroot, arrowleaf	0.77	3.85	7.7
Burnet, small	0.77	3.85	7.7
Flax, Lewis	0.16	0.8	1.6
Globemallow, gooseberryleaf	0.09	0.45	0.9
Goldeneye, showy	0.04	0.2	0.4
Lupine, mountain	3.45	17.25	34.5
Milkvetch, cicer	0.38	1.9	3.8
Penstemon, Palmer	0.07	0.35	0.7
Sainfoin, common	1.67	8.35	16.7
Sweetvetch, northern	1.30	6.5	13.0
Shrubs			
Bitterbrush, antelope	2.8	14.0	28.0
Ceanothus, redstem	0.37	1.85	3.7
Chokecherry, western	10.0	50.0	100.0
Cliffrose, Stansbury	0.68	3.4	6.8
Ephedra, green	1.75	8.75	17.5
Kochia, forage	0.08	0.4	0.8
Mountain mahogany, curlleaf	0.83	4.15	8.3
Mountain mahogany, true	0.71	3.55	7.1
Rabbitbrush, low mountain	0.06	0.3	0.6
Rabbitbrush, white rubber	0.06	0.3	0.6
Sagebrush, basin big	0.02	0.1	0.2
Sagebrush, black	0.05	0.25	0.5
Sagebrush, mountain big	0.02	0.1	0.2
Sagebrush, Wyoming big	0.02	0.1	0.2
Saltbush, fourwing	0.77	3.85	7.7
Serviceberry, Saskatoon	1.0	5.0	10.0
Winterfat	0.38	1.9	3.8

[a] Based on seeds per pound at 100 percent purity (table 1).

flexibility in spacing and seeding rates. Certain shrubs can be seeded separately from grasses, and a greater percent of the shrub seed sown will establish (fig. 10).

Various seed agitators and regulating mechanisms now exist that more uniformly plant seeds of irregular shape and size (Wiedemann 1983; Wiedemann and others 1979). Seed loss due to irregular plantings has been decreased with the use of new seeders, and seed is more efficiently planted.

Interseeding into existing stands is often employed to improve stand composition (Stevens 1985a,b). In addition, seeding some species in strips, rows, or selected spots is commonly done (Welty and others 1983). Species are often seeded using single row planters or Hansen Seed Dribblers mounted on wheeled tractors or track-driven “cats”. These seeders may be used to plant areas where broadcast or drill seeding is also being used. Seeding individual species using separate items of equipment can greatly reduce the amount of seed planted. Shrub seeds that are sown in furrows spaced 10 to 20 ft (3.1 to 6.1 m) apart often provide an acceptable cover, and subsequently furnish an adequate seed source for natural seeding. If furrows are spaced 10, 15, or 20 ft (3.07, 4.6, 6.14 m) apart, only 10, 6.7, and 5 percent of the total area is actually sown. Seeding rates and amount of seed sown at different row spacings are presented in tables 5 and 6.

Spot seeding is a practical method of seeding many species, particularly with highly expensive seed or species that may require specific seedbed conditions. Spot seeding following chaining on pinyon-juniper sites is a useful and successful practice. Certain browse seeds can be hand planted into the pits and depressions created where trees are uprooted. These depressions or catchment basins are favorable sites for seedling establishment.

Figure 10—Seeding of whitestem rubber rabbitbrush in alternate rows with fairway crested wheatgrass.

Table 6—Seeding requirements for some Intermountain shrubs. Shown are pounds of pure live seed required per acre, for four seeding rates, at each of four different row spacings.

			Number seeds per linear foot							
			Five				Ten			
			Row spacings ft							
	Purity/	No.	5	10	15	20	5	10	15	20
Species	germination	PLS per lb[a]	Amount of seed sown, PLS lbs per acre[b]							
	Percent									
Bitterbrush, antelope	95/90	15,370	2.83	1.42	1.0	0.71	5.67	2.84	1.98	1.42
Ceanothus, Martin	98/75	82,900	0.53	0.26	0.18	0.13	1.05	0.53	0.37	0.26
Ceanothus, redstem	98/85	131,860	0.33	0.17	0.12	0.09	0.66	0.33	0.23	0.17
Chokecherry, black	98/80	4,150	10.50	5.25	3.67	2.63	11.00	5.50	7.35	2.75
Cliffrose, Stansbury	95/85	64,615	0.67	0.34	0.24	0.17	1.34	0.67	0.47	0.34
Currant, golden	95/65	356,180	0.12	0.06	0.04	0.03	0.24	0.12	0.09	0.06
Elderberry, blue	95/50	216,770	0.21	0.11	0.07	0.06	0.42	0.21	0.14	0.11
Ephedra, green	95/85	24,955	1.75	0.88	0.61	0.44	3.50	1.75	1.22	0.88
Eriogonum, Wyeth	95/75	141,310	0.31	0.16	0.11	0.08	0.62	0.31	0.22	0.16
Mountain mahogany, curlleaf	90/80	51,865	0.84	0.42	0.29	0.21	1.68	0.84	0.59	0.42
Mountain mahogany, true	90/80	59,030	0.74	0.37	0.26	0.19	1.48	0.74	0.52	0.37
Rabbitbrush, whitestem rubber	15/75	693,220	0.06	0.03	0.02	0.01	0.12	0.06	0.04	0.03
Rose, Woods	95/70	45,300	0.96	0.48	0.34	0.24	1.92	0.96	0.67	0.48
Sagebrush, big basin	12/80	2,575,940	0.02	0.01	0.006	0.005	0.04	0.02	0.01	0.01
Sagebrush, black	12/80	907,200	0.05	0.03	0.02	0.01	0.10	0.05	0.03	0.02
Saltbush, fourwing	95/50	55,365	0.79	0.40	0.28	0.20	1.58	0.79	0.55	0.39
Serviceberry, Saskatoon	95/85	45,395	0.96	0.48	0.34	0.24	1.92	0.96	0.67	0.48
Shadscale	95/35	64,920	0.67	0.34	0.24	0.17	1.34	0.67	0.47	0.34
Snowberry, mountain	95/80	54,065	0.81	0.41	0.28	0.21	1.62	0.81	0.56	0.41
Sumac, smooth	94/40	62,430	0.70	0.35	0.24	0.18	1.40	0.70	0.49	0.35
Winterfat	50/85	112,270	0.39	0.20	0.14	0.10	0.78	0.39	0.27	0.20

			Number seeds per linear foot							
			Fifteen				Twenty			
			Row spacings ft							
	Purity/	No.	5	10	15	20	5	10	15	20
Species	germination	PLS per lb[a]	Amount of seed sown, PLS lbs per acre[b]							
	Percent									
Bitterbrush, antelope	95/90	15,370	8.50	4.25	2.98	2.13	11.34	5.67	3.97	2.83
Ceanothus, Martin	98/75	82,900	1.58	0.79	0.55	0.39	2.10	1.05	0.74	0.52
Ceanothus, redstem	98/85	131,860	1.0	0.5	0.35	0.25	1.32	0.66	0.46	0.33
Chokecherry, black	98/80	4,150	31.49	15.75	11.00	7.87	41.98	20.99	14.69	10.49
Cliffrose, Stansbury	95/85	64,615	2.02	1.0	0.71	0.50	2.68	1.34	0.94	0.67
Currant, golden	95/65	356,180	0.37	0.18	0.12	0.09	0.50	0.25	0.17	0.12
Elderberry, blue	95/50	216,770	0.60	0.30	0.21	0.15	0.80	0.40	0.28	0.20
Ephedra, green	95/85	24,955	5.24	2.62	1.83	1.31	7.00	3.50	2.44	1.75
Eriogonum, Wyeth	95/75	141,310	0.93	0.46	0.32	0.23	1.24	0.62	0.43	0.31
Mountain mahogany, curlleaf	90/80	51,865	2.52	1.26	0.88	0.63	3.36	1.68	1.18	0.84
Mountain mahogany, true	90/80	59,030	2.21	1.10	0.78	0.55	2.96	1.48	1.03	0.74
Rabbitbrush, whitestem rubber	15/75	693,220	0.19	0.09	0.07	0.05	0.24	0.12	0.09	0.06
Rose, Woods	95/70	45,300	2.89	1.44	1.01	0.72	3.84	1.92	1.35	0.96
Sagebrush, basin big	12/80	2,575,940	0.05	0.03	0.02	0.01	0.08	0.04	0.02	0.01
Sagebrush, black	12/80	907,200	0.14	0.07	0.05	0.04	0.20	0.10	0.07	0.05
Saltbush, fourwing	95/50	55,365	2.36	1.18	0.83	0.59	3.15	1.57	1.10	0.78
Serviceberry, Saskatoon	95/85	45,395	2.88	1.44	1.01	0.72	3.84	1.92	1.34	0.96
Shadscale	95/35	64,920	2.01	1.00	0.70	0.50	2.68	1.34	0.94	0.67
Snowberry, mountain	95/80	54,065	2.42	1.21	0.85	0.60	3.22	1.61	1.13	0.81
Sumac, smooth	94/40	62,430	2.09	1.04	0.73	0.52	2.80	1.40	0.98	0.70
Winterfat	50/85	112,270	1.16	0.58	0.41	0.29	1.55	0.78	0.54	0.39

[a] Number of PLS/lb is determined on the number of pure live seeds per pound.
[b] Amount of seed sown is computed in pounds of pure live seed.

Spot seeding also allows for more careful control of the number of seeds sown. Ferguson and Basile (1967) reported that a lone seedling of antelope bitterbrush is less likely to survive than if a group of seedlings emerge together. Seedlings grouped together provide mutual protection from heat and aid in breaking of a soil crust during emergence. Evans and others (1983) reported rodent depredation of planted antelope bitterbrush seeds is reduced if seeds are not placed on a continuous, uniform row. Also, placing seeds at different depths in the soil and seeding fewer seeds together in a spot reduced the chance of rodents being able to locate and destroy the seeds.

Compensating for Seed and Seedling Losses—A high percentage of seeds sown fail to emerge or establish. Seed and seedling losses normally result from poor seedbed conditions, unfavorable moisture conditions, frost, animal depredation, damage by insects and disease, and competition. Less than 10 percent of viable wheatgrass seeds sown produce seedlings (Cook and others 1967). Luke and Monsen (1984) reported from plantings in southern Wyoming that seedling establishment of different species of shrubs varied between 0.01 to 3.30 percent of all seed planted.

Plantings of fourwing saltbush in central Nevada have resulted in established plants from over 10 percent of the seed sown (Monsen and Richardson 1984). Big sagebrush and rubber rabbitbrush exhibited excellent ability to establish amid considerable competition, but less than 3.5 percent of the seed sown for each of these two species produced seedlings. Seedling density is apparently regulated by site factors, and overseeding is not necessary.

Rodents feed on the seed of numerous species (Everett and Monsen 1990). These animals frequently destroy nearly entire plantings by foraging upon the seeds and seedlings (Nelson and others 1970; Nord 1965; Sullivan and Sullivan 1982). Although rodents consume the majority of seeds produced each year, their caches are also instrumental in plant recruitment (McAdoo and others 1983; West 1968). Rodent caches benefit species that respond favorably to grouped seedings (Ferguson and Basile 1967).

Deer mice eat or dig up seed of commonly seeded species equal to approximately one-third of their body weight daily (Everett and others 1978b). The amount of seed taken in the field is proportional to the amount available (Sullivan 1978). Thus, animals quickly gather and use planted seeds (fig. 11).

Figure 11—Mouse excavation of planted antelope bitterbrush seed.

Rodents apparently operate under an “optimal factor” strategy where they harvest seed from dense patches or clumps rather than dispersed seeds (Price and Jenkins 1986; Pyke and others 1977). However, seeds broadcast on the soil surface are nearly entirely consumed even though located in a random pattern (Nelson and others 1970). Buried seeds are less preferred because of the energy spent in digging (Price and Jenkins 1986). Rodent mining for seeds has been reported to occur if seeds are concentrated in rows (Nord 1965), and high losses can result if seeds are placed at uniform depths. Drilling may place seeds in fixed horizontal and vertical planes. Therefore, if seeds can be randomly located in the soil, losses to rodents can be reduced. Rodents favor large seeds over small seeds (Everett and others 1978b; Howard 1950; Standley 1988), because they are more easily located (Price and Jenkins 1986). Large seeds may be preferred as the relative number required to meet daily energy demands is less (Kauffman and Collier 1981; Reichman 1977).

Rodents are able to locate buried seeds by olfactory search image (Sullivan 1979). The size and planting depth of the seed affects detection (Reichman and Oberstein 1977). Evans and others (1983) found that seeds of antelope bitterbrush planted in groups of 2, 10, 45, or 100 were much more easily located and consumed by rodents than if one seed was planted per spot. Also, rodents never dug up one bitterbrush seed, but if two were planted together, over 75 percent were removed. Over 98 percent were taken if more than two were planted. Rodents were able to detect most bitterbrush seeds if planted at normal seeding depths. Planting fewer seeds per spot or randomly placing desirable seeds in the soil are procedures that can be used to lessen losses to rodents.

Although sacrifice foods have not been fully tested as a means to protect range seedings, laboratory and field trials suggest millet, sunflower, and rolled barley as potential sacrifice foods (Everett and Monsen 1990; Kelrick and MacMahon 1985; Kelrick and others 1986). Feeding sunflower seeds as sacrifice food to rodents increased conifer survival from 5 to 70 percent (Sullivan 1979).

Various repellents have been applied to seeds to reduce animal depredation. Endrin has been the most successful (Plummer and others 1970b), but use of this compound has been prohibited because of environmental concerns. Everett and Stevens (1981) found that alpha-naphthylthiourea (ANTU) reduced deer mice consumption of bitterbrush seed more than other chemicals tested. Passof (1974) reported that the chemical effectively doubled seedling stocking rates of conifers.

Late fall or winter seedings are recommended to reduce the loss of seeds to rodents. At this time rodent activity has declined. Rodent populations are at their lowest point in the early spring, but spring seedings are not the most desirable.

Modification of Seeding Rates—Seeding rates and planting procedures can be modified when necessary. In high risk areas where soil stability, aesthetics, or habitat are of prime concern, increasing seeding rates and intensifying planting may be justified. Using high quality seed, and delaying planting until conditions are ideal for seeding are useful practices that can increase success (Phillips 1970).

Using high seeding rates and planting techniques that may be less than optimal may be justified in certain situations. For example, aerial seeding of big sagebrush, winterfat, and rubber rabbitbrush followed by chaining or harrowing may not produce as many seedlings as using a modified ground seeder. However, satisfactory stands can be achieved, and savings in seeding costs more than compensate for losses of seed by broadcast seeding.

Low seeding rates can also be justified at some locations. If weed invasion is not a problem, some pinyon-juniper chainings can be lightly seeded to allow more complete recovery of desirable species. Although the planting sites may initially appear weedy or support a weak ground cover, the ultimate plant community usually forms a diverse, acceptable cover.

Effects of Seed Characteristics on Seeding Rates—Seed size occurring in different seedlots of many species may vary enough to require adjustments in seeding. Differences in seed size of fourwing saltbush (Foiles 1974), black chokecherry (Grisez 1974), curlleaf mountain mahogany (Deitschman and others 1974a), and bottlebrush squirreltail necessitate considerable adjustment in computing seeding rates and operation of seeding equipment.

The percent moisture in seedlots of fourwing saltbush, winterfat, Apache plume, and vegetable-oyster salsify can also affect the amount of seed needed. Also, the amount, size, and shape of debris in seedlots can determine the choice of equipment, planting methods, and seeding rates used. Seedlots of Apache plume, Rocky Mountain maple, and western virginsbower are difficult to clean, and the methods used to collect and clean the seed often determine the methods that can be used in planting.

Seeds extracted from berries or dry fruits sometime have portions of the fruit attached to the seed. The rough surface of the attached material reduces the flow of the seed through most seeders. Seed regulatory gates or control openings must be opened wide to accommodate movement of the seed through the seedbox and dispensing mechanisms. In doing so, seeding rates become difficult to regulate. Such seed must often be diluted to prevent overseeding.

Seeds of extremely different size, shape, density, and purity often cannot be seeded together without modification of planting equipment. Seeds of big sagebrush, rubber rabbitbrush, and winterfat are commonly seeded with other species and this may necessitate improvisations to permit seeding. Additions of very small or extremely large seeds to a mixture can be accommodated by using materials to reduce planting rates. Some seeding equipment, particularly picker-type seeders or fluted seeders and are designed to plant irregular sized and mixed seedlots. However, trashy seedlots are not easily planted. In most situations extremely trashy seedlots must be planted separately with special equipment. Spending time to clean seed to a desired condition is usually well worthwhile. Some time should be spent calibrating the selected seed dispensing mechanism to achieve the rate of seeding desired.

Treating Seeds to Improve Establishment

Preconditioning Seeds—Various treatments have been employed to pretreat seeds that are difficult to germinate. Seeds with thick, impermeable seedcoats or structures can be mechanically fractured to promote germination (Stein and others 1974). Hammermilling utricles of fourwing saltbush and shadscale fractures the tough wall and allows seeds to germinate quickly and more uniformly. Hard seedcoats or fruit structures can also be treated with sulfuric acid (Brinkman 1974g; Krugman and others 1974), but this treatment is difficult to apply, particularly to large seedlots.

Pretreating some seeds with various chemicals can relieve dormancy and allow seeds to germinate. Antelope bitterbrush and Stansbury cliffrose are two species that respond to treatment with hydrogen peroxide or thiourea (Everett and Meeuwig 1975; Young and Evans 1983). Breaking seed dormancy with chemical treatment facilitates seeding in the spring. However, seeding success is not as good as with fall seeding, and this practice is not usually recommended.

Priming seeds to hasten germination is a technique that appears practical to improve seedling establishment (Bleak and Keller 1972) particularly when seeding in semiarid communities. Hardegree and Emmerich (1992) reported seed priming can be used to regulate seed germination of perennial grasses and enhance seedling establishment when seeded in areas occupied by cheatgrass.

Seed processing—Improving seed cleaning and seeding practices has significantly increased planting success. Removing fruit and floral structures by improved cleaning techniques greatly enhances seeding and helps ensure that seeds are correctly placed in the soil. However, removal of tissue attached to seeds of rabbitbrush and winterfat can reduce seedling establishment (Booth and Schuman 1983; Stevens and others 1986). Slight heating of seeds of Utah sweetvetch by grinding to open or remove the pod is very damaging. In this case, the seeds are not visually damaged, but germination is greatly reduced. Planting techniques and equipment have been developed to plant seedlots having trashy, lightweight, and fluffy seeds (Carlton and Bouse 1983; Hardcastle 1983; Stevens and others 1981b; Weidemann 1983). These advances have reduced cleaning and conditioning processes that often damage some seeds. Seed cleaning techniques have also been devised to condition seeds of sagebrush, alder, forage kochia, buckwheat, aster, and numerous other species without damage to the seed (Dewald and others 1983).

Seed inoculation—Seeds of all legumes should be treated with a commercial inoculate prior to planting. Lowther and others (1987) reported strains of rhizobia have limited distribution in the Intermountain West and those present have low nitrogen fixation capabilities. Thus, strains of the rhizobia specific for the legume being planted should be used. Pretreated seed can be purchased from most vendors. Strains of adapted inocula are available for some native legumes including Utah sweetvetch (Ford 1988).

At present, 162 species in 19 genera in 7 families of woody plants are known to form actinomycete-type root nodules (Bond 1976; Heisey and others 1980; Righetti and Munns 1980). Certain species of western shrubs of the Rose family function as symbiotic nitrogen fixers (Klemmedson 1979; Lepper and Fleschner 1977; Vlamis and others 1964; Wagle and Vlamis 1961). Nelson (1983) reported that actinorhizal root nodulation occurs with Stansbury cliffrose, desert and antelope bitterbrush, and curlleaf mountain mahogany, but procedures to inoculate the seeds have not been developed (Becking 1977; Nelson and Schuttler 1984).

Seed pelleting—Various methods have been tried to improve success from broadcast seedings. Techniques have been employed to substitute for harrowing, dragging, or chaining to eliminate the costs associated with seed coverage. Pelleting seed has been extensively tested for range, wildlife, and forestry seedings, but plantings have not been very successful (Hull and others 1963). Pelleted seeds require seed coverage or creation of a seedbed as does nonpelleted seed (Chadwick and others 1969). Seeds that establish from surface or shallow planting depths are best adapted to this method of seeding.

Monsen and Pellant (1989) reported that pellet seeding of winterfat significantly aided in aerial distribution of this lightweight seed. Seedlings established well from this method of planting, but success was not an improvement over broadcasting nonpelleted seed. Although pelleting of lightweight, trashy seed can enhance the flow and distribution of the seed through conventional drills and aerial seeders, pelleting is a difficult and expensive process. Pelleting does not overcome problems created by small sticks or other debris that cause material to cluster or lodge in the seeder.

Increasing the seeding rate of pelleted seed has not improved seedling establishment (Bleak and Hull 1958; Hull 1959) and no improvement in rodent deterrence has been detected with treated seed. Application of fungicides has been proposed as an added benefit with pelleted seed, but results have not been conclusive. Also the costs of pelleting, and the added shipping and handling fees are very high (Chadwick and others 1969).

Treating seeds to control pathogens—Treating seeds and soil to prevent damage by pathogens may be beneficial, but it is not widely done in range or wildlife seedings. Seed collected from wildland stands is often infested with seedborne pathogens (James 1985; James and Genz 1981), and various treatments have been tested to eliminate or reduce pathogenic organisms, particularly on conifer seeds (Barnett 1976; James and Genz 1981; Trappe 1961; Wenny and Dumroese 1987). Treatments have included the use of 100 percent ethanol or sodium hypochlorite with lowered pH, and soaking seeds in a 2 percent aqueous suspension of thiram for 24 hours (Maude and others 1969; Sauer and Burroughs 1986). Dodds and Roberts (1985) discuss the sterilization of seed using a 1 to 3 minute soak in a 70 percent ethanol solution, followed by a soak in sodium hypochlorite. Hot water treatments have also been employed without reducing seed germination (Baker 1962a,b), and the use of a microwave oven to heat water to the desired temperature (Lozano and others 1986).

Damping-off fungi are particularly damaging to antelope bitterbrush, winterfat, and fourwing saltbush seedings (Ferguson and Monsen 1974). Organisms can be transitted through ingestation of the seed or potting media. Treatment with a mixture of Benlate (methyl 1-[butylcarbamcyl] -2 benzimidazole-carbamate) and Dexon [p-dimethlamino] benzenediazo sodium sulfonate has been successful as a drench. Treatment of nursery beds using a soil drench (Pawuk and Barnett 1974) has been effective in controlling fusarium fungi that are responsible for seedling mortality (Landis 1976) due to damping-off and rootrot.

Pretreating seeds may be effective in reducing seed disease problems, but the use of disease-free seeds is preferable, whenever possible. Nelson (1984) cautions that fungicidal treatments to prevent seedling diseases often only suppress the pathogen which will later induce further disease. However, sufficient seed damage from pathogens has been observed in various wildland plantings to suggest that control measures would be beneficial to some species. Heavy losses occur with lupine, balsamroot, Utah sweetvetch, antelope bitterbrush, serviceberry, and blue elderberry. Seeds should be pretreated if disease problems are likely to be serious.

Seedbed Preparation and Seeding

An ideal seedbed for range or wildlife seedings: (1) is free of competitive weeds (seeds and plants) that may prevent establishment of seeded species; (2) has a friable structure that allows infiltration of moisture and does not puddle or become compacted by seeding equipment or rainfall; (3) can be easily worked to incorporate seed into the soil; (4) has a firm soil beneath the seeding depth; and (5) contains sufficient surface mulch to prevent rapid drying. The principal purpose of seedbed preparation is to control weeds and condition the soil for seeding. A minimum number of tillage or treatment operations are used on most wildland sites. Access is often limited; debris, rock, or terrain limit the techniques that can be used. Often only one or two techniques are used to control weeds, prepare, and seed a site.

Control of Competition

Seedings have been most successful when existing competition has been eliminated (Cox and others 1986; Holmgren 1956; Hubbard and Sanderson 1961). Most control measures are designed to remove existing vegetation and seedbanks. These procedures are particularly important in semiarid and arid regions where moisture is critical to seedling establishment (Vallentine 1989), and in vegetative types where competition is severe. Adequate weed control is usually difficult to accomplish, particularly on sites infested with annuals (Plummer and others 1955).

Weed control or reduction of competition is necessary to (1) allow seeded species to establish; (2) release existing, but suppressed desirable plants; and (3) allow the spread of native and seeded species. To facilitate seeding, weed control measures are necessary for at least one season and sometimes for 1 or 2 years thereafter.

Figure 12—Well designed pinyon-juniper chaining. Allowances given for aesthetics, thermal, escape and travel cover, and sufficient edge effect.

Control measures do not always require complete elimination of all plants (fig. 12). Chaining of pinyon-juniper stands, dense patches of oakbrush, or thick stands of big sagebrush usually leave considerable vegetation, but the overstory plants are suppressed and seeded species are able to establish (Aro 1971; Davis 1987; Plummer and others 1968). Plant control measures are most critical in areas receiving limited rainfall (Houston 1957). Complete elimination of black greasewood or low rabbitbrush is not as critical if normal amounts of moisture are received following treatment. These plants are not overly competitive and some can be left in place. However, rainfall is too often unpredictable and leaving a high number of plants in place is risky.

Cook (1966) reported that complete removal of brush on low foothill ranges in the Intermountain area allowed seeded species to reach maturity in 5 years. Seeded stands required 10 to 11 years to attain full potential when brush control was only 60 to 80 percent. The time required for seeded stands to attain maturity is not as critical as the chance of having seedlings fail to establish. Control measures should be designed to assure stand establishment. Maturation and productivity levels may be delayed but can be tolerated.

Planting sites that are infested with annual weeds usually requires complete weed control (fig. 13). Cheatgrass, medusahead, and most summer annuals offer serious competition to seeded species (Evans and Young 1978; Hull 1963a; Hull and Pechanec 1947; Robertson and Pearse 1945; Rummell 1964). Decreasing the density of annuals does not always reduce the deleterious competitive effects of the remaining plants.

Nearly complete removal of all annual plants and seed is necessary to establish new seedlings of most seeded species (Hulbert 1955; Robertson and Pearse 1945; Young and others 1969a). Annual weeds compete directly with natural seedlings of Stansbury cliffrose (Cline 1960), and shrub seedlings succumb in the late spring and early summer as soil moisture is depleted. Summer annuals are also highly competitive (Haas and others 1962), particularly when mixed stands of Russian thistle and pepperweed exist with annual grasses.

'Hycrest' crested wheatgrass (Asay and Knowles 1985a,b), forage kochia (Monsen and Turnipseed 1990), bottlebrush squirreltail, and 'Appar' Lewis flax are species able to compete as seedlings with a moderate population of annual weeds. However, direct seeding into unprepared weedy seedbeds should be avoided. In general, shrub seedings are less competitive with annual grasses than are most commonly seeded herbs (Hubbard 1964). Seedlings of antelope bitterbrush are better able to compete with summer annuals than with cheatgrass (Holmgren 1956). Monsen and Pellant (1989) found that seedlings of winterfat competed better with perennial native grasses than with cheatgrass. If cheatgrass cover approached 10 to 15 percent, few winterfat seedlings survived.

Giunta and others (1975) reported differences in establishment success among several shrub species seeded on a pinyon-juniper site in central Utah, when various size clearings were used to reduce cheatgrass competition. Most shrub seedlings required clearings that were 30 and 40 inches (76 to 102 cm) wide to establish (fig. 13). Holmgren (1956) reported similar sized openings were required in cheatgrass-infested ranges in Idaho to assure the establishment of seeded antelope bitterbrush. From studies in California (Hubbard 1964) and Idaho (Medin and Ferguson 1980) clearings of 30 to 40 inches (76 to 102 cm) were recommended for antelope bitterbrush seedling establishment.

In more mesic sites where annual rainfall exceeds 14 to 16 inches (360 to 410 mm), herb seedings are usually more successful, and weed control is not as difficult. However, even here shrub species cannot be established without seedbed preparation. Mountain snowberry, Saskatoon serviceberry, Martin ceanothus, and true mountain mahogany are commonly seeded in these sites, but are sensitive to the competitive effects of associated herbs. Weedy or competitive plants must be controlled for 1 to 3 years to allow seedlings time to establish.

Dense stands of highly competitive perennial sod and annual weeds occur on high summer ranges and require control measures (McGinnies 1968). Treatment of cluster tarweed (Hull 1971b) is essential for seedling establishment of seeded species. Seeding of inland saltgrass and disturbed meadow sites also requires extensive weed control.

Figure 13—Antelope bitterbrush seeded into clearings where competition has been removed.

Riparian disturbances often require considerable control measures to eliminate persistent and competitive weeds (Platts and others 1987). Disturbances are often occupied by rhizomatous sod and root-proliferating noxious weeds. These plants must be eliminated or dramatically reduced. Treatments such as deep plowing or disking may not kill the plants without repeated treatments (Platts and others 1987; Plummer and others 1968). These measures leave the surface subject to serious erosion from spring runoff and storm events. However, such extensive control measures are necessary to seed many sites (Neiland and others 1981).

Conservation of Moisture

Site preparation treatments should be designed to conserve and aid in storage of soil moisture. Most mechanical practices—plowing, railing, disking—tend to dry the soil surface, and should be done when moisture loss is kept at a minimum.

The most practical means of providing the maximum soil moisture to the seedbed is to treat sites at the right season. Site preparation and seeding should be conducted prior to the season when most precipitation is received. In most situations, late fall treatments are most successful. Disturbance to the soil can reduce infiltration and cause crusting and moisture loss. Disturbances should be limited in both seedbed preparation and seeding. Hyder and others (1955) found that rolling loose seedbeds improved seed placement and seedling emergence. Rolling, after broadcast seeding, was also a reliable method of covering seed and firming the seedbed, but rolling can also compact some soils, reducing seedling emergence.

Within the Intermountain area, seeding and weed control conducted in the fall allows spring-germinating species a better opportunity to use winter moisture stored in the soil. Stored moisture, coupled with spring rainstorms, provides the most favorable conditions for seedling establishment.

Fall or spring treatment of annual weeds, particularly cheatgrass, is helpful in eliminating annual growth (Klomp and Hull 1972). Treatments must be conducted after cheatgrass plants have germinated and emerged (Evans and Young 1978; Plummer and others 1968; Young and others 1969a).

Weed seeds normally are not eliminated unless the soil is deeply plowed and seeds are planted too deep to emerge. Light or shallow cultivation in the spring or fall can normally kill small seedlings (Bement and others 1965; McGinnies 1968).

Summer fallowing can be used to control plant growth and prevent the development of a seed crop (Harris and others 1972; Hart and Dean 1986). Summer fallowing is a useful technique to conserve soil moisture in areas of low annual rainfall, but fallowing practices are often quite expensive. Fallowing over a 1- to 2-year period is often necessary to control sod in mountain meadows.

Pitting, trenching, deep-furrow drilling, and creation of catchment basins have been used to intercept and accumulate moisture near the seedbed (Barnes 1952; Branson and others 1966; Hubbard and Smoliak 1953). Chaining also creates pits and small depressions, especially in areas where trees or large shrubs are uprooted (fig. 14). These spots also collect additional soil moisture that aids seedling establishment.

Treating soils that are wet can cause compaction and crusting. This reduces infiltration and may interfere with seedling emergence. On the other hand, treating sites when the surfaces are dry and loose can cause serious wind erosion. Such sites should not be left barren for long periods. Loose soil surfaces also dry rapidly, and site preparation treatments that leave a protective surface mulch should be used to conserve moisture (Hyder and Bement 1969).

Maintaining surface mulch and a standing crop to protect the soil surface improves seedling establishment (Malakouti and others 1978). Most planting sites contain some surface litter or mulch. This material should be kept in place, if possible, to lessen surface evaporation, provide protection to small seedlings, and reduce soil crusting (Herbel and others 1973). Mulch is particularly important for soils that dry rapidly, and may be subjected to fluctuating temperatures.

Deep furrow drilling using 12 to 16 inch (30 to 41 cm) row spacings has been a method used to concentrate soil moisture and improve seedling density (Anderson and others 1953; Artz and others 1970; Fisser and others 1974; Neff 1973; Wight and White 1974). Deep furrows have been reported to increase soil moisture during the period of spring germination by an average of 50 percent and sometimes up to 100 percent (McGinnies 1959). The deep furrows reduce soil moisture loss from evaporation, allow seedlings to use deeper stored moisture, and reduce temperatures near the seedling (McGinnies 1959). Deep furrow drilling should not be done when soils are dry, as sloughing normally occurs, causing seeds to be buried too deep.

Figure 14—Chaining can create excellent seedbeds, pits, and small depressions.

Entrapment of winter snow cover is essential to seedling establishment of many small-seeded, surface germinators. Meyer and others (1990a) reported that entrapment of winter snow on the planting site until the time of seed germination in the spring resulted in a significant increase of sagebrush seedlings from plantings in Idaho, Nevada, Montana, and Wyoming. Entrapment of snow by standing plants, particularly shrubs, is important to natural seedling establishment in arid and semiarid sagebrush communities of the Intermountain area. Maintaining some erect or standing plants can improve the soil moisture for new seedlings. Downed pinyon and juniper trees resulting from chaining trap snow and greatly improve seedling establishment in the affected areas. The tree litter remains effective for over 25 years.

Seedbed Firmness

Most undisturbed seedbeds are loose enough to be drill-seeded or seeds can be incorporated in the soil by chaining or harrowing. Sites that have been plowed or disked may require mechanical compaction to reduce moisture loss (Hyder and others 1961) and the problem of seeding too deep. Loose soil surfaces normally result in seeds being planted too deep and at irregular depths (Hyder and others 1955). Also, loose soil has poor moisture-holding capacity (Vallentine 1989). In contrast, firm seedbeds retain moisture near the seed zone and are much easier to plant at the desired depth. A loose or friable soil with an underlying firm soil is ideal for seeding. These surfaces are easy to plant at the proper depth.

Figure 15—Result of aerial seeding forbs, grass, and shrubs on top of snow.

Most drill seeders are equipped with packer wheels to compact the seeded furrow and lessen the depth of the soil overlying the seed. Rollers and other compaction equipment are available to pack or compress loose soils prior to seeding (Anderson and others 1953; Hyder and others 1955; Hyder and others 1961). Rolling or compaction before drilling allows for better seed placement (Hyder and others 1961). Cultipacker, roller type, or press seeders can be used to seed loose surfaces (Anderson and others 1953; Booster 1961; Richardson and others 1986). These seeders do not plant at depths exceeding 0.5 to 1.5 inches (1.3 to 3.8 cm). Depth bands and other modifications are used on many conventional drills to aid in suspending or preventing the disk from digging and planting too deep (McGinnies 1962). Hydraulically supported furrow openers and no-till seeders are also designed to control seed placement.

Offset furrow openers, or disks, are used to cut into dense litter and hard surfaces (Asher and Eckert 1973). Front-mounted rippers and no-till seeders are designed to plant firm seedbeds. Anchor chain modifications, pipe harrows, and chain harrows are effective implements used to seed and prepare firm or hard surfaces (further information related to the function of seeders is presented in chapter 9).

Seeding—Seeding is normally intergrated with the seedbed preparation. Often, chaining or drilling accomplishes both practices. To be successful, both practices must be conducted during the appropriate season or period. Seedbed preparation and seeding may be completed in the fall or early winter. During the interval between seeding and seedling emergence, the seedbed may be altered. Soil sloughing may bury some seeds too deep, or wind erosion can expose planted seeds. Dry, loose seedbeds can be expected to settle, which may result in satisfactory or unsatisfactory stands depending on the methods used in planting.

Planting Season

Fall or early winter seeding is necessary to provide seed stratification for many species (fig. 15). Most native shrub seeds require a cold, moist period to adequately overcome embryo dormancy (Shopmeyer 1974b). Seed germination may not occur until after stratification of 100 to 150 days for some species. Prestratified seed is frequently spring planted at nurseries, but gauging the stratification period to coincide with spring weather conditions is extremely hazardous. Pretreating seeds of antelope bitterbrush and a few other shrub species with hydrogen peroxide or thiourea can induce germination, but is not a satisfactory means of seeding large projects (Alexander and others 1987; Everett and Meeuwig 1975; McConnell 1960; Neal and Sanderson 1975; Pearson 1957; Young and Evans 1983). Different seedlots of antelope bitterbrush respond differently to the chemicals; some germinate quickly and uniformly and others do not. Spring plantings of naturally dormant seeds should be avoided.

Seeds of alfalfa and certain collections of winterfat and fourwing saltbush and many commonly seeded grass species are nondormant, and may be spring sown at certain locations. However, fall seedings generally provide more favorable stands of most species particularly under arid situations (Cook and others 1967; Plummer and others 1968). Alfalfa seeds that are fall sown often germinate in the early spring and many are killed by frost. Spring planting in early April, on a fall-prepared seedbed, usually reduces the problem. Spring planting may also reduce seedling losses to frost for some ecotypes of fourwing saltbush and winterfat. Seedlings of most grasses are quite frost tolerant, and stands normally are not lost to spring frosts.

Recent studies have demonstrated considerable variability in seed dormancy and germination requirements among ecotypes of different native species (Kelsey 1986; Kitchen 1988; Meyer and Monsen 1990; Shaw and Haferkamp 1990). Plantings of mountain big sagebrush and rubber rabbitbrush seed obtained from areas having relatively warm winters show different germination and emergence responses from collections acquired from cold winter locations (Meyer and Monsen 1990). Seeds of big sagebrush and rabbitbrush collected from areas with warm climates did not survive well from fall plantings in more northern regions. Collections from warm climates that were fall sown germinated quickly, usually in the late fall and winter, but were unable to survive beneath the snow. Germination requirements undoubtedly vary for many species, seedlots, or ecotypes, and these requirements should be understood before extensive seedings are made.

Vallentine (1989) concluded that range seedings should be made prior to the period of longest favorable moisture conditions. Within the Intermountain Region between 45 to 65 percent of the annual precipitation is received in the winter months. Rapid drying normally occurs following germination and seedling emergence in the spring. At most elevations late fall or early winter seeding is recommended. Seeding should be delayed long enough in the fall to prevent germination until the following spring (Gates 1968; Harris and others 1972; Plummer and others 1968; Vallentine and others 1963). Seeding early in the fall can be successful if sufficient moisture is available to germinate and maintain seedlings until cold temperatures arrive. Generally, sufficient soil moisture is not maintained for the entire period, and seedlings often succumb.

Jordan (1983) concludes that sites seeded in the fall to cool-season species should receive on the average 3.5 inches (89 mm) of precipitation through the months of November, December, January, and February. The average annual precipitation should be a least 10 inches (250 mm).

In the Southwest and the southern portions of the Intermountain Region where summer rains are common, spring seeding is advised for species having nondormant seed. Jordan (1981) recommended that warm-season species be seeded in the spring. Ideally, sites seeded in the late spring to either warm- or cool-season species should receive an average of 5.0 inches (127 mm) of moisture through July, August, and September. The average annual precipitation should be at least 11 inches (280 mm).

With respect to precipitation, Jordan (1983) reported that average annual precipitation values are often used to characterize range sites, but they are not adequate to describe the potential for reseeding. He developed a predictive model to determine the potential of a site for seeding based on precipitation, the arid or semiarid boundary, and the average annual temperature. In addition, the soil texture and water holding capacity of the soil is used to determine the availability of stored moisture. The predictive model developed by Jordan has not been widely applied to the germination and establishment of all species normally seeded in the Intermountain area, but it appears useful in defining areas that may or may not be seeded with success.

Fall seedings are more reliable for low valley and foothill communities where the annual precipitation would be less than 12 to 14 inches (300 to 260 mm). These sites normally dry quite rapidly in the spring and are subjected to a long, dry summer. Slow developing seedlings are often too small and weak to survive a dry summer period. Seeding in the spring on a fall-prepared seedbed is most successful if planting occurs early in the season. However, soils may be too wet and muddy to permit early spring seeding. If sites are allowed to dry, additional rain will be needed to germinate and maintain the seedlings. Usually, only a short period exists in the spring when conditions favor seeding (Evans and Young 1987a). Attempting to seed large areas in the spring is therefore, often impractical.

Considerable fluctuation occurs in both temperatures and soil moisture of the seedbed in the spring. Vallentine (1989) reported wet periods may last only 2 days, but seeds of most grasses that do not germinate are able to survive. If the wetting period lasts 5 days or longer, most seeds germinate and seedlings are able to survive subsequent drought periods of 5 to 7 days. Wester and Dahl (1983) reporting on studies in west Texas, concluded that alfalfa requires at least 0.4 inches (10 mm) of moisture at 75 °F (24 °C) to give high germination. Metabolic processes were initiated with only 0.2 inches (5 mm) of moisture, but seeds dried rapidly enough to halt germination before seed energy was spent if no additional moisture was received. Alfalfa seeds germinated and emerged in 3 days, and seedlings were able to survive 7 to 9 days if watered each of 2 days with 0.4 inches (10 mm) of moisture. Because alfalfa emerges so quickly, follow-up rain is needed sooner than for most grasses. Allen and others (1994) reported that seeds of some species may be able to accumulate germination events across periods interspaced with drying, and that continuous moisture is not necessary to sustain germinating seeds. Evans and Young (1987a,b) studying soil moisture conditions in arid regions of the West, found that soil moisture in the first centimeter of soil may decrease to –1.5 MPA and below in less than a week. Natural soil moisture depletion often coincides with the period of active seedling emergence.

Most seeds are conditioned to germinate in the spring after fall plantings. Fall sown seeds usually have imbibed necessary moisture, and exist in a moist medium under the snow. Seeds in this state can germinate quickly as the snow recedes. Seedlings that emerge first in the spring are better able to survive the dry summer period.

Seed Coverage and Planting Depths

Seed should be in firm contact with the soil to increase moisture availability (Stevens and Van Epps 1984), thus a majority of seeds require some amount of soil coverage (table 2). Soil can also act as an anchor to hold or maintain seed in a proper position, especially seeds with hairy or fluffy appendages that are carried or moved by wind (Booth and Schuman 1983; Stevens and others 1986). Proper depth of planting is generally governed by the size of the seed. However, the seed or fruit structure that is sown does affect planting depth. Care should be taken to distinguish between fruits and seeds. For example, dewinged utricles of fourwing saltbush are normally sown. The wings that are attached to the bracts are often quite large, as is the structure that encloses the small seed (utricle). Cleaning usually removes most of the wings. This dewinging reduces the size of the structure by three or four times. The degree or amount of wings, awns, or attached appendages removed in cleaning can affect the planting depth. In most cases, the entire structure must be incorporated in the soil to reduce or prevent differential drying.

Generally seeds of most species should be covered about 2.5 to 3 times the thickness of the cleaned seed. For small seeded grasses this would be more applicable to length than diameter. Ragsdale and others (1970) suggest not planting any deeper than seven times the diameter of the seed for plantings in Texas. The optimum planting depth for small seeded grasses, including Sandberg bluegrass and mutton bluegrass, is about 0.25 inches (0.64 cm). Planting depths of 0.5 inches (1.7 cm) are suitable for Idaho fescue, and 1 inch (2.5 cm) for larger seeds such as mountain brome and western wheatgrass (Hull 1966; Hull and others 1958; Reynolds and Martin 1968; Plummer and others 1968; Vallentine and others 1963).

Soil texture and the nature of the soil surface influence planting depth. There are few points of contact between the soil particles and the seedcoat with coarse-textured soils. Seeds have more points of contact with finer textured soils. The moisture is held tightly to the clay particles, but the soil capillaries are much finer (Young and others 1987).

Clay soils that expand and contract during wetting and drying may leave seeds in a pedestaled situation that is a harsher environment than is provided by a sandy seedbed (Koller and Hadas 1982). Clay soils generally hold more water than sandy soils, and rewetting is not required as often to maintain soil moisture for germination. Generally, seeds should be planted deeper in sandy soils than in clay or loamy soils.

Determining the appropriate seeding depth presents a paradox. The closer a seed is located to the surface, the less energy is required for emergence and initiation of photosynthesis. However, greater diurnal fluctuations in temperature and soil moisture occur near the surface that dry the soil and seed. The soil particles and soil atmosphere act as an insulation barrier to lessen changes in soil temperature and water availability (Chippendale 1949). Having at least some soil covering the seed prevents or lessens drying. The ideal seedbed is one in which the seed is firmly enclosed within soil particles to provide hydraulic conductivity of moisture to the seed (Collis-George and Sands 1959). Seed should be placed deep enough to prevent rapid drying but shallow enough to allow natural emergence.

Some seeds must be seeded on or near the surface because of physiological restrictions. Young and others (1987) list four principal physiological systems involved: (1) germination requires light or specific light quality; (2) seeds require fluctuating temperatures for germination; (3) nearly complete lack of seed reserves make rapid establishment necessary; and (4) other undefined physiological requirements that precondition germination to the surface seedbeds.

Seed placement in or on the soil influences germination through factors other than the availability of soil moisture. As mentioned, some seeds require light to germinate and burial in the soil restricts germination (Young and others 1987). In addition, soil temperature also regulates germination. Positioning seed at different depths in the soil allows seeds to germinate at different times due to differences in soil temperature. Young and others (1987) reported that soil temperature regimes have different effects upon the germination of ‘Fairway’ and ‘Nordan’ crested wheatgrass, ‘Covar’ and ‘Carbar’ canby bluegrass, and Russian wildrye.

In most situations seeding depth is based on the size or germination requirements of the primary species sown. Too often, seed mixtures are sown at one depth, based primarily on the requirements of grass species included in the mixture. If shrub and many forb seeds are sown with the grasses, different planting depths are required. Springfield (1970a) suggests that winterfat seed should be sown at a shallow depth, about 0.17 inch (0.42 cm). In his studies no emergence was achieved below 0.5 inch (1.27 cm). The optimum seeding depth for antelope bitterbrush is 0.5 inches (1.27 cm) (Basile and Holmgren 1957).

Planting seeds too deep has been a major reason for seeding failures. Forage kochia, sagebrush, rabbitbrush, Lewis flax, Palmer penstemon, and winterfat generally do best when seeded on top of disturbed soil (Stevens and Van Epps 1984). Most conventional drills place seed of these species too deep. Depth rings have been developed for use on the rangeland drill to control planting depth (Larson 1980). Depth rings, however, are fairly ineffective in loose soils and are not able to maintain shallow depths. Beside placing seed too deep in loose soil, drilling generally places the seed in the bottom of small furrows. Unstable furrows can fill in with soil following seeding before seedlings emerge. As a result seed drilled in loose seedbeds can be covered many times too deep.

With proper attention, seeds can be placed at a shallow depth when drill seeded. Also, seed can be placed at the bottom of stable furrows where moisture and temperature conditions are most favorable and seedlings ultimately appear (Hull 1970). In semiarid regions, planting in the bottom of deep but stable furrows is a useful technique as soil moisture is greater at this position in the seedbed (Tischler and Voigt 1983). Deep furrow drilling should be avoided on soils that are loose and unstable causing sloughing of the furrows.

Some soil compaction at the time of seeding can be helpful in regulating planting depths, especially in loose soils. Cultipacker seeders of various kinds have been developed (Larson 1980) to be used in seeding loose soils and planting at controlled depths.

Various drills and special furrow openers are now available and can be used to more closely control seeding depths (Baker 1976; Baker and others 1979; Haferkamp and others 1987; Hauck 1982; Monsen and Turnipseed 1990; Nyren and others 1981; Wiedemann 1987). Punch seeding and compact seeders are particularly useful in seeding loose soils and planting on the surface or at shallow depths.

It is essential that seeds having different depth requirements be sown separately at the appropriate positions in the soil. Where mixed seedings are planted, drill seeders should be used that can dispense seeds of different sizes in separate rows and at appropriate depths. Broadcast seeding followed by anchor chaining or harrowing plants seed at different depths in the soil, and is an appropriate technique for seeding mixtures. Two or more planting methods may be necessary to properly seed all species. Unless seeds can be correctly sown the chance of establishment is usually quite low. Overseeding or seeding heavily is not a corrective measure that can be used to substitute for improper seed placement.

A discussion of seeding machinery is presented in chapter 9.

Row Spacing

Row spacing recommendations have generally been developed for seeding irrigated and nonirrigated pastures, primarily with grasses. Most range-type drills use row spacings of 8 to 14 inches (20 to 36 cm). Maximum forage production of herbaceous species is not significantly affected by row spacing between 10 and 18 inches (25 to 46 cm) (Bement and others 1965; Conrad 1962; McGinnies 1960b; Springfield 1965). Consequently, most drill seeders have been designed to seed rows at these intervals. Wider row spacings on semiarid sites are generally recommended, particularly when native forbs and shrubs are seeded. Increasing the distance between rows is beneficial to the survival and growth of certain species. Plantings of globemallow, lupine, and Utah sweetvetch benefit from row spacings of between 15 and 18 inches (38 and 46 cm).

Narrow row spacings normally result in greater initial production (McGinnies 1960b; Sneva and Rittenhouse 1976), but differences disappear in later years. Narrow spacings usually foster better weed control (Cook and others 1967; McGinnies 1960b), particularly during the initial stages of community development.

Shrub seedings are becoming more important in range and wildlife projects. In general, row spacings for shrubs depend on the mature stature of each species sown. Normally, seedings of big sagebrush, winterfat, Martin ceanothus, fourwing saltbush, and antelope bitterbrush planted in rows are not adversely affected by high seedling density or close row spacings. However, seedlings of green ephedra, Saskatoon serviceberry, Stansbury cliffrose, curlleaf mountain mahogany, and skunkbush sumac are more easily stunted by severe intraspecies competition. The density of plants occurring within the seeded row has a greater affect on shrub establishment than does row spacing. In general, shrub rows should be at least as far apart as the maximum height of the shrub seeded.

Separate Row Seedings

Seeding individual species in separate rows is a useful technique (fig. 6 and 10) when using a number of species with different seedbed and establishment requirements. Seeding a mixture of grasses in certain drops of a drill, and individual forb or shrub species in other drops or furrows, allows all species a better chance to establish. Alternate row seeding has been a successful method of planting grasses with legumes or grasses with shrubs (Hafenrichter and others 1968; Leyshon and others 1981). Slow developing species benefit from being planted alone, particularly when seeded in arid situations. Grasses and legumes have been seeded in alternate rows as a means of increasing herbage production (Kenno and others 1987) and maintaining desired species composition (Gomm 1964; Kilcher 1982). Alfalfa has been most productive when seeded in separate rows from grasses on semiarid pinyon-juniper and big sagebrush ranges in Utah. Kilcher (1982) found that alfalfa comprised a greater percent of the plant composition when seeded in cross or alternate rows than in mixed rows with grasses—40 percent compared to 15 percent. Various native shrubs also exhibit better growth in separate row seedings than when seeded in mixtures with grasses.

The spacing of separate row seedings affects subsequent natural reproduction. Monsen and Shaw (1983c) found that antelope bitterbrush seedlings established better from mature shrubs originally spaced 10 ft (3.1 m) apart than from shrubs having a closer spacing. Closely spaced mature shrubs apparently shade or prevent new seedling establishment. Thus, row spacings may influence the ultimate composition of seeded species when shrubs and forbs are planted in alternate rows. Seeding shrubs in close row spacings will create shading and overstory competition. Understory species that are not able to tolerate shade can and will be eliminated. Row spacing of seeded shrubs is an important consideration in all communities.

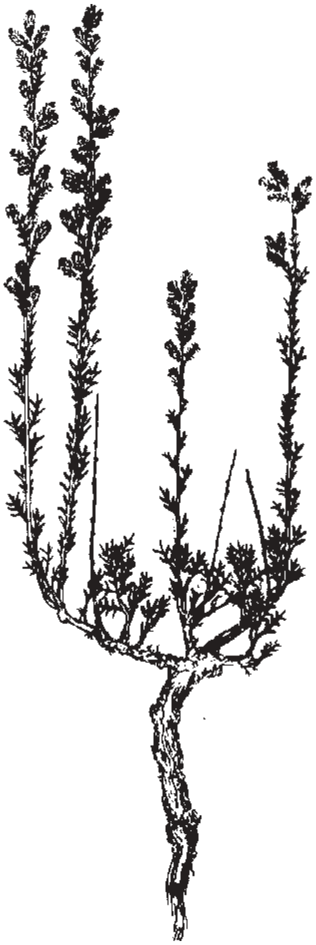
Individual species can be seeded in alternate or separate rows with some broadcast-type seeders. The Brillon seeder has been successfully used in eastern Idaho to seed shrubs through one portion of the seedbox and herbs through a separate section (Richardson and others 1986).

Separate row seedings are important in reducing the amount of seed sown. By seeding individual species in separate rows, the seeding rate can be more carefully regulated. Drills or seeders that are used must be capable of metering seed at different rates for each seed drop. Partitions must be temporarily installed in the seedbox to keep seeds separated. With some equipment the seeding rates cannot be individually adjusted for each seed drop, and carriers must be added to dilute the material and regulate the flow and amount of seed sown.

No single factor—species selection, planting depth, or planting season—can be ignored when seedings are made. Each factor is important, and unless all conditions are favorable seedings will fail. Not properly covering the seed, or planting at the wrong season because of scheduling constraints, is unwise. Because seedings are too often scheduled to accommodate other activities, failures can result and considerable funds may be wasted. Problems associated with the expenditure of funds from one year to the next have plagued agencies for many years and have resulted in numerous seeding failures. Solving such problems would significantly improve the success of rehabilitation programs.

Richard Stevens

Chapter 13



Incorporating Wildlife Habitat Needs into Restoration and Rehabilitation Projects

Habitat Concepts

Wildlife species richness, densities, and distribution are directly related to the quality and quantity of habitat (Autenrieth 1983; Autenrieth and others 1982; Bodurtha and others 1989; Call and Maser 1985; Caughley 1979; Kindschy and others 1982; Leckenby and others 1982; Reynolds 1980; Russo 1964; Thomas and others 1979a,c; Yoakum 1980). Productive big game ranges, are generally productive livestock ranges. Productive livestock ranges can, with proper planning and management, be productive wildlife ranges (fig. 1); however, many livestock range improvement projects have been detrimental to wildlife, particularly to big game and sage-grouse.

Figure 1—Productive wildlife and livestock range rehabilitation project characterized by good diversity, high quality forage, and a good mixture of grasses, forbs, shrubs, cover, and edge.

Any decision a manager makes that changes or alters a vegetative community or landscape, alters wildlife habitats. Range and wildland restoration and rehabilitation projects that increase habitat diversity will most likely be beneficial to wildlife (MacArthur and MacArthur 1961; Roth 1976; Yahner 1988). Rehabilitation projects that result in monocultures of any plant species or group of species, large open spaces, minimal edge, limited cover, and scarcity of water are undesirable and should be reconsidered. A primary goal of any wildlife or wildlife-livestock rangeland improvement project should be to improve wildlife habitat.

Each wildlife species is a product of its environment. If an area has the right combination of habitat components, it will have the potential to produce the maximum amount of healthy wildlife. If an area lacks just one habitat factor, or it is limited in quantity and quality, then it is hindered in its ability to produce a good balance of wildlife populations (Caughley 1979; Dasmann 1971; Maser and Thomas 1983; Russo 1964; Thomas and Bell 1987; Yoakum 1983). Improving nonlimiting factors without improving the limiting factors will do little to enhance the overall habitat or positively affect the key habitat users.

No two wildlife species are affected by habitat changes in the same way or to the same degree. Enhancement of habitat for all species within a given area is not always practical or possible. Key wildlife species must be identified and projects designed and implemented to meet the needs of those species. Project planning and implementation requires information on the habitat needs of each selected wildlife species.

If an area provides optimum habitat for a key wildlife species, then wildlife habitat improvement cannot be used as a justification for a rehabilitation and restoration project. Wildlife habitat improvement can be used in assessing costs and benefits of a proposed improvement project only on those areas that provide inadequate habitats for the key wildlife species and where the project will enhance habitat needs.

A key to productive wildlife habitat is diversity in space, cover, food, and water (Thomas and others 1979a,c) (fig. 2). As diversity in a plant community increases, so does the diversity and health of the animal community (Dealy and others 1981; Reynolds 1980; Thomas and others 1979c). If diversity is not increased, the project most likely will not enhance wildlife habitat.

Each plant community has its own individual potential as wildlife habitat. What is maximum diversity and productivity in one community, most likely will not be in another. Type and amount of diversity and productivity in a black greasewood community for example, will be vastly different from that in a mountain brush community.

Habitat improvement projects may be undertaken for a number of reasons:

l. Reduction in erosion and sedimentation.

2. Revegetation of depleted or severely disturbed areas.

3. Improvement of wildlife habitat.

4. Replacement of undesirable plant species with more desirable species.

5. Improvement in livestock forage production and distribution of grazing animals.

Figure 2—Well planned and implemented 3-year-old deer and elk rehabilitation project.

Whatever the basic reason for the project, these wildlife considerations should be included in the planning and implementation of all projects:

1. Identify wildlife species that use the area and the time of year the use occurs.
2. Identify wildlife species that would make use of the area and the time of year the use would occur once the project is completed.
3. Identify the key wildlife species for which the project is being designed. Key species are not limited to big game. Upland game birds, waterfowl, or nongame species might be key species.
4. Identify the types of use that the key wildlife species make or have the potential to make of an area. Types of use may include: (a) feeding, (b) sleeping and resting, (c) security cover, (d) thermal cover, (e) travel and migration, (f) breeding, (g) nesting, (h) birthing, (i) rearing, (j) social activities, and (k) watering.
5. Determine the habitat factor(s) that currently limit the key wildlife species; then plan, design, and implement projects to ameliorate the limiting factor(s).

Food and Cover

Food and cover are usually interrelated. For some animal species food and cover are provided by the same plants. Sage-grouse eat sagebrush leaves, and use the sagebrush as nesting and hiding cover. Mule deer will use sagebrush, mountain mahogany, cliffrose, Gambel oak, and other shrubs only as cover during the spring and early summer while grazing understory herbs, yet these same shrubs furnish both forage and cover in the fall and winter. Forage may be available on an area but may not be used due to the lack of proper cover.

When planning a rehabilitation project, diversity in both the vertical and horizontal community, along with the composition, location, amount, and type of cover are major components of wildlife habitat that need to be considered. Manipulation of plant communities will create gradation in vegetation between treated, and untreated areas (fig. 3). On some areas more than one revegetation technique may be necessary, due to variation in site potential over the area. The use of more than one seed mixture on a site can result in ecotones between mixtures. Ecotones commonly produce high quality, heavily used security and thermal cover, as well as forage (Yahner 1988).

Figure 3—Two well designed, 1-year-old big game range rehabilitation projects, on juniper-pinyon areas. Allowances are made for security and thermal cover, travel lanes, maximum edge area, and quality forage.

Figure 4—Mixture of native and exotic grasses, forbs (alfalfa, small burnet, Utah sweetvetch), and shrubs (mountain big sagebrush, antelope bitterbrush, and Gambel oak) on a 12-year-old juniper-pinyon rehabilitation project.

The number of species used in seeding or planting mixtures will vary with site potential, key species requirements, and economics. For maximum wildlife value, no single species should make up more than 35 percent (seed per pound, number of transplants) of any mixture. Seedings that consist of only a few species or one plant type (grass, forb, or shrubs) generally provide less productive wildlife ranges than do more varied mixtures. In many cases, wildlife values are compromised when improvement projects consist of few plant species and only one plant type.

Multi-species revegetation projects can benefit wildlife habitat by providing: (a) vertical and horizontal plant diversity, (b) increased forage production, (c) improved variety and nutritional quality in the diet, (d) more and better cover, (e) increased edge effect, (f) increased diversity of the animal communities (Stevens 1986b; fig. 4), and (g) species that will be resistant to drought, and responsive to normal and above-normal precipitation. This allows the site to be productive regardless of climatic conditions. Multi-species mixtures also help to enhance ground cover and soil stabilization, make the seedings more aesthetically pleasing, and decrease the susceptibility of the plant community to plant disease and insect problems (Stevens 1986b).

Individual Species Needs

Mule Deer and Elk

Daily and seasonally, mule deer and elk use a variety of terrain and vegetation types for cover and foraging. Migrating animals use lower winter ranges through spring, then move to higher elevation summer ranges. Fawning and calving usually occur on upper spring and lower summer ranges. Fall migration is largely influenced by weather. Snow precedes migration from fall to winter ranges. In light or moderate winters, deer and elk may not move to winter ranges at all. Elk generally winter at slightly higher elevations than deer; however, during winters with heavy and continuous snow, deer and elk may winter for various periods of time in the same area. Spring and fall ranges, therefore, need to provide plant species that will fulfill fall, winter, and spring requirements. Both cover and forage in proper quantity and quality are essential for big game animals (Brown 1987; Leckenby 1984; Leckenby and others 1982; Leege 1979b; Lyon and others 1985).

All age classes of mule deer and elk require high quality succulent forage in the spring to recover from winter stress, replenish body reserves, and to grow and reproduce at optimal rates. Thus, rangeland improvement projects on fall, winter, and spring ranges require the establishment of succulent, high quality forbs, grasses, and browse. Small burnet, Lewis flax, and Palmer penstemon are semi-evergreen forbs that provide nearly year round forage. Alfalfa, cicer milkvetch, nineleaf and Nuttall lomatium, Rocky Mountain penstemon, and arrowleaf balsamroot provide early spring growth. Utah sweetvetch, sainfoin, yellow sweetclover, crownvetch, and showy goldeneye develop later in the season. All of these species are heavily used in some seasons by all big game. Alfalfa leaves and seed heads are sought out during all seasons. Sufficient plants of alfalfa or other highly sought after species must be initially established in high enough numbers to ensure their survival, as such highly desirable plants can be killed through over use (Rosenstock and Stevens 1989). On juniper-pinyon and sagebrush-grass areas, a minimum of 1.5 to 2 lbs (0.7 to 0.9 kg) of seed per acre must be applied to ensure the establishment of a viable stand.

Indian ricegrass, bluebunch wheatgrass, needle-and-thread, Russian wildrye, mountain rye, and bottlebrush squirreltail begin growth in early spring. Species that start growth later include crested wheatgrass, sheep fescue, and orchardgrass. Grasses that begin growth last include Great Basin wildrye, intermediate, slender, pubescent, and tall wheatgrass, and smooth brome.

Figure 5—Mule deer using low elevation mountain big sagebrush.

Generally, evergreen shrubs provide more nutritious forage during the dormant season than do deciduous shrubs. Major evergreen shrubs include curlleaf mountain mahogany, cliffrose, big sagebrush (fig. 5), ephedra, rubber rabbitbrush, winterfat, and forage kochia. Serviceberry, true mountain mahogany, Gambel oak, bitterbrush, and fourwing saltbush lose their leaves in the fall and early winter and supply only twigs for winter forage.

Seed mixes should include species that fulfill seasonal forage quality requirements. Seed of a large number of species are now available; care must be used in selecting species and sources that are adapted to each site and that satisfy animals needs (Asay and Knowles 1985a,b; Ferguson 1983; McArthur 1983a; Monsen 1987; Stevens 1983a,b; Urness 1986).

Some winter and spring-fall deer and elk ranges may have sufficient browse, but lack forbs and grasses. Succulent herbaceous species can be introduced on these depleted ranges. A pipe-harrow, disk-chain, or chain can be used to thin mature depleted big sagebrush (fig. 6), fourwing saltbush, rubber rabbitbrush, serviceberry, and Gambel oak stands, and to cover broadcast seed. Spot or strip spraying with effective herbicides, and selected prescribed burns are effective methods of reducing and thinning Gambel oak, aspen, pinyon-juniper, and big sagebrush stands (Neuenschwander 1980; Wright and others 1979). Seeding of desirable species should follow. Where a single species of grass has been seeded on big game winter or spring-fall ranges, other desirable species can be established by transplanting or interseeding into scalps, pits, spots, or strips created by mechanical or chemical tillage (fig. 7) (Crofts and Carlson 1982; Monsen and McArthur 1985; Otsyina 1980; Provenza and Richards 1984; Rumbaugh and others 1981; Stevens 1981).

Livestock management can be used to increase shrub density in grass and shrub seedings. Early spring

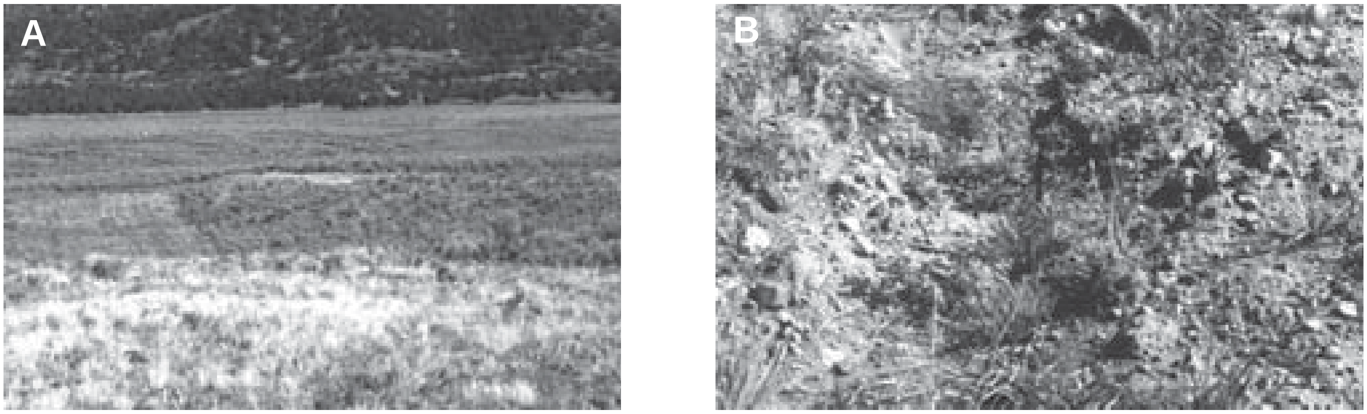


Figure 6—(A) A mature basin big sagebrush site with a depleted understory 1 year following disk-chaining in strips and seeding. This area serves as habitat for sage-grouse, as well as winter range for deer and elk. (B) Species seeded (bluebunch wheatgrass, orchardgrass, basin wildrye, alfalfa, cicer milkvetch, sainfoin, small burnet, yellow sweetclover, and forage kochia) into a disk-chained area. Forage and cover value of adjacent big sagebrush is retained, and succulent, nutritious, forage, and edge areas are provided.

grazing with cattle can be used to reduce the vigor of grasses and provide shrubs the opportunity to increase (Stevens 1986 b).

Ideal summer ranges consist primarily of grasses and forbs (fig. 8). Rangeland improvement projects in aspen, coniferous forest, and other higher elevation summer ranges are appropriate in areas that are depleted of perennials, highly erodible, and support closed, unproductive vegetative communities (Debyle 1985a; Frischknecht 1983; Lyon and others 1985; Patton and Jones 1977).

Summer succulents are generally lacking on most desert ranges. Rehabilitation project should include adapted forbs, grasses, and shrubs. The tendency has been to convert desert shrublands to single or few-species grass communities. Many of these conversion projects have decreased wildlife values. Every effort should be made to ensure that adapted forbs are included in seedings and that a variety of grasses, forbs, and where needed, shrub species are used.

Elk generally summer in aspen, spruce-fir, ponderosa pine, lodgepole pine, and subalpine areas (fig. 9). They

Figure 7—A palatable variety of rubber rabbitbrush transplanted into a crested wheatgrass field 3 years after planting. Deer, elk, and pheasants moved into and used the area once the shrubs were established and desirable forage and cover were available.

Figure 8—Excellent high-elevation summer ranges offer good diversity in forage and cover.

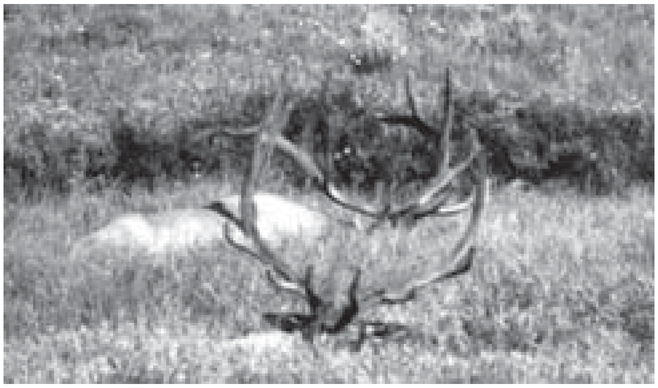


Figure 9—Elk on excellent summer range with a good mixture of succulent forbs and grasses.

prefer grasses and forbs, wet and semi-wet meadows, forest openings, and open grass herblands next to cover (fig. 10). Elk seek out clearcuts and burns in aspen and conifer forests, especially those with small openings and irregular edges (Brown 1987).

Fire can be used as an effective tool for improving wildlife habitat in aspen and conifer stands (Brown 1985b; Canon and others 1987; DeByle 1985b; DeByle and others 1989). Openings in these stands can be created by prescribed burns (fig. 11), timber harvest, fuelwood harvests, and herbicides (Harniss and Bartos 1985). Optimum size of openings for maximum elk use varies considerably. Factors affecting optimum size include variation in topography, aspect, vegetative communities, makeup of adjacent tree communities, shape of opening, location of roads, and other disturbance sources (Brown 1987; Thomas and others 1979a,c). An opening can be larger if the edges are irregularly shaped, providing maximum edge effect and ensuring that maximum distance between edges at any one point in the opening is less than 500 ft (152.4 m). Patches or islands of cover within openings are sometimes desirable (Peek and Scott 1985; Winn 1985). Greatest benefits are realized when islands are connected to edge by stringers of trees. The Interagency Workgroup (1981a) recommends that patches or islands be 30 to 60 acres (12.1 to 24.3 ha). Allen (1971) and Brown (1987) suggested that pattern and juxtaposition of cutting units and openings may be more important than number of acres treated.

On many summer ranges, forage is not a major limiting factor. Lyon and others (1985) working on elk summer ranges, concluded that selection of habitat for forage alone was a less specific requirement than selection for shelter and security. Collins and Urness (1983) found that elk preferred aspen stands over adjacent clearcut areas, even though the clearcuts produced considerably more available and palatable forage. The proper ratio between cover and forage for elk differs from area to area and from forest type to forest type (Brown 1987; Interagency Workgroup 1981a,b; Peek and Scott 1985; Thomas and others 1979c; Winn 1985). Slash left following timber harvest can adversely affect elk use of clearcuts and adjacent areas (Lyon 1975). It is recommended that slash be removed, preferably by broadcast burning to a height of less than 1.5 ft (0.5 m) (Interagency Workgroup 1981a,b).

Spring and fall ranges for elk are generally in the mountain brush and lower aspen community. Elk seek out succulents in the form of green grasses and forbs. Dry and semi-evergreen grasses and forbs, and some shrubs, are consumed during fall and spring. Rehabilitation projects in these areas should emphasize species

Figure 10—Elk prefer openings and meadows in aspen and conifer forests. Succulent forbs and grasses are preferred on summer ranges.

Figure 11—Forbs and grasses have responded to removal and thinning of mountain big sagebrush in this burned forest opening.

that green early in the spring and stay green late into the fall. Escape and thermal cover are especially important on spring, fall, and winter ranges (Peek and Scott 1985; Winn 1985). Rehabilitation and restoration projects should leave undisturbed cover in sufficient quantity and quality, strategically placed to accommodate elk and deer requirements (fig. 3). Known calving and fawning areas should be left undisturbed.

In the Intermountain West (Idaho, Montana, Nevada, and Utah), hundreds of thousands of acres of pinyon and juniper have been chained or burned and seeded. In the late 1950s and 1960s, projects involved seeding primarily introduced grasses, a few forbs (alfalfa and yellow sweetclover), and a few slow-growing shrub species. Projects usually produced large openings with little edge and a lack of thermal or security cover. As these older projects developed with time, deer and elk use increased (Barney and Frischknecht 1974; Stager and Klebenow 1987; Stevens 1986a; Tueller and Monroe 1975). Trees that were not killed during chaining have grown and now provide much needed cover (fig. 12) (Stevens 1986a; Van Pelt and others 1990). Introduced and native shrubs have had a chance to grow, reproduce, and spread (Skousen and others 1986; Stevens 1987b). Many mature seedings are now providing forage and cover for elk and deer during fall, winter, and spring. Elk especially are staying on older, more mature juniper-pinyon improvement projects the entire year (fig. 13). The question is often asked, "What are we going to do about the juniper and pinyon trees that are growing on older chainings?" As far as big game is concerned, the answer should be, "Very little or nothing." Juniper and pinyon trees, especially those over 5 ft (1.5 m) tall, provide excellent thermal and security cover. As habitat requirements were better understood and techniques, equipment, seed of additional grass, forb, and shrub species became available, projects improved. Almost immediate positive effects on mule deer and elk populations have occurred on more recent, well-planned juniper-pinyon chainings and burns. These have incorporated multi-species mixtures of succulent forbs, grasses, and rapidly growing shrubs, employed proper treatment design for maximum edge area (fig. 14), regulated size of openings, and left travel lanes and escape-and-thermal cover within the project area.

Figure 12—Young pinyon and juniper trees in an 18-year-old juniper-pinyon chaining. Deer make extensive use of forage where cover is available.

Figure 13—Eighteen-year-old juniper-pinyon project used extensively by elk year round, and by deer during winter and spring.

Thermal cover becomes very important, and many times it is the limiting factor for survival of wintering elk and deer (Fowler and Dealy 1987; Hobbs 1989). Maximum distance between edges should not exceed 325 ft (99.1 m). Best results have been obtained when groups or islands of trees have been connected with corridors and edges, rather than with isolated islands. No more that 50 percent of an area should be treated. Undisturbed areas should be no longer or no smaller than disturbed areas. Patches or islands of trees, and travel lanes (fig. 14) that are left for deer should be selected carefully. Leckenby and others (1982) recommend that either evergreen or deciduous trees and shrubs can be used for thermal cover, but they should be at least 5 ft (1.5 m) tall, and the crown closure within the island should be greater than 75 percent. Cherry (1984) recommends that security islands can be from one tree to 100 acres (40.5 ha). The size of areas left for thermal cover should be at least 2 to 5 acres (0.8 to 2.0 ha). Topographic features are used for security cover, but have limited value as thermal cover (Fowler and Dealy 1987; Wood 1988). Activities of mule deer are associated with vegetation density (Owen 1980). Security cover requirements are generally highest during fawning, calving, and hunting seasons. Optimum security cover for mule deer on shrublands has been defined as vegetation over 24 inches (61.0 cm) tall and capable of hiding 90 percent of a bedded deer from view at 150 ft (45.7 m) or less

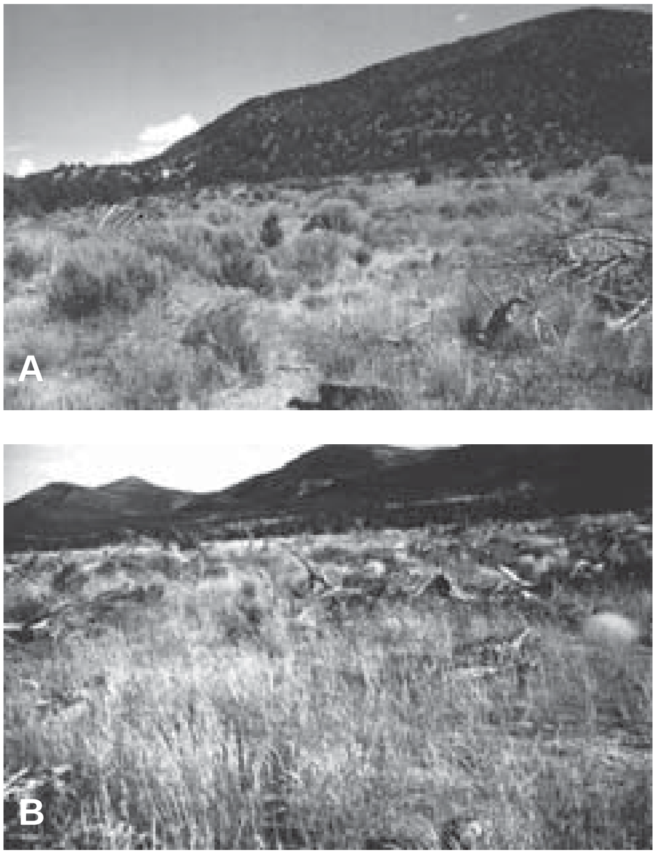


Figure 14—Five-year-old range rehabilitation projects with excellent and intermediate big game values. (A) A good mixture of succulent, early-greening grasses and forbs, and fast-growing (white rubber rabbitbrush, fourwing saltbush, and big sagebrush) and slower growing (bitterbrush and green ephedra) shrubs. Quality edge areas and security and thermal cover are available. (B) This seeding mixture was made up primarily of exotic aggressive grasses on this area. Thermal and security cover are lacking. Edges are too straight and openings too large, resulting in a project of only intermediate value.

(Leckenby and others 1982). Security cover requirements are less for bedded fawns, and more for standing fawns and mature animals. Phenological development of plants can influence the effectiveness of an area to provide cover. During the growing season, shrubs, trees, and grasses furnish maximum cover. Cover decreases as leaves drop. Size of thermal and security cover areas varies with density and height of vegetation. Areas with vegetation over 5 ft (1.5 m) tall and fairly dense can be smaller than areas with shorter, less dense vegetation or where mature conifers are highlined. Downed trees can be used as cover (Cherry 1984; Short and McCulloch 1977); however, as downed trees break up and decay their effectiveness as cover decreases.

Big sagebrush occupies a considerable area in the Intermountain West. In many places it is the dominant plant on winter and spring ranges for mule deer and elk. On many desert ranges it is browsed and used as cover year round. In the basin big sagebrush type, where the understory has been lost, the potential for range improvement is generally high. Big sagebrush can be killed with prescribed fire (Bunting and others 1987), herbicides, plows, rails, chains, and disks. Thinning and spot or strip treatments (fig. 6) are recommended on most big sagebrush ranges. A large number of grasses, forbs, and shrubs are adapted to the various big sagebrush types (Stevens 1983b, 1987a). Diversity of food and cover types over short distances is the key to enhancing mule deer populations in big sagebrush areas (Holecheck 1981). The distribution and pattern of a shrub stand is generally far more important than the quantity of brush. If sufficient sagebrush is available to meet an animal's cover and browse requirements, quantity and quality of succulent forbs and grasses become the second most limiting factor.

Ideal late fall and winter ranges for mule deer and elk are sites where shrubs extend above the snow (fig. 15). Elk and deer also make use of most herbs that are exposed by snowmelt or that extend above the snow. Austin and others (1983) report that ungrazed crested wheatgrass is more available and is used more by deer than are grazed plants. Snow around and on ungrazed plants melts faster and plants are available over larger periods of time. On some winter ranges, elk spend considerable time on open, windswept ridges where plants are exposed. Great basin wildrye (fig. 16)

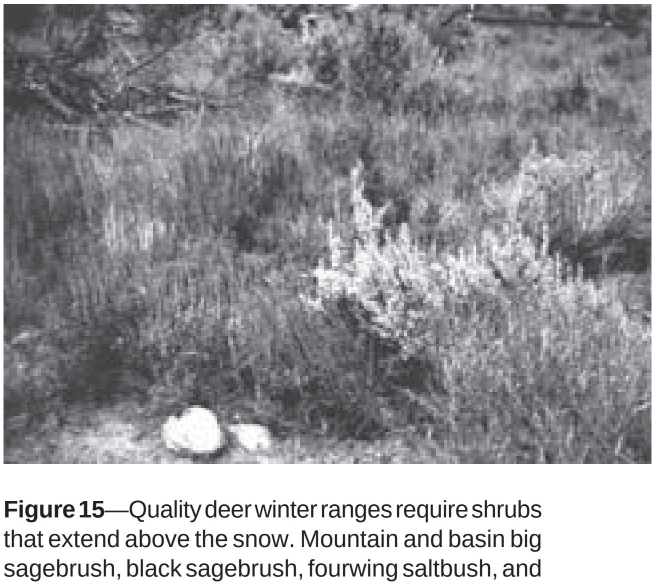


Figure 15—Quality deer winter ranges require shrubs that extend above the snow. Mountain and basin big sagebrush, black sagebrush, fourwing saltbush, and rabbitbrush are available during the winter period.

Figure 16—Elk range rehabilitation project. Great Basin wildrye was seeded to provide forage that will extend above snow level.

and, to a lesser extent, tall wheatgrass and intermediate wheatgrass are three species that can extend above moderate snow levels. Evergreen shrubs such as cliffrose, big and black sagebrush, curlleaf mountain mahogany, ephedra, rubber rabbitbrush, forage kochia, and winterfat (fig. 17), generally provide more forage than do deciduous shrubs such as fourwing saltbush, bitterbrush, true mountain mahogany, and serviceberry. In the absence of snow, or when elk and deer are able to paw through the snow, they prefer and will seek out evergreen and semi-evergreen species such as forage kochia, Lewis flax, small burnet, and Palmer penstemon. Range improvement projects should include adapted species that provide nutritious forage during the dormant season.

Figure 17—Rubber rabbitbrush, mountain big sagebrush, and forage kochia established by seeding, provide evergreen forage year round to elk and deer on an 8-year-old-rehabilitation project.

Rapid seedling development of a shrub is an important consideration in selecting shrubs for wildlife plantings (fig. 17). Big sagebrush, fourwing saltbush, winterfat, rubber rabbitbrush, and forage kochia exceed most other shrubs in their growth rate, rate of recovery following browsing, and ability of young plants to survive browsing. Planting these shrubs with slower growing shrubs is a means of providing forage and cover very quickly and allowing slower developing species time to establish (Monsen 1987). Fall, winter, and spring range improvement projects should be designed to encourage and increase desirable onsite shrubs. Bitterbrush, cliffrose, mountain mahoganies, ephedras, serviceberry, blue elderberry, big sagebrush, Gambel oak, and rubber rabbitbrush can all be suppressed by pinyon and juniper. Once the trees are removed these shrubs will respond rapidly, put on considerable growth, and may reproduce. Smooth anchor chains or cables should be used for chaining pinyon and juniper with the intent of releasing shrubs. A smooth chain does less damage to shrubs than does any other type of chain. Less shrub damage results if the chain is held taut and the crawler tractors travel further apart. When sufficient shrubs exist, shrubs can be left out of the seeding plan. Forbs and a few grasses may be seeded to fill in the interspaces and tree root pits to prevent invasion of undesirable annuals and to stabilize soils and reduce erosion.

In most cases, areas heavily used by animals are sites that are the most difficult and costly to improve. South and west facing slopes and ridgetops are generally more open and heavily used. They are also most often depleted of desirable vegetation. Poor access, less favorable soil temperatures, high evaporation rates, winds, shallow soils, predominance of annual weeds, and concentrated use by animals can reduce the success of improvement projects. Rehabilitation projects on more favorable sites such as basins, valley bottoms, and north and east facing slopes will not compensate for lack of treatment on the more preferred south and west slopes, and ridgetops (fig. 2, 3, 10, 14). It is on these latter sites where big game naturally concentrate. Many times these areas are the only sites open and available when other areas are covered with snow. Rehabilitation projects should be planned for areas most used by big game. Sites should not be selected for treatment based on forage potential (Short and McCulloch 1977) ease of treatment, or anticipated future use by big game.

Big game depredation problems on agricultural lands can be reduced, and in some cases eliminated, by providing game animals cover and an alternate source of forage. Wildlands adjacent to farm lands can be used to intercept big game. On agricultural lands deer and elk generally seek succulent plants. Where sufficient succulent and highly preferred plants are provided along with security and thermal cover, animal use can be diverted from agricultural fields. Range improvement projects with travel lanes and escape cover adjacent to agricultural fields encourage big game to use the fields. Establishment of travel lanes and escape cover that enhance access to agricultural fields should be avoided. However, at times, big game will cross large, open areas to use highly desirable forage.

Shiras Moose

Shiras moose (fig. 18) are generally found in mountain brush, aspen, mixed conifers, and subalpine communities. In central Utah they use juniper-pinyon and upper sagebrush-grass areas. As snow melts and succulent grasses and forbs appear, moose turn from their browse diet to succulent species. Grasses and forbs are used abundantly from snowmelt to mid June and early July. Willows and aspen (Babcock 1981; Wilson 1971) are major components of their diet in late summer and early fall. By September their diet is almost exclusively browse. Willow and aspen are important browse species all winter, along with Gambel oak, serviceberry, chokecherry, and true mountain, and curlleaf mountain mahogany. Depending on occurrence and availability, cottonwood, birch, elderberry, snowberry, maple, antelope bitterbrush, and cliffrose can be important fall and winter browse. It does not appear that moose use mountain big sagebrush to any great extent.

During summer months, moose require water and shade in close proximity to succulent forage. Aspen, aspen-spruce-fir, aspen-lodgepole pine, and willow bottoms are important summering areas. Movement from summer to fall and winter ranges can mean moving only from a north or east facing slope, around the hill to south- or west-facing slopes at the same elevation, or it can mean movement down a drainage, or from one drainage to another (Babcock 1981). Time of movement is triggered by the switch in diet from succulents to browse and not by snow depth. Fall, winter, and spring ranges are generally shrub communities with open side hills. Moose generally winter at a higher elevation than elk. Snow depths of 4 to 5 ft (1.2 to 1.5 m) are not detrimental to moose and do not cause them to move.

Beneficial range improvement projects on spring and summer moose ranges are those that increase herbaceous succulents. This can be accomplished by seeding adapted grasses and forbs into depleted openings in aspen, conifer, and subalpine communities that are adjacent to water and shade. Where summer, fall, and winter ranges overlap, special consideration should be given to enhancing the availability and quantity of browse. Projects should never decrease browse quantity.

Figure 18—Moose on a summer range with a variety of succulent forage.

Fall, winter, and spring range improvement projects in moose habitat should be designed to increase and improve browse. Prescribed burning or accidental fire in aspen, aspen-spruce-fir, and aspen-lodgepole pine communities can promote sprouting of aspen (DeByle 1985b). Burning closed, mature lodgepole pine stands does not generally benefit moose. Moose show particular preference for aspen reproduction. On fall, winter, and spring ranges commercial harvest, chaining, or any other type of disturbance that promotes aspen sprouting should be encouraged. Chaining and burning of thick, tall Gambel oak (Stevens and Davis 1985), willow, chokecherry, and maple stands can result in more nutritious and available browse. As on all moose range, no treatment should decrease the amount or availability of browse.

Antelope

Forage needs, plant size, and species density requirements for pronghorn antelope are specific, and critical to animal survival (fig. 19) (Yoakum 1983). Rehabilitation of antelope ranges must include consideration of proper forage and plant structure requirements (Autenrieth 1983; Kindschy and others 1982; Neff 1986; Yoakum 1980, 1983).

In most cases, rehabilitation of antelope ranges is best restricted to flats, bottoms, and valleys. Open ridges and slopes on some areas should not be treated, because plant community structure is generally adequate. Flat bottoms and valleys are the areas where forage and plant structure requirements are generally lacking. These areas frequently have the highest site potential and provide the best opportunity for rehabilitation efforts that will benefit antelope.

Shrubs are a most important component of antelope habitat. Availability of shrubs as winter forage has been directly linked to antelope survival (Barrett

Figure 19—Antelope on black sage and Wyoming big sagebrush range. This community has a good mixture of grasses, forbs, and low-growing shrubs. Clear, unrestricted vision is provided.

1982; Bayless 1969; Kindschy and others 1982; Neff 1986; Smith and Beale 1980; Yoakum 1980). Shrubs are used as cover for young fawns as well as for adults. Big and black sagebrush, low and rubber rabbitbrush, winterfat, budsage, and bitterbrush are all important forage and cover species for antelope. These shrubs should be protected and managed as a part of the natural plant community. If necessary, they should be included in improvement projects on sites where they are adapted.

Excessively high shrub density can suppress much needed forbs and grasses (Yoakum 1980, 1983). Shrubs over 2 ft (0.6 m) tall can impede animal mobility and provide cover for predators (Yoakum 1983). Yoakum (1983) suggested that a plant community containing five to 10 shrub species that comprise 30 to 50 percent of the ground cover provides optimum vegetation for antelope. Shrub communities that are too dense or too tall can be thinned using a pipe harrow, disk-chain (fig. 6), anchor chain, or rail. Grasses and forbs can be seeded prior to or in conjunction with the treatment.

Forbs are essential to antelope. Fawns as well as mature animals use forbs when available. Rehabilitation projects should be designed to encourage and increase forbs on all antelope ranges. Alfalfa is highly preferred by antelope. Other forbs that antelope use, and for which seed is available are small burnet, Lewis flax, sainfoin, Utah sweetvetch, yellow sweetclover, cicer milkvetch, globemallow, alfileria, western yarrow, balsamroot, goldeneye, lupine, and Palmer penstemon.

Monotypic shrublands and grasslands are generally poor antelope habitat. Antelope make only slight use of pure fairway crested wheatgrass stands. Considerable use is made of areas where alfalfa and other forbs are found along with fairway crested wheatgrass (Hall 1985; Kindschy and others 1982; Urness 1986; Yoakum 1979). Diversity in plant community makeup enhances antelope ranges. Forbs and grasses can be incorporated into shrub communities as well as forbs and shrubs into grass communities.

Rehabilitation projects should be designed to encourage and increase forbs on all antelope ranges. Prescribed burns are sometimes used as a range improvement technique. Burns should be planned for seasons when they are the least harmful to forbs. Livestock management plans should be designed so that severe competition for forbs between antelope and livestock is avoided.

Antelope consume grasses year-around in small amounts (Urness 1986; Yoakum 1980, 1983). Use is greatest in the spring when new growth is available. They prefer the less coarse species like the bluegrasses and fescues. Grasses should be included in rehabilitation projects, but should not make up the majority of any seed mixture.

Mature antelope generally do not require security cover; but fawns do. Security to mature antelope is clear unrestricted vision and rapid mobility. Antelope prefer low growing vegetation, open valleys, and level to moderate topography. Antelope will, however, modify their behavior according to local conditions. In central Utah, antelope are found in a number of vegetative communities ponderosa pine, aspen parklands, sagebrush grass, and salt desert shrublands.

Barriers to antelope movement include net wire fences, large bodies of water, large rivers, deep canyons, rocky ridges, and dense brush and trees. Dangerous and restrictive fences can be removed or rebuilt and dense shrubs and trees can be removed and trimmed. An inadequate water supply can restrict antelope use. Where needed, consideration should be given to developing and improving water sources.

Bighorn Sheep

Bighorn sheep are generally found in remote, rugged terrain such as mountains, canyons, and escarpments (fig. 20). The major habitat requirements for bighorn are forage, water, thermal cover, escape cover, and adequate rutting and lambing areas.

Bighorn sheep prefer to feed in open areas with low vegetation, like grasses and low shrubs (Hansen 1980). Various sagebrush-bunchgrass communities, and wet and semi-wet meadow communities are preferred. Successional communities that result from wildfire, prescribed burns, and seedings are used if location and composition are suitable. Grass can be the staple of the bighorn sheep diet. They do, however, use a variety of shrubs and forbs (Johnson and Smith 1980). Bighorn sheep are opportunistic foragers, and will adapt their diet to what is available (Browning and Monson 1980). They prefer green forage, and will move to different areas to find more-preferred forage. Bighorn sheep foraging areas usually have tree and shrub cover of

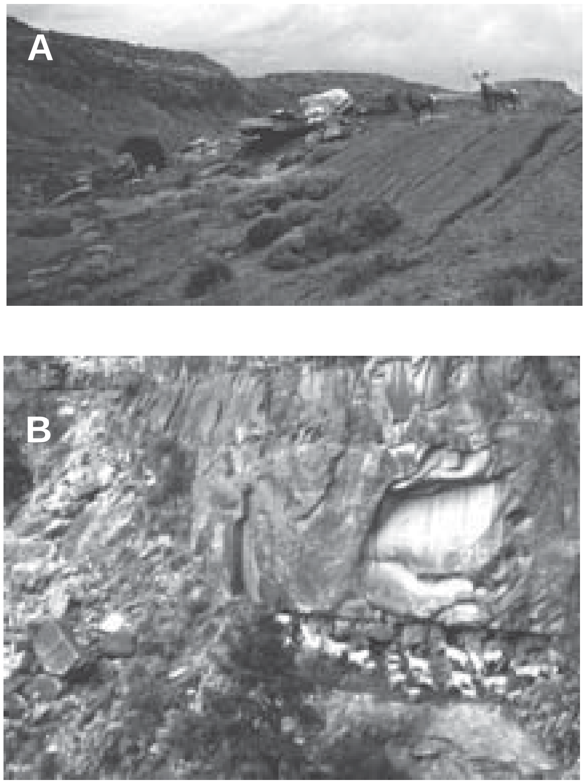


Figure 20—Bighorn sheep prefer remote, steep, rugged terrain. (A) Desert bighorn. (B) Rocky Mountain bighorn.

less than 25 percent with shrub height less than 2 ft (0.6 m) (VanDyke and others 1983).

The availability of water and escape terrain can affect the use of feeding areas. Foraging areas located more than 0.5 mi (0.8 km) from escape terrain, and farther than 1 mi (1.6 km) from water are used very little (VanDyke and others 1983).

Escape and rutting areas are generally associated with cliffs and steep, rough, rocky, inaccessible terrain (fig. 20). Disturbances, and increased human and livestock use can destroy the value of areas for escape, rutting, and lambing purposes. Travel corridors between seasonal feeding areas should be protected, and not disturbed.

Lambing and foraging areas can be improved through rehabilitation projects and water development. Because escape cover and availability of water are so important to bighorn sheep, little to no use of improved areas will occur unless escape cover and water is available. Water developments can be undertaken to improve existing sources and to make new sources available. Development of water near escape cover can make otherwise unused ranges usable.

Location of a proposed improvement project on bighorn sheep range should be considered first. Increasing the amount of open habitat and the quantity of high quality forage should be the primary goals of bighorn sheep habitat improvement projects.

Fire or chaining can be used in opening up tree and shrub stands and in improving forage quality and quantity. Where understory species density and richness is lacking, preferred species can be seeded.

Sage-Grouse

Seventy-five percent of the annual diet of an adult sage-grouse may consist of sagebrush leaves and shoots (Autenrieth 1980a). During the fall and winter over 95 percent of the diet may be sagebrush; during the spring, 85 percent; and during the summer, 40 percent. The species and subspecies of sagebrush used varies among areas. The birds do, however, make more use of shrubs where adequate cover is provided.

Forbs are especially sought out by both adults and young during spring and summer. Insects and forbs are very important to chicks and subadults (Autenrieth 1980a; Roberson 1986). A chick's diet for the first 30 days may consist primarily of insects. Brood-rearing areas, therefore, need to contain a rich diversity of forbs and shrubs; which in turn will help supply an abundance of insects. Wet meadows are important brood-rearing areas, as they provide an abundance of forbs and insects.

Over the past 150 years, hundreds of thousands of acres of prime sage-grouse habitat have been disturbed or destroyed by excessive livestock use, construction activities, mining, petroleum production activities, fire, herbicides, mechanical treatment, and the seeding of grasses (Braun and others 1976, 1977; Fleischner 1994; Swenson and others 1987). All of these factors have resulted in fragmentation and reduction of sagebrush communities. Many remaining sagebrush areas are too small to support viable sage-grouse populations. Populations have been over-harvested in many areas. From loss of habitat and over-harvest, sage-grouse densities have decreased in many areas, and populations have been completely eliminated in others (Autenrieth 1980b; Welch and others 1990).

Range and wildland rehabilitation projects that take into consideration the habitat requirements of sage-grouse provide benefits for both wildlife and livestock. When sagebrush control is being planned, serious consideration should be given to sage-grouse habitat requirements. These requirements have been identified and described by a number of agencies and authors (Autenrieth and others 1982; Braun and others 1977; Call 1979; Call and Maser 1985; Roberson 1986). These authors report sage-grouse require year round, quality sagebrush habitat for breeding, nesting, brood rearing, loafing, and cover.

Hens nest almost exclusively under big sagebrush plants. They prefer tall plants and those with an umbrella type canopy (Autenrieth 1981; Call 1979) (fig. 21). Canopy cover requirement for nesting has been found to be from 20 to 40 percent (Roberson 1984; USDA Soil Conservation Service 1975). If there is too much or too little canopy cover, nesting will not occur. Nest success and early brood survival appear related to residual cover of grasses and forbs during April through June (Drut and others 1994; Gregg and others 1994). It has been found (Beck 1977; Patterson 1952) that winter survival is dependent upon the amount of sagebrush available from January through March. Within each range rehabilitation project, the specific type of use that occurs within the area needs to be identified.

Sagebrush control, thinning, or other efforts aimed at reducing shrub density should not occur on wintering areas, within 2 mi (3.2 km) of a lek (fig. 22), when nesting or brooding habitat is limited, or during periods of nesting and brood rearing. Sagebrush density should not be reduced when live sagebrush canopy cover is less than 20 percent (this does not mean an average of 20 percent of the complete area, but 20 percent where sagebrush reduction is to occur), on shallow soils, or where sagebrush is less than 12 inches (30.5 cm) high (Braun and others 1977; Call 1979; Call and Maser 1985). Mountain big sagebrush adjacent to spruce-fir and aspen should be avoided or treated very sparingly. Ideal brood-rearing areas should have meadows or herbland openings next to or within sagebrush stands. Meadows and herblands can have invading shrubs removed. No sagebrush control should occur within 300 ft (91.4 m) of meadows, herblands, and streams (perpetual or intermittent).

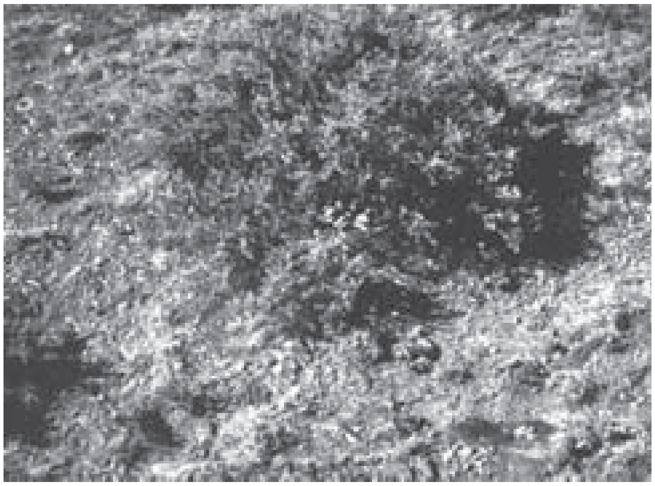


Figure 21—Sage-grouse nest under an umbrella canopy of mountain big sagebrush.

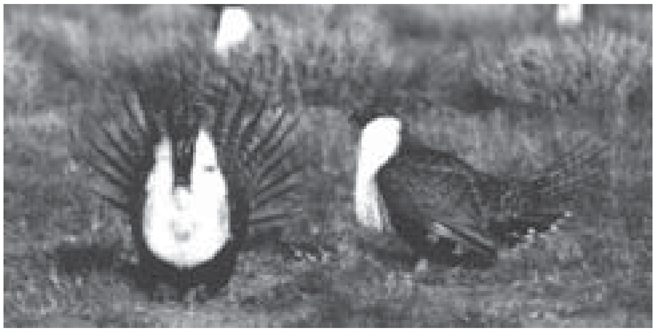


Figure 22—Male sage-grouse on a lek.

Ridgetops and slopes in sage-grouse habitat are generally not treated because sagebrush is generally sparse in these locations. Bottoms and meadows are more likely areas for sagebrush control.

A number of techniques are available for enhancing meadows, increasing herbs within sagebrush stands, increasing edge, and changing the vertical and horizontal structure of a sagebrush stand. Sagebrush stands can be improved for sage-grouse by strict and proper use of a number of herbicides; however, mechanical control and prescribed burns are the most desirable techniques.

The most widely used herbicides are 2,4-D and Roundup. Herbicide application early in the spring, when the ground is still covered with snow, is preferred as it will kill only those sagebrush plants that extend above snow level, and not the forbs. Spraying following snowmelt will increase sagebrush kill and also kill most emerged forbs (Carpenter 1974). Proper use of an herbicide will thin dense sagebrush and release understory forbs and grasses.

Herbicides can also be used to create mosaics in sagebrush stands and to increase edge area. Care must be taken when applying herbicides to ensure that only targeted areas are sprayed. To avoid herbicide drift, spraying should not occur when windspeed is greater than 6 mi per hr (9.7 km/h). Spraying is best done with ground rigs and from low-flying helicopters. When herbicides are used to create openings, only irregular strip and spot spraying should occur. A total of no more than one third of any area should be sprayed (including the area affected by drift). Treated areas should not be wider than 100 ft (30.5 m) (Klott and Lindzey 1990; USDA Soil Conservation Service 1975), and unsprayed areas should be as wide or wider than the sprayed areas.

When range rehabilitation projects are done on sage-grouse areas, anchor chaining, and the use of a pipe harrow is preferable to the use of herbicides. A pipe harrow can be used to: (1) thin sagebrush stands; (2) create edge area and mosaic openings;

(3) encourage forb, grass, and meadow communities by removing competing shrubs; and (4) prepare seedbeds and cover broadcast seed. Meandering strip chaining, pipe harrowing, or light disk-chaining following terrain features are preferred methods (fig. 6). Block and checkerboard clearing and thinning of large areas are not recommended. As with herbicide treatments, treated strips should not be wider than 100 ft (30.5 m) (Klott and Lindzey 1990), nor cover more ground than the untreated areas. When chaining, less damage will occur to shrubs when the chain is dragged somewhat tight rather than in a deep U or J shape between the crawler tractors. Plowing and disking of sagebrush is very destructive to sage-grouse habitat and is not recommended. When disturbance does occur, desirable species should be seeded to establish desirable plant cover and to prevent establishment of annuals. A number of forb species are available that can be seeded successfully into various sagebrush and meadow communities. These include: alfalfa, white and yellow sweetclover, adapted clovers, birdsfoot trefoil, crownvetch, cicer milkvetch, lupine, sainfoin, small burnet, Rocky Mountain and Palmer penstemon, western yarrow, Lewis flax, globemallow, vegetable-oyster salsify, Louisiana sage, alfileria, lomatium, showy goldeneye, and Nevada goldeneye.

Prescribed burns, when used properly, can be beneficial to sage-grouse. Meadow areas and valley bottoms that are being invaded by sagebrush and other shrubs can be burned to remove shrubs. Shrub removal can result in meadow enhancement and healthier insect populations. Fire should occur early in the spring, prior to forb and grass emergence, or in the fall after grasses and forbs have dried. In the spring, snow will leave areas with sparse shrub cover prior to areas with heavier cover. Fire should be set only in the snow free areas (meadows and bottoms). Snow and damp ground can help confine the fire to the desired areas and can result in an improved mosaic burn pattern. Forbs and grasses are generally not out of the ground immediately following snowmelt and are less harmed by fire (Wright and others 1979). Fire can create openings that may be used as leks. Call and Maser (1985) recommended that such lek openings be of l to 10 acres (0.4 to 4.0 ha).

Wet to semiwet meadows are important to sage-grouse. Those that have deteriorated through livestock use lack forbs and desirable species. Proper livestock management of riparian sites will significantly benefit sage-grouse.

Columbian Sharp-Tail Grouse

Columbian sharp-tail grouse are absent from 90 percent of their original range (Marks and Marks 1988) due to loss of habitat caused by farming activities, excessive grazing, fire, herbicides, and mechanical disturbance. Sharp-tail grouse habitat consists primarily of hills, benchlands, and rolling topography dominated by sagebrush and perennial grasses, with adjacent mountain brush and aspen. They also inhabit riparian areas extending out into sagebrush-grass areas (fig. 23) (Klott and Lindzey 1990; Marks and Marks 1988).

The diet of Columbian sharp-tail grouse is made up primarily of seeds, leaves, and floral parts of forbs, grasses, shrubs, and agricultural crops. During winter, buds from chokecherry, serviceberry, mahogany, poplar, maple, rose (hips), aspen, and hawthorn are used extensively (Hart and others 1950; Marks and Marks 1988; Marks and Marks 1987; Moyles 1981).

Once snow is deep enough to allow sharp-tail grouse access to sagebrush seedheads, considerable use is made of the seed, floral parts, and upper leaves. Snow may, however, cover up this important source of food and cover. Insects are very important in the diet of juvenile birds 2 to 4 weeks old.

Cover, feeding, nesting, and brood-rearing areas are closely associated with edge areas, riparian areas, and communities having a rich diversity of shrubs, forbs, and grasses. Lek are very sparsely covered by low stature vegetation, often having numerous bare areas (Kobridger 1965; USDA Forest Service 1985; Waage 1989; Ward 1984). Areas of use can vary between seasons (Marks and Marks 1987; Moyles and Boag

Figure 23—Columbian sharp-tail grouse on a 5-year-old grass-forb seeding.

1981). Movement to wintering areas can be triggered by snow depth and availability of food and cover.

Sharp-tail grouse prefer mixed vegetative communities. Shrub communities with a variety of cover types and a diversity in food items are preferred. Canopy cover of shrubs should not exceed 20 to 40 percent (Marks and Marks 1987; McArdle 1976). Dense sagebrush stands can restrict the grouse's visibility, adversely affect the desired variety and abundance of understory forbs and grasses, and provide ideal habitat for predators. Sharp-tail grouse habitat can be enhanced by proper vegetative manipulation (Autenrieth and others 1977). Reducing the density of sagebrush, creating mosaic patterns within various plant communities, and introducing desirable and adapted grasses, shrubs, and forbs can all improve sharp-tail grouse habitat. Plant communities can be thinned by chaining, disk-chaining, use of herbicides, and fire. The same precautions and concerns expressed for the use of herbicides on sage-grouse range apply to sharp-tail grouse range.

Comparing the effects of chaining, spraying, and burning on sharp-tail grouse activities, McArdle (1976) found that sharp-tail grouse showed a definite preference for rehabilitated areas during spring, summer, and fall, and that chained areas were most preferred. Cover, edge area, and quantity and quality of food were greatest on the chained areas. Mosaic patterns can be effectively created and desirable species seeded with the proper use of a disk-chain followed by seeding (fig. 6). DeByle (1985c) reports that sharp-tail grouse prefer the early successional stages of aspen, which would suggest that fire or logging can be used to remove mature aspen and increase sprouting, thereby increasing sharp-tail grouse use. Variation in vegetative communities, species composition, density, cover, edge area, and disturbance is especially important within a 1 mile (1.6 km) radius of leks (Baydack and Hein 1987; USDA Forest Service 1985; Ward 1984).

Preferred species that can be seeded on favorable sites include: alfalfa, small burnet, Lewis flax, lupine, yellow sweetclover, cicer milkvetch, sunflower, balsamroot, yarrow, showy and Nevada goldeneye, wheatgrasses, perennial and annual grains, Great Basin wildrye, and orchardgrass.

Ruffed Grouse

Aspen is the primary home of ruffed grouse in the Intermountain West. Aspen is heavily used as food and cover throughout most of the year (fig. 24) (Barber and others 1989a,b; DeByle 1985c; Doerr and others 1974; Phillips 1965; Roberson and Leathan 1988). However, an aspen community must possess suitable density and plant species composition to make it good grouse habitat.

Figure 24—Ruffed grouse.

During the spring, ruffed grouse feed almost exclusively on aspen flower buds, catkins, and leaves (Barber and others 1989b). As the season progresses, catkins and leaves of other poplars and willows and leaves of emerging forbs are consumed. During the summer months, leaves, fruits, and seeds of forbs, grasses, and sedges are selected. In the fall, the diet gradually changes to leaves and flower buds of mature aspen. Rose hips, and seeds of forbs, especially those of meadowrue are very important and are used extensively. Winter diets are dominated by buds and twigs of mature aspen, chokecherry buds, and rose hips. Buds of willow, serviceberry, and maple are also used (Doerr and others 1974; McGowan 1973; Phillips 1967). Fruits and seeds are used when available. Chicks use insects very heavily for the first 5 weeks and then start to use increasing amounts of vegetative matter (Barber and others 1989b; DeByle 1985b,c; Gullion 1968; Landry 1980; Phillips 1965).

The home range of males and females is generally small, 20 to 50 acres (8.1 to 20.2 ha). Small home ranges are characteristically found in localized, widely separated patches of suitable habitat, or in areas with considerable diversity of habitat types.

Ruffed grouse do not generally migrate. They are the most widely distributed nonmigrating game bird in North America (Barber and others 1989b). In the Intermountain West they are found year round in aspen, spruce-fir-aspen mixes, and in patches of maple and other shrub species along streams and around springs.

Preferred habitats are those that have a diversity of plant communities. The single most important component of ruffed grouse habitat is brood cover (Barber and others 1989a,b; Landry 1980). Good brood habitat consists of sapling aspen, intermediate aged aspen, and aspen intermixed with, or adjacent to, mountain brush species along streams with sufficient understory of grasses and forbs to supply quality summer food (Barber and others 1989a,b; Gullion 1990; Runkles and Thompson 1989; Thompson 1989). Summer and fall activities are greatest in sapling and immature aspen stands; winter and spring activities are greatest among mature aspen.

Well planned and executed vegetative manipulation can be beneficial to ruffed grouse. The goal in habitat improvement should be to provide a diversity of aspen age classes so that food, roosting, and cover requirements are met in a manner consistent with the limited mobility of this bird (Gullion 1990; Thompson 1989). A number of recommendations for improving ruffed grouse habitat have been made (Gullion 1968, 1990; Landry 1980; Utah Division of Wildlife Resources 1978). Recommendations include: aspen saplings 5 to 25 years old, with densities in the range of 3,000 to 8,000 per acre (7,400 to 12,300 per ha); small irregular clearcuts up to 10 acres (4.0 ha) in size, but no more than 330 ft (100.6 m) wide; burning of clearcut areas following cutting; use of cutting cycles and cutting patterns that will maintain both young and old aspen in close proximity or interspersed; maintenance of dense shrub borders and the seeding of clearcuts; burns; creation of disturbed areas with succulent forbs (with special emphasis on clovers, vetches, other legumes, and shade tolerant succulent grasses).

Blue Grouse

Blue grouse are migratory. In the summer and fall they can be found in aspen, mountain brush (fig. 25), and mountain big sagebrush. In the late fall they generally migrate up in elevation into Douglas-fir, subalpine fir, Engelmann spruce, and other higher elevation conifers (Roberson and Leatham 1988). Spring migration is triggered by snowmelt. Birds move down in elevation when openings in the snow appear under the aspen, in the mountain brush, and the mountain big sagebrush communities. Fall movement generally occurs in September (Rogers 1968; Utah DWR 1978; Weber 1975).

Conifers are used extensively in the winter for cover and food (Hoffman 1961). In Utah, Douglas-fir needles are the single biggest winter food item. Considerable use is also made of currant bushes as cover. In the summer, adults feed extensively on seeds and leaves of forbs, especially legumes. As the season progresses and the forbs dry up, feeding shifts to leaves of shrubs, particularly serviceberry and snowberry. Juvenile birds' major food item for the first 3 months of life is insects, especially grasshoppers (Weber 1975). Plant material and seeds become more important as they grow and mature.

Figure 25—Blue grouse make extensive use of conifer and deciduous trees for cover and food.

Weber (1975) reports that most nesting occurs under mountain big sagebrush. Diversity in community makeup is very important to blue grouse. They prefer areas with trees, shrubs, open flats, and riparian sites in close proximity to each other.

Vegetative rehabilitation projects can be beneficial to blue grouse if planned and executed properly. Items that should be considered on blue grouse ranges include: creation of small openings or clearcuts up to 5 acres (2.0 ha) in any of the inhabited communities; creation of openings with maximum edge area; and seedings that include the maximum number of succulent forbs, with special emphasis on legumes. Openings can be created by clearcutting, prescribed burns, chaining and proper use of herbicides, plowing, and disking. All treatment methods should result in a mosaic treatment pattern.

Chukar Partridge

The chukar prefers arid, rough foothills, and low mountainous country that consists of steep rugged ranges with cliffs, bluffs, rocky outcrops, talus slopes, and brushy creek bottoms and swales (BLM 1970; Bohl 1957; Roberson and Leatham 1988; Young 1981). Areas inhabited by pinyon, juniper, big sagebrush, black sagebrush, bitterbrush, ephedra, rubber rabbitbrush, broom snakeweed, and bunchgrasses are prime chukar habitat (fig. 26). Cheatgrass can be the principal understory or interspace species.

Chukar migration is very limited. In early fall, birds tend to move to lower elevations. When annual grasses germinate and green up in the hills and canyons, birds move into these areas. Heavy snow will move chukars to lower elevations (USDI Bureau of Land Management 1970; Bohl 1957; Molini 1976). Cover requirements are generally met with rocky outcrops, talus slopes, cliffs, small trees, and sagebrush.

Figure 26—Chukar partridge on winter area consisting of juniper, big sagebrush, and annual and perennial grasses.

Nesting is on the ground next to or under rocks and shrubs.

Chukars will eat grains, fruits, berries, and plant parts including stems, blades, and seeds. Plant material from perennials and annual forbs and grasses are consumed (Bohl 1957; Roberson and Leatham 1988). Alfalfa leaves are highly preferred. Cheatgrass is a major food item, seeds and leaves are consumed year round (USDI Bureau of Land Management 1970; Christensen 1970; Young 1981). Insects, principally grasshoppers, beetles, crickets, and ants are also consumed. Most feeding occurs within 1 to 2 miles (1.6 to 3.2 km) of water. Availability of water can be important on dry, summer ranges.

Most range and wildland rehabilitation projects are designed to reduce the density of cheatgrass and shrubs associated with chukar habitat. Care should be taken to identify areas important to chukars. When major chukar populations exist, rehabilitation projects should not occur that will adversely affect chukar habitat. Projects that leave islands of shrubs and cheatgrass, or irregular edges within these types, can benefit chukars. Seedings in treated areas should not be composed of any one species but should include succulent species. Improving available water sources can be most critical on many ranges.

Water

Water is critical to the survival of all wildlife. All areas must have sufficient water available throughout all seasons. Free or running water or moisture contained in snow may be satisfactory. Most gallinaceous birds are able to satisfy their water requirements from dew and succulent forbs, if available (Barber and others 1989b).

Many rehabilitation projects may be unused by wildlife because water is lacking during specific seasons. Water should be a major consideration of every improvement project, especially on arid desert ranges (Gubanich and Panik 1987; Hervert and Krausman 1986). Water is generally less limiting on more mesic summer and spring-fall ranges. Snow, when present, can provide sufficient water for most species. When water is unavailable, provisions need to be included in rehabilitation projects for the development of water sources. This could include the development of springs or wells, construction of water catchment structures (Frasier 1985; Menasco 1986), and the diversion of water from one point to another.

Care must be taken when developing a spring and transferring water to another area. Some water must be retained throughout the year at the spring or collection site. Water catchment devices and areas need to have water available to all wildlife at all times. Water catchments cannot be emptied by livestock when wildlife remain in the area. Water troughs should not be turned off or accessibility to watering areas restricted when livestock leave the area (fig. 27). All too often, when springs are developed and the water is moved to a trough, the free water that previously existed at the source is eliminated. Such developments also damage or eliminate the attendant mesic vegetation, and riparian values that may be present.

Some water developments may not be beneficial to wildlife. Extending water to new areas can encourage and increase livestock use in areas where they were once seldom grazed, especially on fall-winter-spring ranges. This may be especially harmful if it is an area that presently receives use by wildlife near or above carrying capacity. Water development can also increase livestock and human use of areas during critical periods, such as calving, fawning, lambing, and nesting. Water developments generally require access roads, which may or may not be beneficial to wildlife.

Figure 27—Guzzler water development on sheep and antelope range. Once livestock leave the area, water must be left on for antelope and other wildlife.

Water development requires continual maintenance to ensure that water is available when needed (fig. 28).

Provisions need to be made so that birds, small game, and nongame species can gain entry to troughs and tanks (Hervet and Krausman 1986; Menasco 1986). Escape ramps should be installed to allow escape if they fall into the trough or tank.

Fences

Fences can be both harmful and beneficial to wildlife. Properly placed fences can be used to control intensity, duration, and time of livestock and human activities on wildlife ranges.

Calving, lambing, fawning, and grouse nesting areas need to have livestock and humans excluded and access restricted during these periods. All rehabilitated sites require restricted grazing for various periods of time. Big game and sage-grouse winter and spring ranges need to have human activities limited. This is especially important during periods when animals are under stress due to weather conditions, of limited food supply, and reproductive activity. Both depleted and rehabilitated riparian areas generally require considerable protection from livestock, humans, and in some cases, wildlife, to become healed and stabilized. Fencing can be used to protect riparian sites, springs, seeps, and other water areas.

Figure 28—Water sources require constant maintenance and checking to ensure that water is available when needed by wildlife.

Improperly placed and constructed fences can be harmful to big game by excluding or limiting wildlife use of critical watering, foraging, and cover sites. Fence height can restrict movement of big game. Barbed, smooth wire, netting, or their combinations under 42 inches (1.1 m) tall generally do not restrict movement of healthy mule deer and elk. A few animals may “hang up” on 42 inch (1.1 m) or shorter fences, but the majority of animals that are killed in fences are on those taller than 42 inches (1.1 m). Antelope and bighorn sheep require fences they can go through. Helvie (1971) has given guidelines for fences built in areas occupied by bighorn sheep. He recommends that fences should not be constructed with woven wire, but with smooth or barbed wire strands spaced 20, 35, and 39 inches (0.5, 0.9, and 1.0 m) above the ground, or be a lay-down type that can be let down when needed. Improperly constructed fences can restrict movement and cause mortality, especially for rams that get their horns tangled in the wire (Welch 1971).

Fences can be modified to allow antelope passage (Anderson and Denton 1980). Autenrieth (1983), Kindschy and others (1982), Neff (1986), and Yoakum (1980) describe antelope fencing construction. Smooth wire is the most favorable type with the lowest wire being at least 16 inches (0.4 m) off the ground. This size opening will allow the antelope to pass under. Barbed wire can be used on the upper strands but is not recommended. Net wire fences will not allow antelope and bighorn sheep to pass. When net wire fences are built they should have sufficient strategically located and specifically built openings and pass through spaces so that normal movement to feeding and watering areas, and to seasonal ranges is not disrupted or stopped (Mapston and ZoBell 1972).

Electric fences, when properly constructed, are an effective means of controlling livestock, humans, and big game. Electric fences have been used to prevent use by livestock and big game of hay stacks, and feed yards, and to alter the use of agriculture areas, campgrounds, riparian sites, and small, treated disturbances.

Roads

All rehabilitation projects require access for people and their machines. This may involve construction of some type of road and, in some isolated areas, an air strip. Roads can be beneficial to wildlife by providing: (1) a means whereby rehabilitation projects can be completed, (2) access for habitat management, (3) access for harvest and observation of wildlife, (4) increased and improved law enforcement activities, (5) an increase in edge area and diversity of plant development and growth along the road, where extra water is collected, (6) road bars, when properly constructed, act as water collection and storage areas, and (7) access for fire control. On the other hand roads can be detrimental to wildlife by: (1) increasing human and livestock activity (especially during critical periods), (2) increasing harvest of game animals, (3) increasing poaching, (4) reducing wildlife use, (5) increasing the chance of human-caused fire, (6) encouraging off-road vehicle travel that can reduce the production and effectiveness of a rehabilitation project, and (7) increasing soil erosion.

All roads associated with a rehabilitation project need to be evaluated prior to construction and following completion of the project. Road location can be critical. Calving, fawning, nesting, brood rearing, riparian areas, travel and migration lanes, leks, and meadow edges should be avoided when locating roads. Nonessential roads and disturbed areas should be closed and revegetated. Properly closed and revegetated roads in forested areas can be used extensively by big game.

In selecting species for the rehabilitation of cuts, fills, and disturbed areas associated with roads and highways, big game feeding habits and preferences should be considered. Establishing evergreen or semievergreen species, species that green early or stay green into the summer, and shrubs and trees that provide cover can actually encourage big game use and increase chances of big game-automobile collisions. In an effort to reduce such accidents, low-growing, unpalatable species of grasses, forbs, and shrubs should be used along highways.

Bruce L. Welch

Chapter 14

Nutritive Principles in Restoration and Management

Most range management or revegetation programs are aimed at providing forage to support the needs of range animals. Among these needs are supplying the nutrients required to drive the physiological processes of the animal body. One major principle in this report is that there is no “perfect forage species” that will supply all the nutrients needed by any range animal for all seasons. The best approach to range management or revegetation is to supply a diversity of palatable shrubs, forbs, and grasses. Major topics to be discussed are (1) nutrient requirements of range animals, (2) judging the nutritive value of range plants, (3) factors affecting the nutritive value of range plants, and (4) seasonal nutritive value of range plants.

Nutrient Requirements of Range Animals

It is a fundamental principle that effective range management or revegetation programs rest on knowing the nutritive requirement of the target animal. The nutrient needs of range animals can be divided into five classes: dry matter intake, energy-producing compounds, protein, minerals, and vitamins.

Dry Matter

Intake of dry matter by range animals varies according to the weight and activity of the animal. Greatest consumption of dry matter, with weight held constant, occurs with lactation, followed by growth, as a percent of live range animals. This is of considerable importance to the range manager when it comes to calculating carrying capacity. Dry matter intake of selected range animals is tabulated in table 1.

Energy-Producing Compounds

From a quantitative point, energy-producing compounds make up the single largest class of nutrients needed by range animals. A lack of sufficient energy is probably the most common manifestation of nutritional deficiency in range animals (Dietz 1972). Range animals can derive energy from a variety of compounds including sugars, fats, pectins, starch, and protein. In ruminants and other range animals that can support fermentation digestion, energy can be derived indirectly from cellulose and hemicellulose.

To understand the energy requirements of range animals, the range manager or revegetation specialist needs first to understand the various terms that are used to express the energy requirement.

Energy requirements of range animals are expressed in several forms such as total digestible nutrients, digestible energy, metabolizable energy, and net energy. Total digestible nutrients, a noncaloric measurement, is the sum of all the digestible organic matter (crude protein, crude fiber, nitrogen-free extract, and crude fat) in a forage. Because fat supplies 2.25 times more energy than protein or carbohydrates, the fat content is multiplied by this 2.25 energy factor to calculate this principal measurement (table 2). The total digestible nutrients requirement of an animal is expressed as kg per animal per day or as percent of the diet. For range managers or revegetation specialists the latter expression is the most useful.

Digestible energy, a caloric measurement, is calculated by subtracting the caloric content in the feces from the caloric content of the range forage. The caloric content of a range forage is often called gross energy. In turn, metabolizable energy is calculated by subtracting the caloric content in the urine and gases lost from the body from the digestible energy of the range forage. Net energy then is calculated by subtracting the calories used to produce body heat from metabolizable energy. Net energy thus represents the amount of energy an animal has for maintenance and production. The relationship of these three caloric energy measurements was demonstrated (fig. 1). Range animal requirements for any one of these measurements is expressed as megacalories per animal per day or as

Table 1—Daily dry matter consumption by selected range animals. Data expressed as pounds of dry matter consumed on a daily basis and as a percentage of live weight (Halls 1970; National Academy of Sciences 1975, 1976, 1977, 1978, 1982, 1984).

			Dry matter	
Animal	**Activity**	**Weight**	**Per day**	**Live weight**
		- - - - - Lbs - - - - - -		*Percent*
Sheep (ewes)	Maintenance	110	2.2	2.0
		132	2.4	1.8
		154	2.6	1.7
		176	2.9	1.6
	Last 6 weeks of gestation	110	3.7	3.3
		132	4.2	3.2
		154	4.6	3.0
		176	4.8	2.8
	Lactation	110	5.3	4.8
		132	5.7	4.3
		154	6.2	4.0
		176	6.6	3.7
	Growth	66	2.9	4.3
		88	3.1	3.5
		110	3.3	3.0
		132	3.3	2.5
Cattle	Maintenance	881	13.4	1.5
		1,102	15.9	1.4
		1,323	18.3	1.4
	Gestation	881	16.5	1.9
		1,102	19.0	1.7
		1,323	21.4	1.6
	Lactation	881	23.8	2.7
		1,102	26.0	2.4
		1,323	28.4	2.1
	Growth	661	19.4	2.9
		881	24.3	2.8
		1,323	26.5	2.0
Horses	Maintenance		16.4	
	Gestation		16.4	
	Lactation		21.5	
	Growth		13.2	
Deer	Maintenance		2.2	
	Gestation		2.5	
	Lactation		3.0	
Elk	Maintenance (mature)		9.6	

Table 2—How the amount of digestible nutrients are calculated for a hypothetical range forage.

Nutrient	Total nutrients in 100 kg	Digestion coefficients	Digestible nutrients
	kg	- - - - - - *Percent* - - - - - -	
Crude protein	9.0	50.0	4.5
Crude fiber	30.0	40.0	12.0
Nitrogen-free extract	50.0	50.0	25.0
Crude fat	11.0	50.0 (2.25)	12.4
Total digestible nutrients			53.9

megacalories per kg of dry matter. The latter expression is the most useful for range managers or revegetation specialists.

Energy needs of range animals vary according to weight and activity (lactating, fattening, growing, gestation). Larger animals require more kilograms of total digestible nutrients per day for a given activity than smaller animals, yet when total digestible nutrients is expressed as a percent of the diet the percentage is the same. This is due to differences in dry matter intake. Thus a large animal extracts more kilograms per day of total digestible nutrients than a smaller animal eating the same forages. Similarly, a lactating female requires more energy than a nonlactating female of similar weight. On a constant weight basis, lactation requires the greatest amount of energy followed by fattening, growing, gestation, and maintenance. Table 3 lists the energy requirements of selected range animals. Unfortunately, the total digestible nutrients content or amount of metabolizable energy is unknown for many range forages. More information is expressed as *in vitro* digestibility. I have attempted to express the energy requirements of range animals in terms of *in vitro* digestibility (table 4). Maintenance was set at 50 percent *in vitro* digestibility with all other activities adjusted accordingly (Ammann and others 1973).

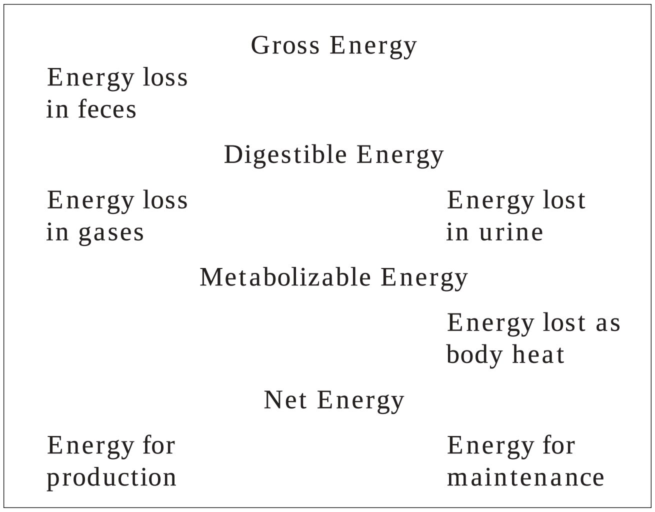


Figure 1—Relationship of gross, digestible, metabolizable, and net energy.

Protein

Protein in animal bodies makes up a large chemically related, but physiologically diverse, group of compounds. Protein is the major organic compound of the organs and soft tissues of the animal body. All proteins are made from a common set of building blocks known as amino acids. It is the sequence of these amino acids along the protein molecule that gives a particular protein its character which, in turn, determines its function. Proteins are the chief component in nearly all body parts including skeletal muscle for external movement; smooth and cardiac muscle for internal movement; tendons and ligaments for tying together body parts; organs and glands such as the stomach, eyes, pituitary, and skin with its covering of hair; and other structures including hemoglobin, cytochromes, and membranes. Enzymes are also an important group of proteinaceous compounds that provide the framework in which the chemical reactions of the body take place.

Because of the involvement of protein in so many bodily functions, the animal body needs a liberal and continuous supply of protein. Like energy, the protein requirement of range animals varies according to the weight and activity of the animal. From a qualitative point, the protein requirement varies according to the type of digestive system operating in the range animal. For ruminants and other range animals that can support fermentation digestion, including horses, rabbits, burros, and sage-grouse, the quality of the protein—that is the actual amino acid makeup—is not important, only the quantity. The microorganisms responsible for the fermentation also manufacture needed amino acids from plant protein and organic nitrogen compounds.

Protein requirement of range animals is expressed either in terms of digestible protein, or as crude (sometimes called total) protein. The requirement values in the diet are expressed as grams per day or as a percentage. For range managers or revegetation specialists, the term crude protein as a percent in the diet is the most useful. As with energy, the greater the weight of the animal, the higher the protein requirement, assuming similar body activity. Because larger range animals consume more dry matter, their higher protein requirement can be met by consuming diets with the same percentage of protein as smaller animals. The difference is in the amount of dry matter eaten. Protein requirement varies also according to animal's activities. Lactation has the highest demand

Table 3—The energy requirements of selected range animals. Data expressed on a dry matter basis as a percent of total digestible nutrients in the diet, as a percent of *in vitro* digestibility[a], or as megacalories of metabolizable energy/kg of dry matter (Halls 1970, National Academy of Sciences 1975, 1976, 1977, 1978, 1982, 1984).

Animal Activity Weight (lbs)	**Total digestible nutrients (dry)**	***In vitro* digestibility[a]**	**Metabolizable energy**
	Percent		*mcal/kg*
Sheep			
Maintenance	55	50	2.0
110-176			
Last 6 weeks of gestation	65	60	2.4
110-176			
Lactation	62	56	2.4
110-176			
Growth			
66	62	56	2.2
88	60	56	2.1
Cattle			
Maintenance and gestation	52	50	1.9
882-1,323			
Lactation	55	53	2.0
882-1,323			
Growth			
661-882	64	57	2.3
1,323	61	56	2.2
Horses			
Maintenance	47	50	1.8
Gestation	58	53	2.1
Lactation	62	56	2.2
Growth	66	58	2.5
Work			
Light	58	53	2.1
Moderate	65	57	2.4
Intense	66	58	2.5
Small range animals (rabbits, squirrels, foxes)			
Maintenance	—[b]	—	3.6
Gestation	—	—	3.9
Lactation	—	—	4.5
Growth	—	—	3.9
Range birds (grouse, pheasant, quail, turkey)			
Maintenance	—	—	2.9
Breeding	—	—	2.9
Growth	—	—	3.1

[a] Unfortunately, the total digestible nutrients content or amount of metabolizable energy is unknown for many range forages. More information is expressed as *in vitro* digestibility. In this table, energy requirements are expressed in terms of *in vitro* digestibility. Maintenance was set at 50 percent *in vitro* digestibility with other activities adjusted accordingly (Ammann and others 1973).

[b] A dash ("—") means no information available.

followed by fattening, growth, gestation, and maintenance. The protein requirements of selected range animals demonstrates this hierarchy (table 4).

Minerals

There are 15 mineral elements essential for the health of animals. Of these, seven are considered major elements: sodium, chlorine, calcium, phosphorus, magnesium, potassium, and sulfur. The remaining eight are classified as being trace elements: iodine, iron, copper, molybdenum, cobalt, manganese, zinc, and selenium. These essential mineral elements perform many vital functions in the body. They constitute the major components of bones and teeth, maintain osmotic relations and acid-base equilibrium, play an important role in regulating enzymatic systems and muscular contraction, and are constituents of most organic compounds. They are also important in energy transfer.

Under most conditions, calcium and phosphorus are the mineral elements of major concern, although other mineral elements (copper, cobalt, magnesium, sulfur, zinc, and molybdenum) may be locally in short supply. These can be supplemented easily by adding them to salt. For calcium and phosphorus, range animal requirements are expressed as grams per day or as a percent of the diet. For the range manager or revegetation specialist the expression as a percent of the diet is the most useful. Under similar activity, larger range animals need greater amounts of calcium and

Table 4—The protein requirement of selected range animals. Data expressed on a dry matter basis as a percent of crude or digestible protein needed in the diet (Halls 1970, National Academy of Sciences 1975, 1976, 1977, 1978, 1982, 1984).

Animal	**Activity**	**Weight**	**Crude protein**	**Digestible protein**
		Lbs	*Percent*	
Sheep	Maintenance	110-176	8.9	4.8
	Last 6 weeks of gestation	110-176	9.3	5.2
	Lactation	110-176	11.0	7.2
	Growth	66	10.0	5.8
		88	9.5	5.3
Cattle	Maintenance and gestation	882-1,323	5.9	—[a]
	Lactation	882-1,323	9.2	—
	Growth	661-882	10.2	—
		1,323	8.8	—
Horses	Maintenance		8.5	—
	Gestation		11.0	—
	Lactation		14.0	—
	Growth		16.0	—
	Work			
	Light		8.5	—
	Moderate		8.5	—
	Intense		8.5	—
Mule deer	Maintenance		7.0	—
	Growth		16.0	—
Small range animals (rabbits, squirrels, foxes)				
	Maintenance		22	—
	Gestation		38	—
	Lactation		46	—
	Growth		35	—
Range birds (grouse, pheasant, quail, turkey)				
	Maintenance		12	—
	Breeding		14	—
	Growth		20	—

[a] A dash ("—") means no information available.

phosphorus than smaller animals. With size held constant, lactating animals require the most calcium and phosphorus followed by growth, fattening, gestation, and maintenance as an analysis of the calcium and phosphorus requirements of selected range animals confirms (table 5).

Vitamins

Vitamins are organic compounds needed by the body in relatively small amounts. They are unrelated chemically, but function as metabolic regulators. For range animals capable of supporting fermentation digestion, only vitamin A is of concern. Vitamin A combines with a specific protein of the eye to produce visual purple. A range animal with a vitamin A deficiency may develop an abnormal condition called night blindness. Vitamin A also plays an important role in normal development of bones, disease resistance, and maintenance of healthy epithelium tissues. Vitamin A is manufactured from the plant precursor carotene. Sometimes plant carotene is referred to as provitamin A. As a result the vitamin A requirement of range animals is expressed in a variety of terms, such as, milligrams per day per animal, or milligrams per kilogram of dry matter of carotene, or provitamin A, and as international unit per day, or international units per kilogram of dry matter of vitamin A. For range managers or revegetation specialists, the expression on a per kilogram of dry matter is the most useful. Larger animals with similar activities require more vitamin A than smaller animals. With size held constant, a lactating animal requires the most vitamin A, followed by growth, fattening, gestation, and maintenance (table 6).

Table 5—The calcium and phosphorus requirement of selected range animals. Data expressed on a dry matter basis as a percent needed in the diet (Halls 1970, National Academy of Science 1975, 1976, 1977, 1978, 1982, 1984).

Animal	Activity	Weight	Calcium	Phosphorus
		Lbs	- - - - - -*Percent*- - - - - -	
Sheep	Maintenance	110	0.30	0.28
		132	0.28	0.26
		154	0.27	0.25
		176	0.25	0.24
	Last 6 weeks of gestation	110	0.24	0.23
		132	0.23	0.22
		154	0.21	0.20
		176	0.21	0.20
	Lactation	110	0.52	0.37
		132	0.50	0.36
		154	0.48	0.34
		176	0.48	0.34
	Growth	66	0.45	0.25
		88	0.44	0.24
		110	0.42	0.23
		132	0.43	0.24
Cattle	Maintenance	881-1,323	0.18	0.18
	Gestation	881-1,323	0.18	0.18
	Lactation	881	0.42	0.38
		1,102	0.39	0.36
		1,323	0.36	0.34
	Growth	661	0.31	0.26
		881	0.21	0.21
		1,323	0.18	0.18
Horses	Maintenance		0.30	0.20
	Gestation		0.50	0.35
	Lactation		0.50	0.35
	Growth		0.70	0.50
	Work		0.30	0.20
Deer	Maintenance		0.30	0.25
	Growth		0.38	0.27
Small range animals (rabbits, squirrels, foxes)				
	Maintenance		0.30	0.30
	Gestation		0.40	0.40
	Lactation		0.60	0.60
	Growth		0.40	0.40
Range birds (grouse, pheasant, quail, turkey)				
	Maintenance		0.50	0.25
	Breeding		2.25	0.35
	Growth		0.75	0.38

Table 6—The vitamin A requirement of selected range animals. Data expressed on a dry matter basis as milligrams or international units needed per kilogram of dry matter (Halls 1970, National Academy of Sciences 1975, 1976, 1977, 1978, 1982, 1984).

Animal	Activity	Weight	Carotene	Vitamin A
		Lbs	*mg/ka*	*IU/kg*
Sheep	Maintenance	110	1.9	1,275
		132	2.0	1,391
		154	2.2	1,488
		176	2.3	1,569
	Last 6 weeks of gestation	110	3.6	2,500
		132	3.9	2,684
		154	4.2	2,833
		176	4.5	3,091
	Lactation	110	2.6	1,771
		132	2.9	1,962
		154	3.1	2,125
		176	3.3	2,267
	Growth	66	1.5	981
		88	1.8	1,214
		110	2.1	1,417
		132	2.5	1,700
Cattle	Maintenance and gestation		4.1	2,800
	Lactation		5.7	3,900
	Growth		3.2	2,200
Horses	Maintenance		2.4	1,600
	Gestation		5.0	3,400
	Lactation		4.1	2,800
	Growth		2.9	2,000
	Work		2.4	1,600
Small range animals (rabbits, squirrels, foxes)			8.7	5,930
Range birds (grouse, pheasant, quail, turkey)			5.9	4,000

Knowing the nutritive needs of range animals is the first step for sound effective range management or revegetation projects. The next task for range managers or revegetation specialists is to gain skills at judging the nutritive values of range plants.

Judging the Nutritive Values of Range Plants

Nutrient value of a range plant is judged in terms of the plant's ability to meet the various nutrient requirements of the consuming range animal. Estimates of the value of range forage can be classified into three groups: (1) proximal or other chemical analysis; (2) *in vitro* digestibility (outside-the-living-body digestibility); and (3) *in vivo* digestibility, (in-the-living-body digestibility). From the point of view of range managers or revegetation specialists, nutrient measurements obtained from *in vivo* digestibility are the most useful followed by *in vitro* digestibility and chemical analysis. Unfortunately, information obtained from *in vivo* digestibility is time consuming, expensive, and there is simply not enough information to cover most rangeland situations that confront range managers or revegetation specialists.

Recognizing that all plant substances are not equally digestible, nutritionists have attempted, with varying degree of success, to devise series of chemical measurements that would partition the digestible plant substances from the hard or nondigestible substances.

Proximal and Other Chemical Analyses

One such measurement is called proximal analysis. This analysis is based on dividing plant substances into five classes: crude protein, crude fat, crude fiber, ash, and nitrogen-free extract. The first four classes are determined by chemical means, the fifth is determined by subtracting the sum of the percentages of the first four classes from 100. All classes are expressed on a dry matter basis.

Crude protein is measured by determining the nitrogen content of the forage and multiplying the nitrogen content, expressed as a percent, by the factor 6.25 (sometimes a worker chooses to give just the nitrogen content of range plants, the range manager or revegetation specialist can calculate the crude protein content by multiplying the nitrogen content by 6.25). Chemical determination of crude protein does not take into account the digestibility of the protein. Fortunately, crude protein content is significantly related to digestible protein. As crude protein increases, so does the digestibility of the protein. In general terms, the higher the crude protein content of a range forage, the more likelihood it will meet or exceed the animal needs.

Crude fat is measured by determining the compounds soluble in ether. Crude fat then is a mixture of compounds including waxes, monoterpenoids, chlorophyll, carotene, triglycerides, and phospholipids. Not all of these compounds are digestible but those that are, such as triglycerides, phospholipids, and fatty acids, yield 2.25 times more energy than do sugars, starch, and protein. Range plants with high and digestible crude fat levels are excellent sources of energy. In general, crude fat is about 45 percent digestible.

Crude fiber is the residue left after plant samples have been alternately boiled in weak acid and in weak alkali. This residue consists chiefly of cellulose, hemicellulose, and lignin. Hemicellulose is more readily broken down into simple sugars by microbial fermentation than is cellulose. Lignin is not digested by microbial fermentation or by the range animal, and may even form a coating around cellulose rendering portions of it undigestible. The digestibility of crude fiber varies greatly among range forages. Crude fiber regulates the bulk in a diet. Bulk, up to a certain point—30 to 35 percent—has a beneficial effect on the digestive tract of a range animal by preventing the formation of a doughlike mass in the stomach. Also, it promotes the elimination of undigested food from the digestive tract. In general, range forages that are higher in crude fiber are less digestible.

Ash is the mineral matter of a range forage. It is determined by burning off all the organic matter and weighing the residue. This chemical analysis gives the total mineral content of a range forage but tells nothing about the individual mineral elements. In general, the values are needed to calculate nitrogen-free extract.

Nitrogen-free extract is determined by calculation but not by chemical means. After the contents of crude protein, crude fat, crude fiber, and ash have been determined, these values are added together and subtracted from 100. The result is nitrogen-free extract. This portion is composed mainly of sugars and starch. In general, range forages that are highest in nitrogen-free extract are among the most digestible.

There are problems with the proximal analysis method. Because nitrogen-free extract is determined by the difference, it accumulates all the errors of the other analyses. Crude fiber fraction does not always divide carbohydrates into digestible fractions. Recognizing these problems, a series of chemical analyses has been devised. This series partitions the plant substance into three classes: (1) cell contents plus pectin, (2) neutral detergent fiber, and (3) acid detergent fiber. Cell contents are very highly digestible and contain sugars, starch, organic acids, protein, and pectin. Neutral detergent fiber is much less digestible and contain hemicellulose, cellulose, and undigestible lignin. Acid detergent fibers is less digestible than the other two fractions because it contains just the cellulose and undigestible lignin. This procedure may, in time, replace the old proximal analysis method. At present, very few range forages have been analyzed by the detergent or Van Soest method. When the information is available, the range manager or revegetation specialist needs to recognize that the higher the cell content and lower the acid detergent fiber the more digestible the range forage.

Other chemical analyses that are useful in judging the nutritive value of range plants are the percentages of lignin, calcium, phosphorus, and carotene. In general, with the exception of lignin, the higher the better. Although the chemical makeup of range forages gives an indication of their probable nutritive value, their digestibility is important in evaluating the ability of a forage to meet the nutrient needs of a range animal. The most useful information then, to a range manager or revegetation specialist, is digestibility.

Digestibility

Digestibility can be determined by either *in vitro* (outside) or *in vivo* (inside) means.

In vitro digestibility is a laboratory technique that simulates natural ruminant digestion. This technique includes the fermentation of a forage substrate with rumen microorganisms in a buffered digestion solution at body temperature, and a neutral to slightly acidic pH. After fermentation, the digestive solution is acidified with hydrochloric acid to pH of 1 to 2, and pepsin, an enzyme that digests protein, is added to the digestive solution. Upon completion of acidified-pepsin treatment, the residue from the test forage is filtered, dried, weighed, and percent of dry matter calculated.

Range animal requirements as expressed in terms of *in vitro* digested dry matter is about 50 percent for maintenance, 53 percent for gestation, 56 percent for growth, and 60 percent for lactation. In general, the higher the *in vitro* digestibility of a range forage the higher the nutritive value.

The main advantages of the *in vitro* technique are simplicity, speed, precision, and costs. Disadvantage is that the digestibility of individual nutrients is unknown.

In vivo digestibility technique consists of feeding the range forage of interest, usually alone, to an animal or set of animals and collecting the feces. Using chemical analysis, the amount of nutrients (1) consumed by the test animal(s), and (2) excreted in the feces is determined. The difference between the two would represent the portion of the nutrients in the forage digested by the animal(s). Results of *in vivo* digestibility trials are expressed as digestion coefficients of the various proximate analysis classes, and as total digestible nutrients. The calculating of total digestible nutrients had been described earlier (table 2).

Another way the results of *in vivo* digestion can be expressed is in terms of digestible energy (fig. 1). In general, the higher the digestive coefficients, total digestible nutrients, and digestible energy, the higher the nutritive value of the range forage. Complicating the judging of nutritive value of range plants is the fact that the nutrient content of a given species varies over time and space.

Factors Affecting the Nutritive Value of Range Plants

Factors that affect the morphology and metabolism of range plants also affect the nutritive value of the plants, both quantitatively and qualitatively. These factors include climate, soil, and genetic factors, and express themselves in influencing the speed of the phenological development of the range plants. In general, the qualitative nutritive value of range plants peak in the spring and then decrease, reaching a low level during the dormant or winter season as demonstrated by the range plants big sagebrush, bitterbrush, and unknown grass (table 7). Fall green up on the part of certain grass species during wet falls changes this pattern considerably. Influences on the nutritive content of range forage and on the nutritive requirement of range animals, actual listing of nutritive values of range plants is done according to season—spring, summer, fall, and winter.

Seasonal Nutritive Value of Range Plants

For the range manager or revegetation specialist the task becomes one of balancing range animals' nutritive needs with the nutritive content of range plants. The range manager or revegetation specialist should think in terms of range plants providing so many pounds per acre of total digestible nutrients, digestible or crude protein, carotene, and phosphorus. The other nutrients, with the exception of water, are probably in adequate amounts. Sometimes deficiencies occur but only in local areas. This section is an attempt to list what is known about the nutritive values of range plants. The section is divided seasonally, and the particular needs of the range animals are also discussed.

Table 7—Seasonal variation of crude protein for *Artemisia tridentata* (big sagebrush), *Purshia tridentata* (antelope bitterbrush), and an unknown Nevada grass.

Month/year	Big sagebrush	Bitterbrush	Grass
	- - - - - - - - - - - - -	*Percent* - - - - - - - - - - - - -	
June 1968	11.8	13.4	13.4
July 1968	12.7	12.8	7.8
September 1968	11.8	9.7	9.6
December 1968	10.5	7.5	2.7
March 1969	14.0	9.9	3.4
May 1969	15.0	11.3	21.3

Source: Data from Tueller (1979).

Spring Range

Spring range is a time when the energy, protein, phosphorus, and carotene requirements of range animals are highest. This is due to the growing of young and the lactating of females. From a qualitative view, this is the time when nutritive value of plants is also highest; however, dry matter production is low at this time, but increases in late spring. There are some who believe that early spring range plants do not provide good forage for range animals. Their belief is based on the idea that high water content of the forage is a controlling agent in forage intake. Dry matter, not water content, controls daily forage intake. Grasses and forbs

Table 8—Spring nutritive value[a] of selected range plants. Data expressed on a percent of dry matter, except carotene, which is expressed as mg/kg of dry matter.

Plant name **Common** **Scientific**[b]	***In vitro* digestibility**	**Crude protein**	**Phosphorus**	**Carotene**
	- - - - - - *Percent*	- - - - - -	- - - - - -	*mg/kg*
Grasses				
Bluebunch wheatgrass *Agropyron spicatum*	60.6	17.0	0.30	414
Bottlebrush squirreltail *Sitanion hystrix*	72.3	18.5	0.24	3
Crested wheatgrass *Agropyron cristatum*	72.6	11.3	—[c]	—
Desert wheatgrass *Agropyron desertorum*	73.6	23.7	0.36	452
Idaho fescue *Festuca idahoensis*	—	14.0	0.30	92
Indian ricegrass *Oryzopsis hymenoides*	67.1	15.9	—	—
Intermediate wheatgrass *Agropyron intermedium*	74.3	8.2	—	—
Needle-and-thread grass *Stipa comata*	—	16.2	0.40	—
Reed canary grass *Phalaris arundinacea*	—	16.2	0.40	—
Sand dropseed grass *Sporobolus cryptandrus*	—	15.1	0.25	—
Sandberg bluegrass *Poa secunda*	62.2	17.3	0.33	—
Smooth brome *Bromus inermis*	—	23.5	0.47	493
Western wheatgrass *Agropyron smithii*	77.2	17.6	0.45	185
Shrubs				
Antelope bitterbrush *Purshia tridentata*	49.2	12.4	0.19	—
Big sagebrush *Artemisia tridentata*	58.1	12.6	0.25	—
Curlleaf mountain mahogany *Cercocarpus ledifolius*	—	9.9	—	—
Fourwing saltbush *Atriplex canescens*	—	14.1	—	—
Low rabbitbrush *Chrysothamnus viscidiflorus*	—	22.6	0.46	—
Rubber rabbitbrush *Chrysothamnus nauseosus*	—	20.7	0.45	—
Utah juniper *Juniperus osteosperma*	49.0	6.2	0.15	—
Winterfat *Ceratoides lanata*	—	21.0	—	—
Forbs				
Alfalfa *Medicago sativa*	86.8	28.5	0.37	372
American vetch *Vicia americana*	71.3	21.2	—	—
Arrowleaf balsamroot *Balsamorhiza sagittata*	—	28.8	0.43	—
Gooseberryleaf globemallow *Sphaeralcea grossulariifolia*	69.7	19.7	—	—
Oneflower helianthella *Helianthella uniflora*	—	20.0	0.40	—
Small burnet *Sanguisorba minor*	—	17.4	—	—

[a] Values represent the average of a number of studies reported in the literature. References are on file at the Rocky Mountain Research Station's Shrub Sciences Laboratory, Provo, UT. References are also listed in the references section.

[b] Common and scientific names after Plummer and others (1977).

[c] A dash ("—") means information not available.

in the spring exceed the nutritive content of shrubs. This is illustrated in tables 8 and 11, both listing the spring nutritive values of selected range plants. On spring ranges, range managers or revegetation specialists should emphasize the production of grasses and forbs with shrubs as backup during drought. Shrubs are more productive during drought than grasses or forbs.

Summer Range

During the summer, range animals' demands for energy, protein, phosphorus, and carotene is a little lower

Table 9—Summer nutritive value[a] of selected range plants. Data expressed as a percent of dry matter, except carotene which is expressed as mg/kg of dry matter.

Plant name **Common** **Scientific**[b]	***In vitro* digestibility**	**Crude protein**	**Phosphorus**	**Carotene**
	Percent			*mg/kg*
Grasses				
Bluebunch wheatgrass *Agropyron spicatum*	3	14.5	0.23	77
Bottlebrush squirreltail *Sitanion hystrix*	59.7	8.0	0.17	1.1
Crested wheatgrass *Agropyron cristatum*	—	—	0.13	—
Desert wheatgrass *Agropyron desertorum*	51.0	12.1	0.23	153
Galleta *Hilaria jamesii*	—	7.7	0.09	0.4
Idaho fescue *Festuca idahoensis*	54.0	9.5	0.18	34
Needle-and-thread grass *Stipa comata*	—	6.5	0.10	0.4
Reed canary grass *Phalaris arundinacea*	—	12.4	0.20	—
Sand dropseed grass *Sporobolus cryptandrus*	—	5.7	0.10	0.4
Sandberg bluegrass *Poa secunda*	—	9.4	0.17	43
Smooth brome *Bromus inermis*	60.6	11.0	0.28	103
Western wheatgrass *Agropyron smithii*	—[c]	11.8	—	117
Shrubs				
Antelope bitterbrush *Purshia tridentata*	—	13.1	0.22	—
Big sagebrush *Artemisia tridentata*	—	13.2	0.40	—
Curlleaf mountain mahogany *Cercocarpus ledifolius*	—	12.2	0.23	—
Fourwing saltbush *Atriplex canescens*	47.1	12.0	—	—
Gambel oak *Quercus gambelii*	—	15.8 (leaves)	—	—
Low rabbitbrush *Chrysothamnus viscidiflorus*	—	12.1	0.35	—
Rubber rabbitbrush *Chrysothamnus nauseosus*	—	12.8	0.38	—
Utah juniper *Juniperus osteosperma*	—	8.1	0.21	—
Winterfat *Ceratoides lanata*	—	13.6	—	—
Forbs				
Alfalfa *Medicago sativa*	—	17.8	0.28	109
American vetch *Vicia americana*	—	17.6	0.20	—
Arrowleaf balsamroot *Balsamorhiza sagittata*	—	17.0	0.26	—
Oneflower helianthella *Helianthella uniflora*	—	12.4	0.31	—
Small burnet *Sanguisorba minor*	—	9.8	—	—

[a] Values represent the average of a number of studies reported in the literature. References on file at the Rocky Mountain Research Station's Shrub Sciences Laboratory, Provo, UT. References are also listed in the references section.

[b] Common and scientific names after Plummer and others (1977).

[c] A dash ("—") means information not available.

Table 10—Seasonal variation in the nutritive value[a] of desert wheatgrass. Data expressed on a dry matter basis except carotene which is expressed as mg/kg of dry matter.

Season	*In vitro* digestibility	Crude protein	Calcium	Phosphorus	Carotene
		- - - - - - - - - - - - - *Percent*	- - - - - - - - - - - - - -		*mg/kg*
Early spring	73	23.6	0.47	0.36	452.0
Spring	61	18.0	0.41	0.32	239.0
Early summer	51	12.5	0.39	0.23	153.0
Late summer	49	12.1	0.29	0.18	75.4
Winter	44	3.5	0.27	0.07	0.2

[a] Values represent the average of a number of studies reported in the literature. References are on file at the Rocky Mountain Research Station's Shrub Sciences Laboratory, Provo, UT. References are also listed in the references section.

than during the spring but the nutritive value of range forage starts to decline with grasses declining more rapidly than forbs and shrubs (tables 9, 10). By this time the protein, phosphorus, and carotene levels in grasses are at or just below the needs of most range animals. Energy level of grasses remain above that in forbs and shrubs. This supports the importance of having a mixture of palatable grasses, forbs, and shrubs available for range animal consumption.

Fall and Winter Range

During the fall and winter season, the nutritive needs of range animals, especially wild range animals, drop to maintenance levels. Also, the nutritive content of range plants drops, in many cases, below the maintenance levels. Grasses lead this decline in every category except in energy, followed by forbs, with shrubs showing the least amount of decline. In general, shrubs supply higher fall and winter levels of crude protein, phosphorus, and carotene than grasses or forbs (table 11). Grasses, in general, supply higher fall and winter levels of energy than shrubs or forbs. However, some evergreen shrubs, such as big and black sagebrush and curlleaf mountain mahogany, contain as much energy as grasses. From a nutritional point of view, it is a good range management practice to manage fall and winter ranges for a balance among grasses, forbs, and shrubs.

There are two additional points regarding winter nutritional values that need to be discussed (table 11). First: fall regrowth of grasses (crested wheatgrass) provides excellent winter forage to wintering range animals. But crested wheatgrass cannot constitute the mainstay of a fall and winter range program. This is due to two factors; first, fall regrowth does not occur

Table 11—Winter nutritive value[a] of selected range plants. Data expressed as a percent of dry matter, except carotene which is expressed as mg/kg of dry matter.

Plant name Common Scientific[b]	*In vitro* digestibility	Crude protein	Phosphorus	Carotene
	- - - - - - - - - - - - - -	*Percent* - - - - - - - - - - - - - -		*mg/kg*
Grasses				
Bluebunch wheatgrass *Agropyron spicatum*	45.5	3.2	0.05	0.22
Western wheatgrass *Agropyron smithii*	50.2	3.8	0.07	0.20
Bottlebrush squirreltail *Sitanion hystrix*	42.0	4.3	0.07	1.10
Desert wheatgrass *Agropyron desertorum*	43.7	3.5	0.07	0.20
Crested wheatgrass (fall regrowth) *Agropyron cristatum*	50.6	15.0	0.39	432
Galleta *Hilaria jamesii*	48.2	4.6	0.08	0.40
Idaho fescue *Festuca idahoensis*	46.1	3.8	0.08	3.00
Indian ricegrass *Oryzopsis hymenoides*	50.5	3.1	0.06	0.44
Reed canary grass *Phalaris arundinocea*	—[c]	7.8	0.14	—
Needle-and-thread grass *Stipa comata*	46.6	3.7	0.07	0.40

(con.)

Table 11—(Con.)

Plant name **Common** **Scientific**[b]	***In vitro* digestibility**	**Crude protein**	**Phosphorus**	**Carotene**
	- - - - - - - - - - - - - -	- *Percent* -	- - - - - - - - - - - - - -	*mg/kg*
Grasses				
Sandberg bluegrass *Poa secunda*	—	4.2	—	—
Sand dropseed grass *Sporobolus cryptandrus*	53.2	4.1	0.07	0.50
Smooth brome *Bromus inermis*	47.0	4.1	0.12	—
Shrubs				
Antelope bitterbrush *Purshia tridentata*	23.5	7.6	0.14	—
Big sagebrush *Artemisia tridentata*	57.8	11.7	0.22	17.6
Black sagebrush *Artemisia nova*	53.7	9.9	0.18	8.0
Winterfat *Ceratoides lanata*	43.5	10.0	0.11	16.8
Curlleaf mountain mahogany *Cercocarpus ledifolius*	49.1	10.1	—	—
Fourwing saltbush *Atriplex canescens*	38.3	8.9	—	3.1
Gambel oak *Quercus gambelii*	26.6	5.3	—	—
Low rabbitbrush *Chrysothamnus viscidiflorus*	36.0	5.9	0.15	—
True mountain mahogany *Cercocarpus montanus*	26.5	7.8	0.13	—
Rubber rabbitbrush *Chrysothamnus nauseosus*	44.4	7.8	0.14	—
Stansbury cliffrose *Cowania mexicana*	37.6	8.6	—	—
Utah juniper *Juniperus osteosperma*	44.1	6.6	0.18	—
Forbs				
Arrowleaf balsamroot *Balsamorhiza sagittata*	—	3.6	0.06	—
Oneflower helianthella *Helianthella uniflora*	—	2.8	0.17	—
Small burnet *Sanguisorba minor*	—	6.6	—	—

---

[a] Values represent the average of a number of studies reported in the literature. References on file at the Rocky Mountain Research Station's Shrub Sciences Laboratory, Provo, UT. References are also listed in the references section.

[b] Common and scientific names after Plummer and others (1977).

[c] A dash ("—") means information not available.

every fall, and secondly, snow can render the green fall regrowth unavailable for the range animal.

The second point of interest is the high nutritive level of big sagebrush (table 11). This range plant species has been, and continues to be, much maligned by range managers due to its general characteristic of being unpalatable to cattle grazing spring and summer ranges. If any single range species could be the mainstay of a winter range program certainly big sagebrush would come the closest. Big sagebrush varies greatly in nutritive value, productivity, site adaption, and preference. Where highly preferred stands of big sagebrush are found they should receive maximum protection from sagebrush control projects. Range managers must make their evaluation of big sagebrush stands before bud break in the spring. Heavily grazed big sagebrush plants can mask the evidence of being grazed within days of bud break. Recent research has shown that these stands of preferred big sagebrush do not affect grass cell wall digestion (Hobbs and others 1985). Also, big sagebrush provides a dependable source of forage during drought for wintering domestic sheep, pronghorn antelope, and mule deer (McArthur and Welch 1982; Medin and Anderson 1979).

David L. Nelson

Chapter 15

Plant Pathology and Managing Wildland Plant Disease Systems

Obtaining specific, reliable knowledge on plant diseases is essential in wildland shrub resource management. However, plant disease is one of the most neglected areas of wildland resources experimental research. This section is a discussion of plant pathology and how to use it in managing plant disease systems.

General principles of agricultural plant pathology apply to wildland plant disease. However, unique features limit a general extension of plant disease control management or methods. For example, some fundamental elements of agricultural plant disease management are not applicable, such as annual crop rotation and soil fumigation; and other elements are not feasible, such as protective chemical treatment of low value (per unit area) wildland plants. We have insufficient knowledge of principles of disease epidemics involving uniform homogenic agricultural plants, as opposed to species diversity, such as heterogenic, wildland plant populations. In the latter case, information is more pertinent from wildland forest tree disease epidemiology.

Although diseases of the more treelike shrubs have received some study, most wild-shrubland plant disease systems remain unidentified. Wildland plant disease research suffers from lack of attention, probably because plant diseases are generally less dramatic than other forms of injury such as fire or insect epidemics. Unless there is a disease epidemic of devastating proportions, little action is taken. If revegetation effort is less than successful, plant disease is usually the last explanation given. The effects of plant disease are usually inconspicuous and subtle. The importance of wildland plant pathogens, in a nonecological sense, can only be judged in terms of competition with humans for the plant harvest or other use. The human-use factor constantly changes, and its dominant feature will be to constantly increase on Western United States wildlands. Restoring and managing wildland range resources is a comparatively recent venture, and the intensiveness of the activity promises only to increase. Why not take advantage of existing knowledge of plant pathology as much as possible to avoid experiencing the pitfalls and disasters, especially in the early phases of agronomy and forestry?

What is Plant Disease?

One cannot see a plant disease. Only the symptomatic results of a disease are visible. Plant disease is a physiological process injurious to the host plant. It is a process that interferes with host plant functions and is extended in time. Disease inducers may be biological, physical, or an interaction of these environmental elements.

The more familiar organisms that induce disease are fungi, bacteria, viruses, and nematodes. Less familiar are insects, microplasmas, rickettsias, algae, and lichens. Parasitic flowering plants also induce disease. These are the mistletoes, dodders, and broomrapes. Physical elements of the plant environment that induce disease include certain soil factors, mineral deficiencies or excesses, air temperature extremes, toxic chemicals, and air pollutants. Damage from lightning strikes or freezing is not considered to result in disease because the resulting injurious process is not pathogen induced.

How to Recognize a Plant Disease

Before plant disease management can be planned, the disease must be diagnosed and the causal agent identified. To do this, presence of a pathogen or symptoms of the dysfunction must be determined and characterized. Diagnosis is still primarily an art, and therefore, experience is an important advantage.

If the disease is new or not readily identifiable, the disease symptoms must be reproduced by experimentation. This is usually a time-consuming project of establishing proof following the procedure of Koch's postulates as follows:

1. The inducing agent should be consistently associated with disease.
2. If an organism, it should be isolated, pure cultured, characterized, and identified.
3. The isolated organism, when applied in inoculation tests under the favorable environment for disease development, should reproduce the disease symptoms.
4. The organism should be reisolated, pure cultured, and found to be the same organism.

Koch's postulates cannot be followed precisely in all instances. Cause of diseases that are induced by insect toxins or abiotic factors can be established by characteristic symptoms and by reproducing the disease by withholding and applying the suspected agent in sequence to reproduce the symptoms. Nematodes, viruses, and obligately parasitic fungi require modification of the rules because they are not readily cultured. A further complication exists because more than one agent can be involved in what is then a disease complex. An associated nematode may act only as a vector. An abiotic factor may predispose the potential host to one or more fungal pathogens that may invade in a specific sequence.

The induced dysfunction or disease, once a pathogen is established, results in visible symptoms for which the disease is named and identified. A term describing the symptom, either alone or along with the name of the inducing agent, forms the disease name—aspen leaf blight, stem necrosis, fusarium wilt, canker, bacterial crown gall, witches' broom, chlorosis, tobacco mosaic, root rot, decay, and so forth. Structures of the inducing organism are also used in identifying and naming the disease; for example, spore masses, fruiting structures, and vegetative body—and thus, the signs of the disease such as black stem rust, smuts, blisters, powdery mildews, tar spots, and potato scab.

Identification of wild-shrubland plant diseases suffers immensely from a lack of specific literature, particularly in host-pathogen indices, descriptive keys, monographic treatments, and color illustrations for recognition and verification of diseases.

Disease Occurrence and Development

The occurrence and development of a disease depends on a triad of events: a pathogenic agent, a susceptible host, and a favorable environment interacting to result in a disease. The host and pathogenic organisms are reciprocal environmental elements. Both exist in a soil and air environment and are influenced by moisture, temperature, light, air movement, soil aeration, chemical and physical soil factors, organic soil constituents, microorganisms of the leaf, stem, root zone, and an interaction of combinations of these factors. The pathogenic organism, in addition to the external environment prior to penetration and establishment, is influenced by resistance mechanisms of the host that may be directed either actively or passively or both. The host contends with the external environment and the pathogenic mechanisms of the invading parasite. Both organisms have characteristic environmental limits and optimal zones of function. During periods within the required environmental limits, a pathogen penetrates the host and becomes established. When the established pathogen withstands host defenses, disease development proceeds and the successful pathogen completes its cycle to reproduction.

The occurrence of plant pathogenic organisms and plant disease is a natural, normal phenomenon and part of the evolutionary and ecological systems of all flora. In natural systems, disease incidence fluctuates endemically. During periods of change, either natural or because of human activity, a pathogen may become epidemic. Plant diseases caused by pathogenic organisms are thought of as contagious. Various types of propagules spread or are dispersed in numerous ways: airborne, waterborne, or entirely on their own power (for example, dwarf mistletoe seed). With an unlimiting food source and absence of inhibitors, reproduction is logarithmic, and the amount of propagule or inoculum increase is exponential. Circumstances are ideal for an epidemic or explosive spread of a disease when there is a large host population that is homogenic, nonspecific, in a uniformly susceptible stage of development, and where environmental conditions are optimal for pathogen spread, infection, and rapid regeneration.

Some common wildland management practices that could create ideal circumstances for epidemics are as follows:

1. Introduction of a plant that is susceptible to an endemic pathogen or the reciprocal.
2. Genetic selection of a plant population without regard to disease resistance.
3. Vegetative modification through management practices that tend to reduce heterogeneity both inter- and intraspecifically.
4. Modifications that influence populations of insects that are vectors of plant pathogens.
5. Large scale off-site plantings.

Principles of Plant Disease Management

Managing plant disease deals largely with prevention of infection in plant populations rather than with cure or therapy of diseased individuals. Therefore, it is imperative that action be taken in advance of infection. Essentials for sound management planning include a basic knowledge of the host plant, pathogen life cycle, and environmental factors such as temperature, moisture, and light intensity that influence pathogen disease dynamics. The rationale or justification for disease management and experimental research is found in past disease experience rather than immediate crises.

Methods for preventing, curing, or reducing the severity of disease are directed at the inducing agent following one or more basic principles as follows:

1. Avoiding the pathogenic agent.
2. Exclusion of the pathogen from an area.
3. Eradication of an established pathogen.
4. Protection of the plant by placing a barrier.
5. Curing infected plants.
6. Improving host resistance.

Avoiding the Plant Disease

Site Selection—In vegetative restoration, selection of the site is not usually a basis of avoiding a plant disease organism on the site. However, potential disease problems can be evaluated, based on an analysis of plant pathogens on the site. Species selection criteria should exclude known potential hosts of endemic pathogens and native or exotic species of unknown susceptibility. Another potential danger could be the presence of insect vectors of an endemic pathogen that could spread a virus, for example, to revegetation plants. Selection of seed increase planting sites or species evaluation sites could avoid pathogen infested agricultural land. Evaluation of soil and climatic factors could avoid abiotic diseases.

Pathogen-Free Planting Stock—Use of pathogen-free planting stock should be a routine revegetation requirement. This applies to seed, bare root nursery stock, containerized stock, or in fact, any propagative material. An inspection and certification program is essential to ensure that planting material is pathogen free. Procedures for sanitary packaging, shipment, and protection from contamination during planting need to be developed. Use of native plants for revegetation projects is in its infancy as is the production, sale, and purchase of seed and planting stock by private firms or government agencies. A major portion of native plant seed is collected from wildlands where disease status is unknown. Only recently have private and government concerns begun producing planting stock. Presently there is little or no factual basis for evaluating the disease status of propagative material. Revegetative work in the Western United States is proceeding at great risk in view of this well established principle.

Excluding the Plant Pathogen

Plant pathogens may be excluded from a revegetation site by inspection, pretreatment of propagative material, soil treatment, and eradicating insect vectors.

Treatment of Propagative Material—Propagule treatment to assure pathogen-free planting material is more applicable at the propagule increase certification level than for large rangeland revegetation efforts. Aerated steam, hot water, gases, and radiation are used to eliminate pathogens from planting material. The thermal death point of most pathogens is lower than for most plants and thus pathogens can be eliminated from the host plant by various heat treatment methods. Ultraviolet light, x-ray, gamma-ray, and other electromagnetic radiations are used to kill pathogens in plant material. Meristem culture is used to eliminate fungi, viruses, and bacteria and produce pathogen-free plants.

Quarantine of Diseased Plants—Quarantines are difficult to implement and control. In most instances they are justified even if they only result in delaying entrance of pathogens into a new area. Excluding a virulent pathogen from an area to which it would not likely spread by natural means is the most justifiable basis for quarantine. If there is little or no knowledge of specific pathogens, as is the case with most wildland plants, there is full justification for a complete quarantine. Present interstate or interregional shipment of seed and other planting material should be discontinued until there is a basis for establishing the risks involved.

Eradication of the Plant Pathogen

Eradication, like other control methods, is not usually thought of in absolute terms. The objective is to reduce the pathogen population to a level that permits a suitable return or product. The objective of biological control is to eradicate the pathogen enough from an area to allow an acceptable return.

Sanitation—This is an extremely important method of preventing disease problems although not as directly applicable to wildland revegetation projects such as production of planting material in nurseries, greenhouses, and seed increase plantings. In the production of certified pathogen-free seed and other planting material, roguing of diseased plants, elimination of weeds that may harbor pathogens, or alternate hosts of heteroecious fungi are essential. Alternate hosts and weeds can also serve as spheres for sexual recombination and evolution of new virulent races. Such hosts and weeds should not be permitted near experimental areas where genetic improvement activities are in progress.

Crop Rotation and Soil Treatment—While not applicable eradication methods in solving disease problems in wildland management, crop rotation and soil treatments are of high value in seed garden, nursery, and greenhouse operations.

Benefits from crop rotation depend on a thorough knowledge of the hosts and pathogens involved. The theory is to plant a nonhost or immune crop following a crop that may have increased a specific pathogen population. Soil fumigation should be a routine practice in nurseries and seed increase plantings. To fumigate only when disease problems begin to threaten is an unwise practice. Aerated steam treatment or soil fumigation should be followed rigidly in all greenhouse operations intended to produce healthy containerized planting stock.

Protecting Plants from Pathogens

Application of protective chemicals is a familiar method of plant disease prevention but is of questionable feasibility on wildlands. The principle is to prevent infection by coating seeds or plants with a substance toxic to the pathogen. With cultural methods, for example, plants in greenhouses may also be protected from pathogens by preventing long periods of free moisture that may be required for infection by certain fungi. Seed is dried and then stored at temperatures unfavorable to seed pathogens.

Curing a Diseased Plant

Some diseases can be cured by use of systemic chemicals that are directly toxic to the pathogen. Heat treatment is also used to cure plants infected with systemic viruses or vascular fungi. Localized diseased portions of plants, like mistletoe, witches' brooms, fire blighted branches, or stem galls, for example, can be removed by pruning to rid the plant of the disease. Curing or therapy as a means of control is limited to high value individual plants and the production of pathogen-free propagative material.

Improving Host Resistance

All plants are susceptible to some pathogens, but all plants are also resistant to most pathogens. Evolution of this equilibrium provides the basis for mutual survival of both organisms (pathogen-susceptible and pathogen-resistant plants), and is exploited in pathogen resistance selection and breeding programs. These programs are, however, long-term, expensive, and unwise ventures without a dedicated commitment. In the final analysis, when disease resistance can be improved, it is usually one of the most economical means of managing disease problems.

The host-pathogen-environment interaction must be thoroughly understood before a breeding program can be credible. There are many examples with agricultural crop plants of successfully improving disease resistance, however, improvement is usually a slow process. The success of using improved resistance in agronomy depends on a corresponding cultural control, and both are justifiable because of the high value of the crop. The infeasibility of practices such as fertilization, weed control, insect control, and irrigation in wildland management limits the usefulness of disease management to improving resistance. Nevertheless, improving disease resistance has an important potential for managing wildland plant disease.

Biological Management of Plant Pathogens

The dynamic fluctuation of organism populations in natural systems has evolved from an interaction of associated organisms and their physical environment to the system said to be in biological balance. Humans are disrupters of this balance, and this is the origin of their problems. The stability of biological systems is proportional to their complexity. Management systems in agronomy and forestry tend to create instability by simplifying biological systems. Parasitic organisms react abnormally in human-disrupted systems in agronomy and forestry, and tend to create instability by simplifying biological systems. The premise of biological management is to use the diverse phenomena of natural systems to restore the balance. But to live with this system, humans must agree to share the harvest with microorganisms. In other words, the objective of biological management is to reduce, not eliminate, human loss to plant pathogens. With this system, people are not direct participants (such as is an application of a fungicide), rather they manage the restoration of natural systems through joining a knowledge of biological plant systems. Recent theory and principles of biological management now being directed toward agronomic plant disease, have evolved by following natural systems.

In restoring and managing wildland plant resources, managing plant disease is an important part of the problem. From a scientific basis there is no benefit to proceed without giving attention to plant pathogens. We can successfully use both low cost plant disease management and also natural biological methods. We have before us, in the Western United States shrublands, biological systems more “truthful” and effective in their natural state than exist in agriculture and intensive forestry. Natural microbiological systems are now being modified and threatened by resource management practices that hardly consider their existence. It is an endangered system. An immediate prime effort of wildland resource management and scientific research should be directed to understanding these systems.

Outline for Managing Plant Disease in Wild-Shrubland Plant Improvement and Revegetation Practice

I. Define management needs
II. Review and select potential plant species with them
III. Establish genetic control
    1. Review plant characteristics desirable for human-centered objectives.
    2. Review plant characteristics required for plant survival and evolution.
    3. Define geographic limits of a plant population possessing these characteristics.
    4. Define the variability of all required characteristics within the population.
    5. Based on variability, develop a statistically valid random sampling method for selection of plant propagule collection points.
IV. Preserve gene pool variability
    1. Evaluate seed collection, cleaning, storage, scarification, stratification, germination, planting, establishment techniques for the potential of reducing genetic variability.
    2. Evaluate loss of individual plants because of biological and physical factors during research experimentation for potential of reducing genetic variability.
    3. Base experimental design on population variability. For example, sample size or replication number should be based on preserving plant variability, not on experimental dollar limitations.
V. Attending dangers of narrowing plant gene pools
    1. Planting site location limitations.
    2. Potential for insect and disease epidemics.
    3. Short-term plant survival.
    4. High cost management.
    5. Modifying the nature and direction of plant evolution.
    6. Decertification.

Richard Stevens

Chapter 16

Management of Restored and Revegetated Sites

Management of restored and rehabilitated ranges can be divided into (1) post-treatment, which we are most concerned with herein, and (2) management of the subsequent mature community. Immediate post-treatment management can positively or negatively affect the ultimate success and longevity of a project, and the actual returns and benefits received. It is essential to follow good post-treatment management practices to obtain the maximum return on investments made. The post-treatment management period may last as long as 10 years following treatment.

Management of restored and rehabilitated ranges will vary depending on the goals or objectives of the project. The most common overall objective of a project is to enhance soil stability. Some companion objectives could be to provide for maximum establishment and maintenance of seeded and desirable indigenous species, increase livestock production, improve wildlife habitat, and improve the appearance of the landscape.

Figure 1—Effect of heavy blacktailed jackrabbit use on seedling establishment and forage production. Mule deer and jackrabbit use on the left, mule deer use only on the right.

The principal immediate post-treatment management objective should be to provide for maximum establishment and development of seeded and desirable indigenous species. Once this has been accomplished, other objectives will likely follow.

An important step in any revegetation project is the selection of species to be seeded. Many species used in rangeland improvement projects are adapted to a wide array of range types. Individual plant species do not respond to various management practices in the same way and to the same degree on all sites.

Amount and distribution of precipitation in the Intermountain West is perhaps one of the most important factors in determining to what degree a range improvement project succeeds or fails during the establishment period. Above-average precipitation can result in some outstanding successful projects. Projects should be planned on the basis of average yearly precipitation. Below-average precipitation during years of establishment will change post-treatment management. Managers have little or no control over climatic factors, outbreaks of rabbits, insects, rodents, or disease, which can affect the success and complicate the post-treatment management of a project (fig. 1). One or all of these factors has the potential of destroying or reducing the success of a project.

Managers must control the influence that human activities and grazing animals have on a project. These factors can positively or negatively affect the success of a project. During the establishment period, livestock grazing and any damaging activities of man must be controlled. Human activities and grazing animals can trample seedlings, pull seedlings up, remove foliage, reduce plant vigor and rate of establishment, reduce growth, retard seed production, decrease or slow down soil stabilization, and spread and increase the abundance of undesirable plant species.

The manager makes the decisions concerning when, where, how much, and what type of grazing and human activity is to occur following treatment. Project objectives and management plans should be based on site potential, expected rate of establishment, plant community makeup, and climatic factors. The presence or absence of rodents, rabbits, insects, and disease must be considered. Plans have to be flexible enough to compensate for any changes from the expected when the decision is made to graze, or not to graze, and how much. Development and condition of the project and not plans should determine post-treatment grazing.

If the project objective is only soil stabilization, establishment and maintenance of seeded species would be simpler than when other objectives are considered. By preventing grazing or other disturbing influences, one should be able to accomplish the desired objective of soil stabilization with less effort and in less time.

As a general rule, treated and seeded sites should not be grazed until at least the end of the second growing season following seeding (tables 1 and 2; Plummer and others 1968; Reynolds and Martin 1968; Vallentine 1980; Vallentine and others 1963; fig. 2). Minimum period of rest following treatment will vary with vegetative type treated; grass, forb, and shrub species seeded; climatic conditions immediately preceding, during, and following treatment; soils; seedbed preparation and seeding techniques employed; presence and severity of competing weedy species; plant disease; and number and kinds of insects, rodents, or rabbits on the site (table 2).

When grazing is allowed, it should be lighter than would normally be allowed with a fully mature community, even if forage production figures suggest that heavier use might be permitted. Grazing should only occur when it is least damaging to the newly established species. Spring and early summer use can be very damaging on newly seeded ranges (fig. 3). Special considerations should be given to seeded and indigenous shrubs, because shrubs establish and develop much slower than grasses and forbs. There are slow growing and fast growing shrubs (table 3; fig. 4). The level of grazing should be controlled to allow seeded and released shrubs to establish, and grow enough that they will not be harmed by grazing. As grasses and forbs mature, cattle and sheep use will be less detrimental. During the establishment period, the intensity of grazing has to be adjusted on a season to season basis, and allowance made for phenological stage of development, as well as for climatic and biotic influences.

The drier the treated site, the slower that planted species will establish and develop. Species seeded on a juniper-pinyon site that receives 11 inches (27.9 cm) of annual precipitation will establish and develop slower

Table 1—Recommended minimum years of nongrazing following revegetation of different vegetative types, and according to special treatments and site conditions.

Vegetative type	Special treatment or site conditions	Recommended growing seasons with no livestock grazing following seeding
Subalpine		3
Aspen-conifer		2
Aspen, Gambel oak, maple	Broadcast seed prior to leaf fall	3
Ponderosa pine		2
Mountain brush		2
Juniper-pinyon	Above 14 inches (36 cm) annual precipitation	2
Juniper-pinyon	Below 14 inches (36 cm) annual precipitation	3
Mountain big sagebrush		2
Basin big sagebrush	Above 14 inches (36 cm) annual precipitation	2
Basin big sagebrush	Below 14 inches (36 cm) annual precipitation	3
Wyoming big sagebrush	Above 12 inches (30 cm) annual precipitation	3
Wyoming big sagebrush	Below 12 inches (30 cm) annual precipitation	4
Black sagebrush		3
Shadscale		3 to 4
Black greasewood		2
Inland saltgrass		1
Blackbrush		3

than the same species on an adjacent juniper-pinyon site that receives 14 inches (35.6 cm) annual precipitation. The drier sites will require at least an additional year or more of nonuse (table 2). If a sagebrush area that receives an average of 15 inches (38.1 cm) annual precipitation is treated and seeded and then receives only 10 to 11 inches (25.4 to 27.9 cm), the first one or two seasons following seeding, grazing may have to be delayed by as much as 2 years beyond what was planned to obtain adequate establishment and growth.

Seeded species need to be given the opportunity to put down substantial root systems, to accumulate carbohydrate reserves, and, in the case of some grasses and forbs, to produce a seed crop. To ensure a healthy vigorous plant community it is essential that grasses and forbs be given the opportunity to produce seed the first few years following seeding and every few years thereafter. Improper grazing and sub-optimal climatic conditions are the two major factors that negatively affect seed production.

Table 2—Additional growing seasons of nonuse (beyond recommended growing seasons indicated in table 1) required due to special conditions.

Site conditions	Years
Burned and broadcast seeded	+1
Slower growing shrubs seeded or released (table 3)	+2 to +4
Seedings in cheatgrass, red brome, medusahead, or halogeton communities	+l to +3
Poor seedbed conditions	+1
Erosive soils	+l to +3
Soils with exposed and disturbed subsoil	+2
Precipitation 2 or more inches (5 cm) less than average during first growing season	+1 to +3
Precipitation 2 or more inches (5 cm) less than average during second and third growing season	+1
Outbreak of insects or disease	+1 to +3
Excessive number of rodents and rabbits	+1 to +3

Figure 2—A highly productive 4-year-old rehabilitation project in a juniper-pinyon-Gambel oak type. The site was grazed lightly at the end of the second growing season following seeding. Light grazing occurred the third year following seeding.

Figure 3—Results of poor post-treatment management. The area was grazed too early and too heavy the second and third year following seeding. The seeded species were weakened and killed by grazing, allowing cheatgrass to once again dominate.

Figure 4—Fast growing white rubber rabbitbrush, fourwing saltbush, and big sagebrush are fully established in this 6-year-old range improvement project in a juniper-pinyon type. Antelope bitterbrush growth is considerably slower. The area was spring grazed by cattle during the 2 preceding years.

The degree of seedling vigor and rate of establishment and growth will influence the timing and intensity of subsequent grazing. Species with exceptional seedling vigor and a fast rate of root and aboveground growth can be grazed sooner than those with less seedling vigor or a slower establishment and growth rate (table 3; fig. 5). A good indication of well established, vigorous plants is excellent seed production. When a mixture of species is seeded, management has to be tailored to accommodate the characteristics and requirements of all the species. Post-treatment management should be directed toward the slower developing species (table 3). Many forbs develop slower than most grasses. Most shrubs develop slower than grasses or forbs. When shrubs are included in the seed mix, more than 2 years, and possibly 5 to 6 years, of nonuse following seeding may be required. A few shrubs such as fourwing saltbush, winterfat, rabbitbrush, forage kochia, and big sagebrush, possess a faster rate of growth and maturation. These species will often produce a seed crop and be within 80 percent of their maximum forage production potential within 3 years following establishment (fig. 4).

Many range improvement projects are conducted on depleted sites having some degree of erosion problem. Because of soil loss, site potential may not be as great

Table 3—Years normally required for certain plant species to establish, mature, and flower.

Fast 2 years	Intermediate 2 to 3 years	Slow 3 to 4 years	Very slow 4 to 6 years
Bluegrass, Kentucky	Alfalfa	Crownvetch	Balsamroot
Brome, mountain	Aster spp.	Lupine spp.	Bitterbrush, antelope
Burnet, small	Brome, Regar	Milkvetch, cicer	Ceanothus, Martin
Kochia, forage	Brome, smooth	Rabbitbrush, low	Ceanothus, snowbush
Orchardgrass	Canarygrass, reed	Rabbitbrush, rubber	Chokecherry, black
Rye, mountain	Dropseed, sand	Ricegrass, Indian	Cliffrose
Squirreltail, bottlebrush	Eriogonum, Wyeth	Sacaton, alkali	Currant, golden
Sweetclover, yellow	Fescue, hard sheep	Sagebrush, big	Elderberry, blue
Timothy	Flax, Lewis	Sagebrush, black	Ephedra, green
Wheatgrass, crested	Globemallow	Saltbush, fourwing	Mountain mahogany, curlleaf
Wheatgrass, desert	Goldeneye, showy	Shadscale	Mountain mahogany, true
Wheatgrass, intermediate	Penstemon, Palmer	Sweetvetch, Utah	Serviceberry, Saskatoon
Wheatgrass, pubescent	Sainfoin	Wildrye, Great Basin	
Wheatgrass, slender	Sweetanise	Wildrye, Russian	
	Wheatgrass, bluebunch	Winterfat	
	Wheatgrass, Siberian		
	Wheatgrass, tall		

Figure 5—Shrubs establish and develop much slower than grasses and forbs. Grazing must be closely controlled until all seeded species become completely established and indigenous species recover.

as it once was. The rate of species establishment and growth is influenced by the soil's productivity potential.

Seedling establishment and growth often vary with site preparation techniques. In soils that have been lightly tilled (plowed or disked), seedlings can develop faster, and may be more numerous the first and second year than on less tilled sites. However, seedlings in tilled soils may be more susceptible to transplanting and pulling damage, due to the loose nature of the soil. Young plants growing in sandy soils are more susceptible to grazing and transplanting damage than are seedlings on areas with heavier soils.

Depleted aspen and Gambel oak areas can be seeded prior to leaf fall, with no other treatment being required. Seedling growth and plant maturity is inhibited under these conditions. Grazing is not recommended on these areas for at least three or four growing seasons following seeding.

Sites with aggressive annuals (cheatgrass, red brome, medusahead, and halogeton) on them prior to treatment, need to be given special management consideration (fig. 3). Care must be taken with grazing. Seeded and indigenous species generally develop slower in the presence of aggressive annuals than on sites without annuals. Livestock grazing in these situations may have to be delayed longer than would normally be needed to allow for proper seedling establishment and community development.

Once a seeded community has become established, grazing must be closely regulated. Most annuals are never totally eliminated from a site. Annuals in a community are waiting for the opportunity to increase, and will do so when the seeded community is weakened through misuse. Annuals can once again become the dominate species with improper management (fig. 3).

It is not fully understood how most seeded (native and introduced) and indigenous species will respond to each other and to grazing. Because of the many physical and biological factors associated with an improvement project, the manager must expect the unexpected, and be flexible enough to adapt management plans accordingly. To do otherwise may harm some species in the community, encourage others, and diminish the potential values and habitats associated with the project.

Some projects may include transplanting. Transplants establish at various rates. Site characteristics, range condition, age and condition of transplants, soil condition and type, soil moisture, and occurrence of post-planting precipitation can all affect rate of transplant establishment. Transplants need to be firmly rooted and producing good top growth before any grazing occurs.

Seeded and transplanted species in riparian situations may require a considerable amount of time to become established and to stabilize the site. Because riparian areas are generally heavily used by livestock and humans, all grazing and human activities should be removed at the time of treatment. Use cannot resume until all seeded and planted species, as well as indigenous species, are completely established or have recovered, and the disturbed areas has stabilized (fig. 6). When grazing is resumed, animal densities, distribution, and duration of use on the area must be closely monitored. Proper distribution of livestock becomes very critical. Human activities must be controlled and monitored, and proper action taken when necessary.

Figure 6—This disturbed riparian site was broadcast seeded. Shrubs were transplanted along the water's edge. Grazing should be excluded until the disturbance is completely stabilized and the shrubs are fully established and reproducing vegetatively.

Excessive use by big game can result in harm to improvement projects. The chances of this happening are small. If this occurs, a reduction in numbers, the exclusion of game animals, and period of nonuse programs can be initiated. This could include the erection of temporary electric fences, implementation of special hunting seasons, or herding of livestock and game. If needed, big game reduction programs should be carried out prior to the project. Animal numbers and degree of use fluctuate seasonally and yearly, depending on weather, conditions of adjacent ranges that big game use, animals' health, reproduction rate, predators, disturbances, and type and timing of hunts and hunter success.

Most project areas require access roads. Unneeded or undesirable roads should be closed and seeded upon completion of each project. When improperly constructed, roads can become erosion channels. New roads can increase human activities on a site, resulting in (a) disturbance of livestock and wildlife activities, (b) reduction in livestock and wildlife use, (c) destruction of seeded and planted species, especially on riparian sites, (d) additional human use of water development, (e) increased on- and off-road vehicle travel, (f) increased fire potential, (g) additional soil erosion, and (h) increased use by horses. New access roads can likewise concentrate livestock use, resulting in depleted areas.

Destructive and harmful human activities that should be controlled on a new rehabilitation project include camping and associated activities, off-road and on-road vehicle travel, horseback riding, fires, gate closure problems (cattle guards can alleviate this problem), wood gathering, livestock trailing and human activity during critical wildlife periods such as breeding, nesting (fig. 7), fawning, calving, periods of deep and crusted snow, low forage availability, and other stressful periods.

Figure 7—A mourning dove nest in an ungrazed juniper-pinyon chaining-seeding rehabilitation project.

Permanent or temporary fences can be used to help control grazing and human activities. Solar-powered electric fences are ideal for temporary protection of rehabilitation sites. Monitoring and repair of fencing is essential to the success of any project.

Richard Stevens
Stephen B. Monsen

Chapter 17

Guidelines for Restoration and Rehabilitation of Principal Plant Communities

Introduction

Range and wildland improvement projects conducted throughout the Intermountain region normally occur within specific plant communities. Each plant community has unique features that require different equipment, planting techniques, and plant materials to conduct improvement projects. Plant communities or associations discussed in this chapter are: (1) subalpine herblands and upper elevation aspen openings, (2) wet and semiwet meadows, (3) inland saltgrass, (4) riparian, (5) aspen-conifer, (6) mountain brush-ponderosa pine, (7) juniper-pinyon, (8) sagebrush, (9) salt desert shrub, (10) blackbrush, (11) annual weedy grasses—cheatgrass brome, red brome, and medusahead, and (12) lowland annual weeds.

Following is a description of each community, equipment and techniques recommended to control competition, a description of methods to prepare sites for planting, and a list of adapted species suggested for seeding. Additional information related to competition removal and site preparation is found in chapters 8, 9, 10, and 11; seeding procedures in chapter 12; and species descriptions, ecological relationships and distribution, plant culture, uses and management, and improved varieties and ecotypes in chapters 18 through 23.

Species selected for seeding depend on the objectives of the project. In general, planting projects fall into two categories: (1) If the principal objective is to restore plant communities, then treatments would be conducted to reestablish native species; this practice is referred to as "Restoration." (2) If the objective is to establish plants on a disturbance or change the species composition, then a combination of introduced and native species could be used and the practice would be considered "Rehabilitation" or "Revegetation." Few, if any, introduced species would be planted in restoration projects because the primary objective is to enhance the ultimate development of native communities. To date, restoration of some native communities may be somewhat limited by the availability of native seeds and planting stock. In addition, techniques and procedures to restore entire native communities are not fully understood. However, considerable information has been developed to restore certain communities and native species. In addition, studies have been directed to investigate ecotypic variability and ecology of selected native species. The studies have been designed to define the range of occurrence of specific ecotypes and the ecological and biotic factors regulating the presence of individual ecotypes. This information has been used to develop specific guidelines for restoration.

Successful restoration plantings are based on the selection of adapted ecotypes and seeding compatible species at appropriate rates with appropriate techniques. Establishment of species that may have existed in a natural community is often difficult to achieve, especially if all species are planted at one time. In most situations, planting should be designed to initiate or promote plant successional changes that would ultimately develop the desired community.

Restoration of depleted plant communities is becoming an increasingly important objective. Reestablishment of resource values is often achieved through recovery of native communities. In many instances, revegetation programs have failed to provide the desired objectives that would be achieved through restoration.

To date, many seeding or planting projects would be classified as revegetation programs. Sites that have been disturbed and support an undesirable array of plants, including some weeds, are frequently planted with a number of introduced and native species. Numerous introduced grasses and broadleaf herbs have proven adapted to western plant communities. Many advanced cultivars have been developed to revegetate disturbed and depleted areas, and these are widely seeded in revegetation projects. Various introduced species are commonly used as substitutes for native species. Many introduced species are widely used because they possess excellent establishment traits and furnish high quality forage. Although these are important characteristics, a few introduced species have, unfortunately, dominated many seeding programs. Too often, areas seeded to a few introduced species are assumed to restore or provide all of the original resources of a native community. Careful evaluation of such plantings does not confirm these assumptions.

Many introductions possess desirable features and can be seeded for specific purposes. As mentioned, various species provide productive, high quality herbage. Others are extremely valuable in the control of noxious weeds, and many have the ability to stabilize and colonize harsh disturbances. If planted for these specific purposes, the plants are quite valuable. Unfortunately, introduced species have often been sown in an attempt to restore disturbed sites and improve natural conditions. In many situations, the seeded plants have adversely affected subsequent development of entire communities. Misuse of a few widely adapted grasses including smooth brome, intermediate and pubesent wheatgrass, hard sheep fescue, Kentucky bluegrass, and crested and desert wheatgrass has occurred. In general, these species attain dominance and prevent recovery of native species and the ultimate recovery of desired communities. Smooth brome has commonly been seeded throughout mountain brush, aspen, and subalpine communities. This grass has suppressed and replaced many herbaceous species on these sites. Similarly, intermediate, pubesent, crested, and desert wheatgrass have gained dominance when seeded in the pinyon-juniper, big sagebrush, and mountain brush types. Desert wheatgrass has gained control in low elevation regions occupied by big sagebrush and, to a lesser extent, salt desert shrubs. These species prevent the establishment of understory herbs and the natural regeneration of important native shrubs. Consequently, the use of such widely adapted introductions to restore native communities should be avoided. The use of many introductions will likely continue until native plant materials become more widely available. In addition, introductions will continue to be used for specific purposes. Of particular importance is their usefulness to control the spread of some undesirable weeds and to stabilize severely disturbed watersheds.

Native species can also be misused, resulting in disruption of community development or weak stands. In various situations, certain natives have been used in an effort to replace less desirable species without adequate consideration of the adaptability of the planted species. For example, bluebunch wheatgrass has been planted with limited success as a replacement for Sandberg bluegrass. Fourwing saltbush, winterfat, and antelope bitterbrush have been unsuccessfully planted as replacements for big sagebrush. Palmer penstemon and Lewis flax have been widely seeded, often in areas where they are marginally adapted. These practices should be avoided.

Sites that have been altered and are no longer capable of supporting some native species are usually revegetated with the most adapted and available species that would provide needed ground cover or habitat. In these situations, combinations of native or introduced species are commonly used and should be encouraged.

Plantings are often designed to allow for changes in species compositions. For example, many shrublands within the Intermountain region have been converted to grass for livestock benefits. In addition, certain wildlands have been disrupted by municipal or agricultural development. Mitigation programs have been employed to convert the remaining wildlands to a more productive status. Interseeding of additional species accompanied by fertilization, irrigation, or other site improvement techniques are used to support changes in the vegetation. These specific practices would be considered revegetation measures.

In some situations, weed presence has altered many sites, preventing natural recovery. Introductions are often used to control and eliminate weeds, restore site productivity, and provide seedbed conditions that favor the establishment of more diverse species. Revegetation plantings are widely employed to stabilize watersheds, roadways, mining, and other serious disturbances. Some introduced species have proven well adapted to these harsh sites, and are capable of persisting on infertile soils. In addition, they may be able to provide excellent ground cover and soil protection.

Various species are listed in this section that are adapted to major vegetative communities and can be used for different planting purposes (tables 1 to 28; all tables are grouped at the end of the chapter). Appropriate seed mixtures should be used to restore native communities or revegetative sites for specific purposes. Misuse of species can adversely affect community development.

Seeding normally involves the use of more than one species. When combinations of plants with different germination and establishment traits are seeded together, competition among species can regulate seedling survival. Many grass species that are commonly sown have excellent seedling vigor and establishment traits. These plants have been selected for their ease of establishment, uniform stand development, and seedling survival. Many perennial native herbs also possess good establishment features, and generally develop acceptable stands when seeded under most conditions. Many species that normally invade disturbances are able to colonize harsh, open sites. When possible, these pioneering species are commonly used as part of a seed mixture to better assure plant establishment.

When species with different establishment characteristics are seeded together, considerable seedling mortality can be expected unless special provisions are made to separate seeds in the furrow or seedbed. Seeds with different establishment traits can be seeded in separate rows, and the amount of seed sown can be adjusted to reduce competition or compensate for some natural thinning. Broadcast seeding can lessen seedling competition as seeds of different species are more widely distributed and less concentrated compared with row seedings.

The ability of individual species to become established is, of course, dependent on: (1) whether a species is sown alone, (2) the establishment features of the companion species, (3) the amount of seed planted, (4) the composition and density of onsite species, (5) climatic conditions, and (6) seedbed conditions.

It is essential that the compatibility of individual species and seeding requirements are understood before complex seed mixtures are developed. The establishment features of species recommended for seeding specific sites are summarized in tables 1 through 28. The present abundance and composition of remnant plants that exist on a proposed planting site also strongly influence the success of a seeding. Normally, weed control measures are used to eliminate undesirable competition. However, many improvement projects are designed to retain existing native plants. These plants can and do compete with new seedlings. Seeding techniques can be used to interseed or selectively plant areas without significantly eliminating remnant plants.

Subalpine Herblands and Upper Elevation Aspen Openings

Subalpine herblands and aspen openings are usually very productive and important sites. They provide

Figure 1—Subalpine herblands provide summer forage, furnish watershed protection, and provide recreational opportunities.

forage and cover, serve as important watersheds, and provide recreation opportunities (fig. 1). However, many subalpine herblands, with their parklike openings, have been so degraded (fig. 2) that they only support weeds or low-value plants. Natural openings scattered among aspen and conifer forests have been degraded by heavy grazing (Ellison and others 1951; Meeuwig 1960). These areas often support undesirable plants including starwort, goosefoot violet, cluster tarweed, flixweed tansymustard, and Douglas knotweed. Sites within some conifer forests often lack an acceptable understory, and when timber is harvested, the areas are extremely barren and frequently invaded by undesirable weeds (Ellison 1954; Ellison and others 1951). Successful rehabilitation can markedly increase the value of these ranges for wildlife, livestock, and watershed protection (Brown and Johnston 1978b; Brown and others 1978; Heede 1981; Meeuwig 1960; Plummer 1976; Turner and Paulsen 1976).

Figure 2—A subalpine area that has been seriously depleted by grazing lacks essential cover and is a source of erosion.

Some subalpine areas are relatively small, but they can be very productive (fig. 1). These areas are important summer ranges for sheep and cattle, mule deer, elk, moose, bear, and several species of grouse (fig. 3a, b). Elevation of subalpine herblands varies between 7,000 and 12,000 ft (2,150 and 3,600 m). Most sites occur above 7,800 ft (2,400 m). Because these high elevation areas receive 20 to 60 inches (500 to 1,500 mm) of precipitation annually, they are important watersheds. Sites requiring restoration often occur on steep, inaccessible terrain. Within the subalpine communities of the Intermountain West, common grasses include Letterman needlegrass, slender wheatgrass, mountain brome, and spike trisetum. Some important forbs are Louisiana sage, western yarrow, penstemons, geraniums, ligusticum, asters, lupine, and bluebell. Principal shrubs include currants, snowberry, low rabbitbrush, and subalpine big sagebrush. Widespread tree species are Engelmann spruce, subalpine fir, and aspen. Soils can be shallow and rocky; however, deep fertile soils are most common.

Removal of Competition

On level to moderate slopes supporting low-value perennials, plowing or disking is an effective procedure for reducing competition. Plowing eliminates most existing plants, including some highly desirable and sparse species. This procedure should not be used if desirable natives exist; such aggressive treatment should be confined to sites supporting a dominance of weeds. Destruction of the soil structure can also result from plowing. Soil compaction and loss of protective litter may also occur. Plowing should be restricted to only the most disrupted sites. Plowing can be done from late spring through summer, but should not be completed when soils are wet, as this may produce compacted soil and surface crusts. The use of brushland plows, offset disks, moldboard plows, or disk-chains that dig to depths of 4 to 6 inches (10 to 15 cm) are recommended. Plow furrows made at right angles to the slope can help control erosion and retain water. Plowing compacted soils can improve seedbed conditions.

Interseeding can be used where it is desirable to reestablish additional species within the existing community. Scalping and seeding can be accomplished with the browse seeder-scalper or related implements. This type of machine can be equipped with 12- to

Figure 3—Subalpine herblands, including aspen and conifer openings, are important summer ranges for livestock and wildlife.

16-inches (30- to 40-cm) wide scalpers that remove existing competition and plant seed simultaneously. The browse seeder treatment has been especially useful on slopes of up to 30 percent. Scalps should always be aligned at right angles to the slope and may be constructed to control erosion from seriously gullied slopes. Scalping or removing soil to create small terraces can be destructive and leave scars for many years. Clearings to accommodate interseeding should be carefully designed. Interseeding can also be accomplished by using herbicides to remove or reduce competition. Spraying strips with herbicides, and transplanting or seeding following the treatment, is a practical approach. This system is most useful on steep slopes where soil protection is critical and soil disturbance should be avoided.

Surface cultivators can be used to reduce annuals such as cluster tarweed, Douglas knotweed, or flixweed tansymustard. The soil should be cultivated to a depth of 2 to 4 inches (5 to 10 cm) in early spring and summer with duckfoot-weeders, spring-tooth harrows, or similar equipment. Cluster tarweed, the most competitive mountain annual, can be eliminated only if all plants are removed. Most seeds of this plant germinate each year so there is slight year-to-year carryover of seed in the soil. By taking advantage of this characteristic, tarweed can often be eliminated with one thorough treatment, although followup treatments are generally required. Annual species that retain considerable seed dormancy usually cannot be eliminated in one operation. Sufficient seed may accumulate as a seedbank, producing many competitive seedlings following spraying or mechanical tillage.

Cluster tarweed produces a toxic chemical that accumulates in the soil and reduces seed germination of other species or causes abnormal seedlings to develop (Carnahan and Hull 1962). Leachate from cluster tarweed field sites has reduced germination and establishment of introduced grasses and some native herbs. The chemical diminishes within a few months, particularly if sites are disked or plowed. Sites treated by tillage or with a herbicide in late spring or early summer can be fall seeded without adverse effects to new seedlings.

Cluster tarweed should be treated after all plants have emerged, but before flowers appear. To prevent seeds from developing, it is essential that treatments not be delayed. Once flowers appear, seeds ripen quickly and a host of new seedlings is inevitable. If larger areas are treated, it is essential that equipment be available to conduct the work on schedule. Fallowing for two growing seasons may be required to treat some areas to assure complete control. Normally, sites supporting large patches of cluster tarweed have very compact and crusted soils. Disking or tillage may be required before sites can be seeded with most conventional drills. Disking can effectively loosen the seedbed. Drill seeding should be done when surfaces are moist but not wet. Surface-type drills or broadcast seeding lessens the chance of soil compaction that can prevent seedling emergence. Competitive stands of cluster tarweed, goosefoot violet, and various annuals can be eliminated with an application of low-volatile 2,4-D at 1.1 to 1.6 lb per acre (1.25 to 1.85 k per ha) (0.5 to 0.75 lb active ingredient per acre; 0.56 to 0.85 kg per ha). The herbicide glyphosphate (Roundup) is also effective in controlling annual and perennial weeds on high elevation rangelands. Ground spray equipment is best for applying herbicides on most high mountain areas because the herbicide can be more directly applied to a precise area. Spraying should be done early in the spring. Annuals are generally most sensitive to herbicides in the two-leaf stage, and certainly should be sprayed before the four-leaf stage.

Herbicides also eliminate the necessity for soil tillage that tends to dry the seedbed. Surface soils that are disked or tilled in spring dry quickly. Sufficient rainfall must be received following tillage to initiate seed germination and sustain small seedlings.

Clumps or patches of skunk cabbage can occur in open parks intermixed with subalpine herblands and aspen openings. Grazing has eliminated many of the understory broadleaf herbs and grasses, allowing skunk cabbage plants to dominate their area of occupation. Recovery of desirable native understory species occurs slowly once sites are protected from grazing. Some reduction of this weed is required to ensure establishment of seeded species. Effective measures have not been adequately developed to control this plant, but recent studies conducted on the Manti-LaSal National Forest reveal that density of skunk cabbage can be reduced with application of various herbicides, tillage, or mowing. Applying Roundup just prior to flowering killed most plants and prevented any regrowth for 3 years after treatment. Mowing or tilling in early July when plants were less than 15 inches (38 cm) tall removed all current vegetative growth and prevented any resprouting during the remaining growing season. Plants regained about two-thirds of their pretreatment density and growth stature the following summer. Treated patches were able to completely recover in 3 to 5 years. Seeding into mowed, tilled or sprayed plots was equally successful. One-year control, attained by any of these treatments, allowed seeded grasses and broadleaf herbs to become fully established.

Skunk cabbage plants develop robust, erect stems with large, fleshy leaves that form a dense canopy. Plants are usually much taller than other associated herbs. Consequently, Roundup herbicide can be applied with ground spray equipment or roller type applicators with little damage to understory herbs. Rollers are used to simply rub or swab the herbicide on the foliage. The roller bar is suspended on a wheel tractor and the height of the applicator is regulated as the unit is passed over the plant. Commercial applicators used in farming operations work effectively on range sites, and are available through most equipment companies. This practice can be used in most situations, even where retention of understory herbs is a primary objective.

Tall larkspur is a troublesome, poisonous plant throughout this vegetative zone. Although certain herbicides are somewhat effective, Vallentine (1989) stated that repeated treatments are required. This is often costly and difficult to accomplish. Sites infested with this weed are often not suitable for cattle grazing, and are best managed for other uses. Many sites in subalpine and aspen park communities were seriously impacted by heavy grazing that occurred near the turn of the last century. Native species were eliminated and serious erosion resulted. Many sites have not fully recovered, even when protected from grazing for many years. Less desirable species, including Letterman needlegrass, western yarrow, Louisiana sagebrush, dandelion, and Rydberg penstemon have persisted and spread to dominate some areas. These sites are often considered for seeding. Direct seeding may be required to reintroduce desirable plants that can eventually produce seed and increase in importance. However, to accomplish seeding, the existing species must be significantly reduced to lessen competition to new seedlings. Unless the plants are controlled, seeding cannot be recommended. However, disturbance to the site is not always advisable. Natural improvement may occur if a sufficient seed source is available. Although the process may be slow, protection and careful management may be the best alternative to improve inaccessible, steep, or harsh sites. Interseeding of desirable species can be successful, and is an effective technique to stimulate and speed up successional changes. This can be accomplished by seeding strips, spots, or selected patches where natural spread is expected to occur. Many areas that were earlier disturbed have now recovered, and soil loss has diminished. Treatment of these sites should be carefully considered to assure that the best procedures are used—seeding or management. Introducing foreign species to a site that is improving naturally is not advisable.

Planting Season

The planting season for mountainous sites extends from early spring until mid-July. Late fall planting is also acceptable, and can be done from September until snow and frost make planting impossible. In subalpine regions the fall planting season may close in early October or even late September. Planting in areas that have been disturbed by logging or road construction should also be confined to these dates. Seeding is often done throughout the summer as logging progresses. This is not advisable because seedlings are vulnerable and can succumb to climatic extremes. Seeds planted in early summer often germinate precociously, and many of the seedlings die as the soil dries. Seedlings that emerge from mid or late summer plantings are often too small and poorly rooted to overwinter. Unless planting can be conducted in the early spring, work should be delayed until late fall to ensure germination the following spring. Because of lingering snow fields and wet areas in the spring, late fall planting is the most practical.

Planting Procedures

Aerial and ground broadcast seeding in the fall are satisfactory methods of planting large tracts of prepared ground. Soil sloughing resulting from freezing and thawing usually covers the seed adequately on plowed or disked land. Pulling a light anchor chain, chain link fence, or harrow across the treated area assures good coverage. If light chaining is used, scarce and expensive seeds can be dropped into tractor cleat marks from seed dribblers that are mounted on the crawler tractors used to pull the chain.

Drilling is recommended for spring planting and may also be used in the fall. Some risk is involved with drilling in the fall if the seeding is done too early. Most drilled seeds are placed directly in the soil and can germinate if soil temperatures warm up even for short intervals, an undesirable situation. Since this hazard is often present on high mountain ranges, it is important to delay drilling until late fall. Broadcast planting can also be used to seed small isolated tracts. Planting in the late spring and summer should be avoided, as soil moisture may not be available for a long enough period to assure seedling establishment.

Seeds of certain species require a cold stratification period to germinate, and if planted in the late spring and summer, will not be adequately stratified to germinate. Although some seeds will likely remain in the soil to germinate at a later date, many seeds will be lost, and emergence will not occur uniformly with all species planted. Weeds and less desirable plants may likely appear if the seeded species do not develop as planned.

Mixed seedings, including many costly, native, broadleaf herbs, are used to improve these rangelands and watersheds. Seeds vary in size and shape. Mixing all seeds together and planting at a similar depth frequently results in poor or erratic success. A number of commercial drills are now available that facilitate planting seeds of different sizes in separate rows or furrows. Also, seeds of different sizes can be planted at different depths. Improper seeding should be avoided on these important rangelands.

Rodents can quickly and effectively gather certain seeds that are either drilled or broadcast planted. If seeding is delayed until late in the season, small rodents are less active and seed losses can be significantly reduced.

The browse seeder-scalper equipped with 12- to 16-inch (30- to 40-cm) scalpers is an excellent unit for planting weedy sites. Browse seeders and some drills can be used to plant seed of shrubs in alternate rows with herbs. Seeding individual species separately in alternate rows is a practical procedure to reduce competition among seeded species.

Shrubs and herbs can be spring transplanted into mountainous sites. Several adapted herbs, especially rhizomatous species, have been transplanted with good success. Treated areas usually receive sufficient moisture to sustain young transplant stock. Sites should be planted before existing native species initiate growth.

Adapted Species and Mixtures

The features of grasses and broadleaf herbs that are seeded on these sites should be considered before disturbances are planted (chapters 18 and 19). Within this broad community type are various plant associations. Selecting and seeding the most adapted species requires careful inspection of the particular sites under consideration. A combination of species is normally required to restore diverse plant associations. A number of introduced grasses have been selected and widely used to stabilize watershed disturbances and provide forage for livestock and wildlife (Forsling and Dayton 1931; Frischknecht 1983; Hull 1974; Keck 1972; Laycock 1982; Plummer 1976; Plummer and others 1955, 1968). The primary species previously planted through most high-elevation revegetation projects include smooth brome, both southern and northern strains; meadow foxtail; orchardgrass, tall oatgrass, Kentucky bluegrass, hard sheep fescue, timothy, and intermediate wheatgrass. Creeping foxtail was commonly seeded at one time, but currently is only planted in restricted situations. Regar brome is a recent development that is gaining increased use. These plants have been used to protect soils and stabilize disturbances including deteriorated rangelands. However, smooth brome, intermediate wheatgrass, Kentucky bluegrass, and hard sheep fescue are serious competitors with native herbs, and prevent the recovery and persistence of many native species (Monsen and Anderson 1993). Although these introduced species are adapted to subalpine and aspen communities, they should not be used where restoration of native communities is a primary objective.

Smooth brome is well adapted to the subalpine and aspen openings. Planting about equal amounts of northern and southern strains, along with other species, has been recommended and widely used. Although smooth brome has demonstrated adaptation to high-elevation sites, its presence has created serious problems. Plants are moderately slow to establish, but increase in density and ground cover by root proliferation and seed production. This species slowly suppresses the presence of most other species. Mixed seedings established throughout the Intermountain region have developed to nearly pure stands of smooth brome, although the time required to attain complete dominance has varied between 10 and 30 years. The loss of forbs and shrubs due to competition from smooth brome is a serious consideration. Few, if any, native grasses, broadleaf herbs, or shrubs have demonstrated the competitive ability to control the spread or persistence of this grass. In addition, few practical methods are available to remove smooth brome and reestablish other species. Consequently, smooth brome is not recommended for planting many mountainous sites. Unfortunately, this has been a primary grass recommended for seeding high-elevation ranges, as highly erodible sites and harsh disturbances can be quickly and effectively stabilized with this grass. Further use should be carefully regulated.

Meadow foxtail is an excellent companion species to most seedings. Creeping foxtail is also well adapted to mixed seedings, and both plants furnish excellent ground cover. Big bluegrass is moderately productive, particularly on moist areas. Orchardgrass is equally productive, but better adapted to well-drained soils. Slender wheatgrass, mountain brome, timothy, and tall oatgrass are also well adapted to these areas. These latter four species develop rapidly, but diminish within 15 to 25 years. Subalpine and Regar brome are also well adapted to mountainous conditions. Sulcata sheep fescue, intermediate wheatgrass, and bearded wheatgrass are adapted to more arid situations. These three species can gain dominance and exclude native herbs in some situations. Their use should be restricted to sites where the recovery of less competitive natives is not desirable. Tufted hairgrass and Canada bluegrass are well suited to the less fertile sites and exposed outcrops.

Not all introduced species have become serious competitors with native species. Tall oatgrass and timothy are relatively short-lived species, persisting for less than 20 years. Orchardgrass and alfalfa persist much longer, but generally are not highly competitive. Both mountain brome and slender wheatgrass are native perennials that can be used with excellent results. Although seed of both species is less available, supplies are generally adequate to meet most demands.

It is important that site-adapted native species are planted. Considerable variability exists among populations or ecotypes of many natives including mountain brome and slender wheatgrass. Planting nontested sources should be avoided.

Many useful broadleaf forbs occur throughout these sites, and are recommended for seeding (table 1). However, not all species common to undisturbed communities have been able to reestablish from direct seeding on seriously altered sites. Ellison (1951) reported that certain species were capable of invading exposed disturbances as pioneer plants, but others appeared in much later stages. Selecting species based on their ecological status is important in restoring these communities. Many broadleaf herbs establish quite well and are able to compete with other species if seeded at appropriate rates. Most important are showy goldeneye, Porter ligusticum, silky lupine, Rydberg penstemon, low goldenrod, and edible valerian. Seeds of other native broadleaf herbs are becoming available and should be included in seedings. As seeds become more available and less costly, seeding rates can be further adjusted. Usually it is desirable to reestablish a complex of native herbs in most disturbances in high mountain ranges. Successful seedings can be better attained in this climatic zone than in most other areas of the Intermountain region.

Mountain snowberry, mountain big sagebrush, subalpine big sagebrush, low rabbitbrush, and adapted forms of rubber rabbitbrush are useful for direct seeding. Transplanting of any or all of these shrubs is recommended where it is desirable to create immediate browse or cover. Certain rhizomatous and fleshy rooted species are selectively grazed by pocket gophers, and new seedings can be seriously impacted by gophers (Ellison and Aldous 1952). Native fescues and meadow foxtail have been shown to discourage these animals and could be seeded where rodents are numerous.

Adapted species are presented in table 1. Seeding rates are somewhat determined by the number and type of species planted.

Wet and Semiwet Meadow Communities

Wet (fig. 4) and semiwet (fig. 5) freshwater meadows can be found in lowland valleys, but are more frequently

Figure 4—Wet meadows interspaced with willows align a stream in southern Idaho.

Figure 5—Big sagebrush communities often surround small but important meadows.

encountered on mountain rangelands where water concentrates and spreads. While the total area occupied by wet and semiwet meadows is relatively small, these meadows are important to grazing animals and upland game birds (Eckert 1983; Oakleaf 1971; Patton and Judd 1970; Ratliff 1985). They produce succulent herbage throughout the growing season for all classes of game and livestock. Many meadows have been seriously depleted of valuable sedges, rushes, grasses, forbs, and shrubs that once were abundant (Eckert 1983). However, disturbed meadows can be made more productive (Eckert 1975; Eckert and others 1973a). Planting native sedges, broadleaf herbs, and shrubs may be desirable, yet is not always practical because of the lack of sufficient seed or planting stock. Exotic grasses have been used to restore cover and herbage production. In some cases, introduced plants have exceeded the herbage production of some native grasses. Commercial seed production of native herbs is necessary to facilitate planting of desirable species. Consequently, species diversity and structure of seedings are sometimes limited.

Availability of moisture in meadows ameliorates the extremes of climate and tends to create a comparatively uniform environment through all vegetal zones. Some species can often be planted throughout both lowland and mountain ranges. The important factors that favor high production on meadow lands are the moisture availability and high soil fertility.

Removal of Competition

Essential to successful seeding is the control of weedy species (Eckert 1975, 1983). Summer fallow treatments have been used to control weeds in wet and semiwet meadows (Cornelius and Talbot 1955; Eckert 1983; Eckert and others 1973b; Plummer and others 1955). Usually, moldboard plowing is required to eliminate tough, sod-forming, weedy species that may invade disturbed wetlands. Heavy offset disks or brushland plows can be used to control competition and aid in seedbed preparation. Plowing can eliminate most species, including desirable plants. However, existing species must be reduced in order to establish desirable plants. Some species such as Baltic rush provide excellent cover and stability, yet are highly competitive and must be controlled if sites are to be successfully seeded. Where the soil may be too wet for plowing or disking, shallow ripping using a crawler tractor can be employed to break up the existing sod.

Herbicides can be used to control broadleaf weeds and grasses, although streams and waterways must be protected. Noxious weeds, including Canada thistle, have invaded many semiwet areas and must be controlled to assure establishment of seeded species. Repeated treatments are required to reduce competition from this plant. In some situations, Canada thistle may be reduced by spraying, but not completely eliminated.

Removal of competitive perennial grasses, including Kentucky bluegrass, is also necessary to establish more desirable species. Extensive treatments, including mechanical tillage or application of herbicides, are required. These treatments usually eliminate other species, restricting their use to the most critical disturbances.

Planting Season

Early spring to early summer is the most effective planting period. If water does not accumulate and remain on the soil surface, fall or late winter plantings can be successful. However, spring flooding can destroy seedbeds prepared in the fall. Seeds planted in the fall will rot if inundated by water for extended periods. Consequently, areas that are subjected to flooding cannot be planted until the water level recedes. This may delay planting until late spring or summer. Shrubs should be transplanted early in the spring after water recedes but before the soil dries out. Young transplants can usually withstand wet soil conditions for a limited period, yet planting into flooded sites is not practical or desirable.

Planting Procedures

Broadcast seeding on prepared seedbeds is usually recommended on wet sites, especially for fall or early winter seeding. Plowed or disked sites usually leave a rough surface that can be broadcast planted. Drills can be used for spring and fall planting, yet particular care must be taken to avoid planting seeds too deep. Seeding can also be accomplished using the Brillion seeder or surface-type seeders. These units distribute the seed on the soil surface. Seeds are then punched into small depressions within the soil. The depressions are created by these machines, and the planting depth is determined by the rollers or imprinters. Surface seeders do not plant seeds too deep even when seeding on a loose seedbed.

Adapted Species and Mixtures

The most often used introductions for seeding wet and semiwet meadows to increase herbage production have been Reed canarygrass and meadow foxtail. Both grow well in wet and semiwet conditions, although "Garrison" creeping foxtail is better adapted to wet areas. These plants persist even on sites where water may stand for short periods. Alsike clover and strawberry clover are good supporting legumes, although they can survive only short periods of submergence. Black medick grows well except at high elevations. Redtop, smooth brome, timothy, and alpine timothy are also well adapted to semiwet soils and are useful forage plants, although redtop is less palatable than the latter three species. Reed canarygrass and smooth brome are extremely competitive and suppress other plants. These grasses are not recommended if natives or other species are desired on the site.

Species recommended for wet and semiwet conditions differ (table 2). Many native sedges are extremely desirable species, but seed supplies are currently very limited. Attempts to restore these sites will require development of the native seed industry. Sufficient seed cannot be harvested from wildland stands, and field rearing will be required.

A list of shrubs useful for transplanting is presented in table 3. Willows are well suited to a variety of conditions found in meadows. Willows can be established from fresh cuttings placed in the ground in early spring; however, rooted cuttings are preferred. Survival of rooted cuttings is much better, particularly on sites that may dry early in the season.

Planted meadows tend to attract grazing animals. Sites that are seeded to productive and palatable grasses and herbs should be managed to prevent excessive use. Animals will concentrate in treated areas throughout the entire growing season; consequently, sites must be protected or grazed properly to maintain site productivity.

Inland Saltgrass Communities

Inland saltgrass has gained control on many dry to semiwet meadows in upland and lowland areas (fig. 6) where alkalinity is appreciable and where the early-growing grasses, sedges, forbs, and shrubs have been depleted by grazing. Soils are generally heavy with high water tables at least during some period of the year. Some areas may have standing or running water for short periods. While these meadows are relatively small, they usually have a much higher potential for livestock forage production and as wildlife habitat than when dominated by saltgrass (Lesperance and others 1978; Roundy and others 1983). This is particularly evident on sites that remain fairly moist throughout the growing season. Saltgrass produces a dense sod, so vigorous methods must be used to eliminate competition and allow establishment of other species. Not all saltgrass sites should be converted to other species. Some sites have been converted to more desirable and productive forage plants for livestock grazing, but this can be a costly effort. Improvements may benefit wildlife and allow for grazing at different and longer seasons, but revegetation projects should be carefully evaluated before treatments begin.

Removal of Competition

Saltgrass can be difficult to eradicate by plowing or mechanical tillage. McGinnies (1974) reported that saltgrass can be successfully removed by spraying with Roundup. Sites that are treated with this herbicide can be plowed or tilled to aid in seedbed preparation. Saltgrass meadows are commonly located on soils with a high concentration of salt in the C horizon and possess an impermeable B horizon. These soils may be susceptible to soil crusting and exhibit low fertility, but benefit from plowing (Ludwick 1976). Plowing may improve water infiltration and increase the availability of nutrients (McGinnies and Ludwig 1977). However, care should be taken to avoid plowing

Figure 6—Inland saltgrass communities usually remain green and productive throughout the summer.

the C horizon to prevent mixing of the surface horizons with the zone of high salt concentration.

Sodic soils are often impermeable to water and may develop a surface crust when dry. Tillage or deep ripping when soils are dry can improve permeability. If soils are wet at the time of treatment, crusting and surface packing can occur. Disking litter and vegetation into the surface soil can reduce soil crusting. Drilling with heavy equipment can compact the soil and prevent the emergence of small seedlings. Broadcast planting and drilling with light equipment can reduce surface compaction.

Treatment of saltgrass sites usually requires a fallow period. Sites can be plowed in late summer, winter fallowed, and seeded in the spring. Plowed areas usually require disking to kill the roots or sod and prepare the seedbed. Some sites may require two to three diskings to reduce the sod. Sites may also be sprayed with Roundup in the summer, fall plowed, and spring planted. Where complete control is desired, planting an interim annual crop such as yellow sweetclover is suggested. After the annual crop is harvested, the site can again be plowed and disked to control any regrowth of the saltgrass. The area can then be planted to perennials. If satisfactory control of saltgrass is evident, final plowing and seeding of perennials is recommended 1 to 3 years after the initial treatment. By this time most of the saltgrass should have been eliminated.

Planting Season

Best results are obtained with late fall, winter, and early spring plantings. Where land frequently remains wet, spring planting is advised because fall planted seeds can be adversely affected by prolonged flooding.

Planting Procedures

Deep-furrow drills with drops spaced 12 inches (30 cm) apart have performed satisfactorily on tilled soils. No-till drills have been used to drill “Garrison” creeping foxtail directly into saltgrass. The browse seeder, equipped with 16-inch (40-cm) wide scalpers, can be used to interseed species into thin stands of saltgrass. Broadcasting on plowed land in late fall or early winter has been successful for some sites. Plowed soil will slough during the winter and usually covers the seed. These soils sometimes crust, restricting seedling emergence. To avoid crusting caused by surface packing from drills and tractors, broadcast seeding is often advised. The Brillion seeder is also useful in planting into the prepared seedbed and in reducing soil crusting.

Adapted Species and Mixtures

Species adapted to the inland saltgrass type (table 4) must be salt tolerant. Growth of some species occurs primarily in the spring when the salt is diluted by soil moisture. Introduced species that have been seeded successfully in areas with high water tables or running or standing water are: meadow and creeping foxtail, tall fescue, tall wheatgrass, and strawberry clover. Areas that dry out during periods of the year have been seeded successfully to alkali sacaton, crested wheatgrass, streambank wheatgrass, Russian wildrye, black medick, yellow sweetclover, fourwing saltbush, Gardner saltbush, and winterfat. Species’ establishment and stand development can be somewhat slow. Planting native species is recommended, but is currently limited to only a few species because seeds are not available.

Riparian Communities

Riparian sites often occur as narrow corridors traversing many different plant zones. Streams and drainages often occupy very small but important sites within major land types. The vegetation and habitat provided by the riparian zone is extremely important to the management of associated lands (Thomas and others 1979b). Different riparian communities have been identified throughout the Intermountain area (Youngblood and others 1985). Riparian sites usually attract and sustain livestock and wildlife. These sites are particularly important during the midsummer months. Riparian communities often provide diversity to otherwise rather barren and exposed wildlands. Aquatic wildlife are dependent upon a continued supply of high quality water. The vegetation along a stream provides shade that greatly influences water temperature, protects soils and streambanks, and furnishes food for aquatic organisms. Vegetative debris falling into the stream is a highly important food supply for aquatic life. Insects harbored by the vegetation also serve as an important part of the food chain.

Timber harvesting, road construction, agricultural cropping, mining, and recreational uses have all destroyed riparian areas (Council of Agriculture Sciences and Technology 1974). Riparian zones have also been degraded extensively by livestock grazing and trampling (fig. 7). Woody or herbaceous vegetation or both have been eliminated or seriously stunted in many areas. On many sites the understory species have also been replaced by weedy annuals and perennials, including noxious weeds. Frequently, dense stands of sod-forming grasses or forbs gain dominance. Unpalatable and undesirable species are easily spread along waterways.

Figure 7—Improper grazing has disrupted many riparian sites in the Intermountain region.

The woody plants that occur along streambanks have often been destroyed by repeated browsing and trampling. It is critical that woody species are reestablished. Some species can recover and grow if protected from grazing. Willows, aspen, alder, and dogwood normally recover if some live plants remain. If grazing has completely destroyed the woody species, transplanting or seeding will be required. Destruction of stream habitats and associated watersheds has often resulted in serious erosion and damage to the streambank and floodplain. Erosion and flooding often remove topsoil and alter the site, hindering natural or artificial revegetation (Monsen 1983). Structures are often required before vegetation can be reintroduced (fig. 8). Reintroduction of beaver, when managed to fit the food supply, can significantly aid in stabilization of many streams and waterways. Entire watersheds may require treatment before streambanks can be improved. Controlling grazing on riparian sites is not easy (Platts 1981a,b) because the use of adjacent lands is dependent upon access to the stream.

Figure 8—Channel reshaping and construction of impoundments may be required to stabilize stream channels prior to seeding and planting.

A distinct and abrupt ecotone may separate mesic from xeric plant communities that align a stream. Different plant communities must be planted with separate, adapted, species. Seasonal changes in soil moisture affect the occurrence of different plant communities. Since most riparian zones support a mixed array of plant communities, mixed plantings are required. A more extensive plan is required to restore and stabilize riparian communities than for most other sites. Monsen, in Platts and others (1987), discusses the following considerations that influence rehabilitation practices:

1. Alteration of the riparian vegetation and soil may result from onsite impacts, or as a result of poor management of other portions of the watershed (Megahan and Kidd 1972). Proper management of the entire watershed is essential prior to initiation of rehabilitation measures in riparian communities. Restoration of riparian sites may be conducted simultaneously with treatment of other portions of the watershed. Unless adjoining areas are reasonably stable, repair of riparian disturbances will not be effective.
2. Riparian sites usually are extremely heterogeneous, containing different plant communities, topographic conditions, parent materials, and soils within a short distance (Odum 1971). Remedial treatments must be applicable to the different conditions encountered. For example, steep, unstable banks may occur immediately adjacent to wet and boggy meadows, requiring different site preparation practices, planting techniques, and plant materials.
3. Different treatments are often required to correct separate problems, such as controlling surface erosion, eliminating bank slumping, shading the stream, controlling weeds, and providing concealment for wildlife.
4. Riparian sites are often narrow, irregularly shaped corridors that are not accessible to conventional planting equipment. Although only small areas may require treatment, extensive erosion, sedimentation, and plant community alteration may have occurred, thus requiring special equipment for rehabilitation.
5. The dense and frequently storied assembly of many plant species is required to maintain riparian site stability. Grazing and other impacts have often reduced plant density or resulted in the removal of specific species. The loss of key species may seriously affect the persistence of other plants. To be successful,

rehabilitation may require reestablishment of a complex array of plants. Reestablishing woody plants is often essential.

6. Many sites are so seriously altered that extensive rehabilitation measures will be required to restrict further losses of soil and vegetation and reestablish a desirable plant cover (fig. 9).

7. Stabilization of the streambank with vegetation is often the principal concern in rehabilitation. Vegetation is also required to provide shade for the stream and improve wildlife habitat.

8. Some riparian sites have often been so seriously altered that the original vegetation can no longer survive. Thus, attempts to restore the original complement of plants may not be practical. However, unless a grouping of plants similar to the original community can be established, aquatic and terrestrial resources may not be improved.

9. Noxious weeds and other less desirable species have often invaded riparian disturbances. Weeds must be removed to improve the site and allow for planting. These plants do not always provide adequate soil protection or enhance aquatic habitat. Weeds may be spread by the stream to occupy downstream disturbances and interfere with the establishment of more desirable species.

10. Site preparation is usually required to accommodate planting. Some reduction of the existing plant cover may be necessary to eliminate competition with newly seeded or planted species. However, reduction of streambank stability by plowing or similar methods of plant removal is hazardous. Thus, treatments normally include interseeding or planting small strips or sections over a period of 2 to 3 years. By such procedures, small areas can be treated in sequential intervals to retain existing plant cover and encourage natural recovery.

11. Seasonal runoff and flooding influence planting dates as well as establishment and survival of new seedlings or transplants (Aldon 1970b). Sites may be covered with water in the spring for a few days or for weeks. Planting is frequently delayed by flooding until a time when air temperatures and precipitation patterns may no longer be conducive to seedling survival. Disturbances may be seeded in the late summer or fall. However, fall-germinated seedlings may not be able to survive spring runoff. Many riparian species survive or are propagated by flooding (Kozlowski 1984). However, small seedlings usually are not as tenacious as larger plants. Seasonal runoff also disrupts and seriously damages prepared seedbeds. Transplanting large stock is often required to resist the effects of flooding and scouring.

12. Protection of young plants is essential for establishment and survival. Protection from grazing may be required for a number of years to allow plants to attain a reasonable size and furnish soil protection. Transplanting large stock may be necessary to overcome the influences of grazing and flooding.

Figure 9—Transplanting is frequently required to reestablish willows and other shrubs along streams.

Artificial plantings are not the only means to restore and improve riparian communities. Because of the inherent problems associated with revegetation of these areas, consideration should be given to natural improvement whenever possible. Protection from grazing (Meehan and Platts 1978; Vallentine 1980) can be used to improve many situations. If a satisfactory number of remnant plants exist, natural recovery can often occur. Some native herbs, particularly species of sedges and rushes, are extremely vital to streambank stability and herbage productivity. Most species of sedges and rushes have not been investigated for use in artificial seeding programs, but their utility is well known. Where possible, management and revegetation programs should be tailored to promote their recovery. The growth habits and utility of most of the principal sedge and rush species in the Intermountain area are summarized by Monsen (in Platts and others 1987) (table 5).

Removal of Competition

Sites requiring transplanting to reestablish woody shrubs and trees may first require removal of herbaceous species to allow shrubs to establish (Nieland and others 1981). If shrubs or trees are to be transplanted along the edge of a stream, plantings should be selectively located in open sites free of herbaceous competition. Planting directly into dense stands of sod-forming grasses and herbs often requires removal of understory competition. A clearing of approximately

30 inches square (75 cm square) should be created. The vegetation can be removed by hand scalping or by spraying with a herbicide. Scalping is not very successful in controlling sod-forming grasses, sedges, or shrubs, but competition need not be controlled beyond the first growing season in many situations. Scalps may also be created using various herbicides. If Roundup is applied, spots can be transplanted immediately without damage to the transplant. Meadow vegetation is killed with this herbicide; however, sprayed sites actually collapse as their root mass deteriorates. Even small sprayed areas must be carefully located before sites are treated with a herbicide. Care must be taken to ensure that herbicide use complies with all State and Federal laws, and contamination of streams and waterways does not occur.

Noxious weeds commonly invade wet and semiwet meadows occurring within the riparian zone. Canada thistle and whitetop are often encountered in such areas. Noxious weeds must be eliminated or controlled before sites are planted. Plowing or repeated disking is often necessary to remove established sod forming weeds. Plowing is usually not recommended along the edge of the streambank. This area should be protected if possible.

Most meadows adjacent to streams are small irregular tracts. Often they are not accessible to large equipment. Small tractors and implements can be used in these situations. Usually, treatment is delayed until after seasonal water levels have receded. Sites where streambanks are reconstructed or where structures including dams or impoundments are erected are planted to prevent the establishment and spread of undesirable weeds (fig. 8). Often, large acreages surrounding streams should also be treated to prevent the spread of weeds. In addition, these adjacent areas should be planted with useful forage species to better control livestock distribution and use. Control of weeds and maintenance of seeded species is directly dependent on the management of grazing animals. Improperly grazed sites will not retain a suitable plant cover.

Planting Season

Seeding in late fall or early spring may be applicable. Some seeds should not be flooded or left covered with water for extended periods, although some willow seeds benefit from flooding. Consequently, areas that are subject to flooding should be spring planted after the water level recedes. Transplanting should be done as early in the spring as possible. As areas become bare of snow or as the stream flow decreases (fig. 10), the sites should be transplanted immediately. Sites along a stream dry out in irregular patterns. Transplanting and seeding should not be delayed until the soils are dry or existing plants have initiated growth.

Figure 10—Willow cuttings planted as rooted stock grow quickly, furnish cover and protection on highly erosive sites.

Planting Procedures

Areas that are large enough to be plowed or disked can be drill seeded. Meadows can be planted in the same manner as recommended for the inland saltgrass or mountain meadow sites. Small tracts may be broadcast planted, followed by dragging a harrow, chain link fencing, or other small implements over the site to cover the seed. Wet soils frequently crust, settle, or slump when tilled. These soils should not be “overworked” because a poor seedbed may develop. Planting using a culti-packer seeder often prevents or eliminates problems associated with crusting, compaction, and settling. Hand seeding and raking can be used in many small inaccessible sites. Most transplanting should be accomplished using hand-planting bars, shovels, or augers.

Interseeding and intertransplanting are useful techniques to improve portions of riparian areas without extensively disturbing the soil. Transplanting rooted stock is a very effective technique for establishing shrubs and trees. Various drills, disks, scalpers, or spray units can be modified to treat small strips or areas while leaving adjacent sites intact. Transplanting and selected seeding can then occur with the treated strip and areas where competition has been eliminated. Once treated areas become stabilized, the remaining sites can be planted if necessary.

Transplanting both shrubs and herbs on disturbed sites is advised. Transplanting large stock, including poles and rooted stock, is recommended. Large woody transplants can compete satisfactorily with understory competition, and are better able to survive, as stems are placed deep in the soil where a more persistent water table exists. Transplants provide an effective ground cover and can stabilize erosive sites rather quickly. Once a site has been treated, seeded, and transplanted it must be protected from grazing until sufficient establishment has occurred.

Adapted Species and Mixtures

Plants growing along the edge of a stream usually are able to exist throughout a wide elevational range. Consequently, individual species are found growing throughout a number of major vegetative types. Plants not growing immediately adjacent to the stream are not influenced as much by the moderating effect of the stream. Consequently, in selecting species for riparian plantings, separate groupings must be utilized.

Areas requiring treatment that are not directly influenced by the stream can be planted with species adapted to the prevailing plant community. Plantings should include species that provide streambank stability. Only a few herbs produce root or vegetative biomass and structure equal to the amounts furnished by native sedges or rushes. These dense, sod-forming species are vitally important. Transplanting wilding root segments of the native herbaceous plants along the eroding sections of the streambank is an effective method for stabilizing the site.

In addition to the herbs that exist within most native plant communities, Doran (1957), Horton (1949), and Plummer and others (1968) discussed the utility of introduced species for riparian sites. Ree (1976) discussed the rooting features required to provide streambank stability, and identified species that can be used for erosion control. Various introduced species can be used to treat riparian disturbances, but these are generally not compatible with existing natives, and if planted may not allow natural improvement to occur. The species listed in tables 5 through 11 designate those plants that, to date, appear best adapted to various riparian situations.

Numerous species of willow are widely planted in riparian areas (fig. 10, table 11). Propagation requirements and planting techniques differ among these species (Chemelar 1974). Carlson (1950) and Haissig (1970) reported that species with preformed root primordials root freely. Those without preformed root primordials root poorly or not at all.

Small transplants are often difficult to establish on adverse sites, including flooded areas. Consequently, small or poor quality stock is not recommended for riparian plantings. Rooted cuttings (Holloway and Zasada 1979) and large healthy stock should be transplanted, especially when using species that root poorly.

Aspen and Associated Conifer Communities

Aspen is the most widely distributed native tree in North America. In the Intermountain area, there are over 20 million acres (8.1 million ha) of aspen scattered from upper foothill ranges to mountaintops and high plateaus. In Utah, aspen occupies more forested lands than does any other tree species. The majority of the aspen occurs at middle elevations and is associated with, and scattered within, conifer forests (fig. 11). Aspen forests span a broad range of environmental conditions (Warner and Harper 1972). Annual precipitation within the Intermountain aspen zone ranges from 16 to 40 inches (400 to 1,000 mm). The species thrives at a variety of elevations and under a wide range of moisture and soil conditions. (Mueggler 1988; Mueggler and Campbell 1986).

Aspen is found in a number of mountain vegetative zones, ranging from the subalpine to the foothills. Mueggler (1988) lists 14 major, 12 minor, and 35 incidental aspen community types in the Intermountain

Figure 11—Conversion of aspen stands to conifers has been hastened by grazing of understory species.

region. Shepperd (1990) classified aspen communities based on growth and stand characteristics. Aspen can be found growing in association with tall forbs, ponderosa pine, lodgepole pine, spruce-fir, mountain brush, open parks of mountain big sagebrush, snowberry and chokecherry, and on the margin of grasslands. Aspen trees are found along moist streams as well as on dry ridges and southerly exposures, on talus slopes, and in deep to shallow soils of various origins.

Aspen forests are dynamic and in a constant state of change. As change occurs, resource values change. Although some aspen stands are considered climax communities, a majority of aspen forests are probably seral to other vegetative types. Many aspen stands will eventually be replaced by conifers. Seral stands are generally regarded as fire-induced successional communities able to dominate a site until replaced by less fire-enduring, but more shade-tolerant, conifers (DeByle and Winokur 1985; Mueggler 1988). Cryer and Murray (1992) found that stable aspen stands in Colorado are found only on soils with a mollic horizon.

Succession of aspen to conifers can greatly increase the likelihood that an area will experience a devastating fire (Gifford and others 1983, 1984; Jaynes 1978; Kaufmann 1985). As aspen stands convert to spruce-fir, potential surface water runoff is reduced by 33 to 65 percent. White fir uses about 4 inches (10 cm) more water per year than does aspen, and blue and Engelmann spruce may use 8 to 10 inches (20 to 25 cm) more water per year (Gifford and others 1983, 1984; Jaynes 1978; Kaufmann 1985).

With the invasion of conifers into aspen stands, understory carrying capacity for livestock and big game is reduced. In the early seral stages, an aspen forest may produce 1,400 lb (640 kg) of forage per acre. Forage production is reduced to about 500 lb (225 kg) per acre in the early stages of conifer invasion and to only 100 lb (45 kg) per acre in the later conifer seral stages (Gifford and others 1983, 1984; Jaynes 1978; Kaufmann 1985). In the Intermountain region, aspen stands mature in about 80 years; they deteriorate rather rapidly, often in 120 years, and rarely attain ages over 200 years (Mueggler 1994). On the Manti-LaSal National Forest, it is estimated that 1,600 acres (650 ha) per year are being lost to conifer invasion.

Aspen-dominated forests have a wide range of values and are truly multiple-use communities. Forage production and cover for livestock and a wide variety of wildlife species are of high value and priority. Wood fiber is abundant; however, it is grossly underutilized. In the West, aspen is the only upland hardwood tree. High quality water yields develop from aspen forests. In some areas, the aspen type yields more quality water than any other forest type. Aspen is appealing aesthetically throughout all seasons of the year. Recreation values are especially high. Aspen forests also act as a firebreak for the more flammable coniferous types (DeByle 1985c).

Most disturbances that have occurred in aspen communities have resulted from grazing impacts. Past grazing abuses have removed many desirable species, causing a shift in understory species composition. In some situations, conifers have invaded these sites, shifting the aspen stands to conifer forests. Many aspen communities have been so seriously damaged by livestock grazing that soils have been eroded. Recovery of native species has been slow to occur, and many have been seeded with introduced grasses to stabilize watershed conditions and restore herbage productivity.

Aspen reproduction in the West is almost completely dependent upon vegetative propagation by root suckering. Most aspen communities require a major disturbance such as burning or clearcutting to alter competitive relationships and to stimulate root suckering (Bartos and others 1991; Brown and DeByle 1989; DeByle 1985c; Shepperd 1990; Shepperd and Smith 1993). In the past, fire played a prominent role in perpetuation of aspen forests. Today, however, the existence of seral aspen is threatened by suppression of fire in western forests (Bartos and Mueggler 1981; Bradley and others 1992a,b; Cartwright and Burns 1994; DeByle and Winokur 1985). Prescribed burning is widely used to simulate the effect of wildfire that rejuvenates aspen forests. Prescribed burning of mid- to late-seral aspen/conifer stands can be an economical and environmentally acceptable way of rejuvenating aspen, and has proven to be an effective tool for increasing productivity of understory species that provide quality forage for large herbivores, specifically deer, elk, cattle, and sheep (Bartos and Mueggler 1981; Brown and DeByle 1989; DeByle 1985c; Walker 1993).

Extensive plantings have been conducted in the aspen type. Seedings are normally successful as sufficient moisture is available to sustain young seedlings. In addition, various native species are available for treating these areas. With proper planning, both revegetation and restoration plantings can be successfully conducted.

Removal of Competition

Aspen stands that are in an overmature and decadent condition (Schier 1975), or have been depleted of understory herbaceous species, do not require understory plant control measures. The understory plant density has usually been reduced by grazing or suppressed by shading of trees and overstory shrubs. Few weedy species invade or gain dominance within these forested communities. However, serious weed problems can develop on extremely deteriorated sites, particularly areas subjected to prolonged grazing.

The procedure for removing competition in aspen openings or associated conifer forests is similar to those described for the mountain brush and subalpine sites. Where overstory conifers and aspen should be eliminated, prescribed burns, timber harvest, or firewood harvest are appropriate treatments.

Planting Season

Aerial and ground broadcasting are generally the most desirable methods of seeding. Planting in nondisturbed aspen and associated conifer types extends from early September to leaf drop. Seeding should be completed before leaf fall and permanent snow covers the ground. As fallen aspen leaves become wet and stick together, they can form a satisfactory cover for planted seed. If seeds are fall planted within aspen stands immediately prior to leaf drop, no other seedbed preparation is required. Where aspen has been burned, aerial broadcasting should occur from fall to early winter. Seeding on top of early snow, following burns, has the potential to produce desirable results.

Planting Procedures

Broadcasting from a fixed-wing aircraft can be economical and effective for planting large areas. Broadcast seeding from helicopters is best suited for seeding scattered and small patches, especially in deep canyons and on steep hillsides. Many sites are too rough or steep to allow the use of ground equipment. Seeds cannot be distributed as uniformly by hand as from aircraft, yet small areas can be seeded satisfactorily from horseback or on foot. Livestock can often be beneficial in covering broadcast seed if animals are temporarily concentrated on the seeded areas.

Adapted Species and Mixtures

Because the intensity of shade differs among aspen stands, species selected for seeding should be shade tolerant as well as adapted to the specific sites being seeded within the aspen and conifer zone (table 12). Because some shrubs are usually present, it may not be necessary to include these shrubs in the seeding mixture. Many plants that occur within the aspen and conifer forests are very productive and nutritious. Many will withstand heavy grazing and recover well under a rest rotation grazing system. These species are selectively used by both game and livestock; consequently, treated areas usually attract grazing animals and upland game birds, and serve as highly useful pastures and wildlife habitat.

Smooth brome and intermediate wheatgrass have been widely seeded through the aspen type. Kentucky bluegrass has also been seeded and has spread to occupy many adjoining sites. All have established well and provide good herbage. These three species, however, exhibit very aggressive spreading traits, and develop a closed sod that eliminates many important tall forb species. Smooth brome and intermediate wheatgrass have been shown to diminish aspen regeneration (fig. 12). Open parks with interspersed aspen stands have also been seeded with smooth brome and intermediate wheatgrass. This has resulted in the elimination of many native forbs, grasses, and shrubs (fig. 13). Mountain big sagebrush and other shrubs that frequently grow in open areas have been eliminated by competition from these two seeded grasses. Seedling recruitment of serviceberry, snowberry, chokecherry, and curlleaf and mountain mahogany has also been prevented. Once these grasses are established, methods of control or conversion to other species are very limited. These grasses, therefore, should not be seeded where a diverse composition of species is desired because they do not promote recovery of native plants or community restoration.

Regar brome is an introduced species that is now being seeded more extensively. This species does not appear to be as aggressive and dominating as smooth brome, but long-term ecological studies are not available. Timothy and tall oatgrass are introduced species that are well adapted to aspen and conifer areas. They are not as aggressive as smooth brome, yet they

Figure 12—Closed stands of smooth brome often develop within 10 to 20 years following seeding of aspen sites. The dense sod frequently eliminates native grasses and forbs, and diminishes aspen reproduction.

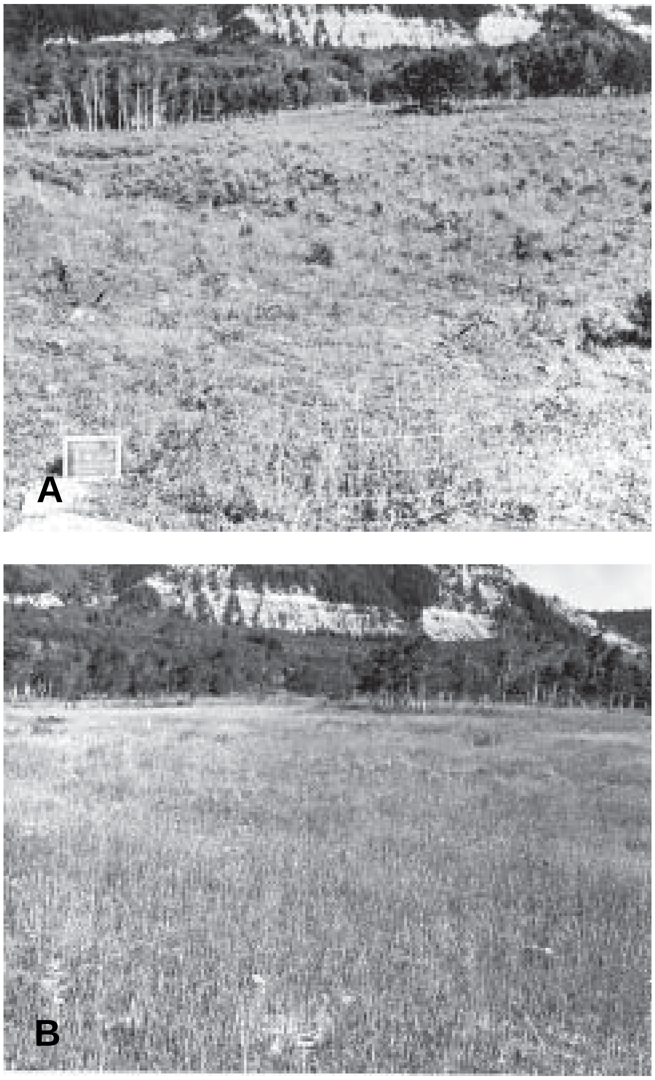


Figure 13—(A) This site was a heavily grazed aspen opening prior to seeding with intermediate wheatgrass and smooth brome in 1959; (B) Same area 30 years later showing displacement of the native shrubs, grasses and broadleaf forbs by the seeded perennials.

establish well, provide good forage and ground cover, and provide for development of the native community in 5 to 20 years. Orchardgrass is also widely planted and is well adapted. It can also suppress recovery of native species, but not to the extent of smooth brome or intermediate wheatgrass.

The natives, slender wheatgrass and mountain brome, can generally be planted in place of the commonly seeded, introduced perennial grasses. Additional native grasses with good potential that should be considered are subalpine needlegrass, alpine timothy, Canadian wildrye, and thurber fescue. Alfalfa has been seeded successfully, especially in open parks. This introduced forb establishes well, provides excellent forage, enhances soil nitrogen, and is compatible with native species. It can be planted to restore severe disturbances, but use of native forbs is recommended. Native forbs that are being seeded successfully include showy goldeneye, tall bluebell, cowparsnip, goldenrod, butterweed groundsel, oneflower helianthella, Porter ligusticum, lomatium, and sweetanise.

Broadcast seeding of most native herbs is not as successful as broadcast planting of grasses. Usually, native forb seeds are more costly and less available. Drilling or some means of placing these seeds in the soil is advised. Small seeded species, including penstemon, meadowrue, and cinquefoil, establish well by broadcast seeding, but drill seeding of expensive seeds is advised.

It is important that species and mixtures planted are site adapted. Attempting to seed extensive areas with a general mixture is not advised. Sites should be inspected and planted with a diverse mixture to assure that different plant associations are able to develop. As native species become more available, more complete and site-specific mixtures can be planted.

Many native herbs are currently being collected from wildland sites and can be used in restoration plantings. Within the Intermountain region, native species are being harvested with greater frequency from the aspen communities than from many other vegetative types. However, seed supplies are not currently adequate to facilitate all planting needs, and cultivated fields must be developed to supply demands.

Many important native grasses and broadleaf herbs that exist in these communities can be successfully planted in mixtures. Natural recovery of depleted and disturbed sites depends upon the degree of soil loss that has occurred and the amount and source of native seeds. Some aspen areas will recover quickly if livestock grazing is controlled, and seeding is not necessary. Seeding to protect exposed soils may be achieved by planting a few species, principally native grasses. Through protection, additional species will likely recover.

Mountain Brush Communities

In the Intermountain West, the mountain brush type occupies considerable acreage. The chief components are Gambel oak, bigtooth maple, Rocky Mountain maple, mountain big sagebrush, Saskatoon serviceberry (fig. 14), and Utah serviceberry. Associated

Figure 14—Mountain brush communities support Gambel oak, mountain big sagebrush, and serviceberry.

with the above species, in various geographic areas, are ninebark, chokecherry, bitter cherry, skunkbush sumac, antelope bitterbrush, cliffrose, true mountain mahogany, and curlleaf mountain mahogany. The type is rich in diversity of forbs and associated grasses. Gambel oak dominates from north-central Utah to northern Arizona, western Colorado, and on scattered mountain ranges in Nevada. Big tooth maple is dominant in northern Utah, northern Nevada, and southern Idaho. Scattered stands of serviceberry and antelope bitterbrush occur over the full range of the mountain brush type. Gambel oak, serviceberry, and maple communities normally occur above the pinyon-juniper zone and below the aspen-fir zone. Gambel oak communities also integrade into ponderosa pine and lodgepole pine forests. Ponderosa pine, in many respects, is a counterpart to the mountain brush type.

Extensive stands of curlleaf mountain mahogany occur intermixed throughout the region with other mountain brush species. Curlleaf mountain mahogany normally grows on shallow, more rocky soils than other associated shrubs. Mature stands often support less diversity of understory herbs than other mountain brush shrub associations. This plant association provides important habitat to big game animals, and stands have frequently been heavily grazed by game and livestock. Mature and taller plants often grow out of the reach of grazing animals, yet smaller or younger plants are often hedged and maintained in a stunted form. Seedling recruitment of the shrub is seriously impacted by grazing, limiting natural regeneration. Extensive areas now exist where reproduction is prevented by grazing and invasion of annual weeds.

Mountain brush communities occur between 5,000 and 9,000 ft (1,524 and 2,743 m). Annual precipitation varies from a low of 15 inches (380 mm) to 26 inches (660 mm). A linear increase in precipitation of 4.94 inches (126 mm) per 1,000 ft (350 m) rise in elevation has been demonstrated for this type (Lull and Ellison 1950). Seasonal moisture distribution shows a crest from February to April and a low from July to September.

Mountain brush communities have been recognized as important, highly productive spring-summer-fall ranges for cattle and sheep (Harper and others 1985; Sampson 1925). Deer, elk (fig. 15), bear, grouse, and Merriams turkeys also make considerable use of the type (Harper and others 1985; Julander and Robinette 1950; Kufeld 1973; Kufeld and others 1973).

Gambel oak grows in clumps that vary in height and density. The foliage of many taller plants can be out of reach of grazing animals. Some stands are thick and impenetrable to livestock and wildlife. Density and size of Gambel oak clumps have increased in many areas due to grazing and fire control measures. Understory forage production has generally decreased due to livestock grazing and competition from the oak.

Serviceberry and maple-dominated communities generally occur in quite open stands. Serviceberry and mountain big sagebrush often occur intermixed, with a number of grasses and forbs filling the large interspaces. Tall, robust plants of serviceberry and maple may become unavailable to livestock and game animals as the plants mature. The desirable understory species that occupy the interspaces are often subjected to misuse by improper grazing. The primary objective in treating most mountain brush communities is to reestablish the understory herbs. Most shrub species still occupy the sites, and shrub replanting is not usually required.

Figure 15—Mountain brush communities are important spring and summer ranges for elk and deer.

Removal of Competition

Reduction of shrub competition is often required to create a suitable seedbed and allow seeded herbs to establish (Engle and others 1983; Marquiss 1973; Plummer and others 1968; Stevens 1983b; Stevens and Davis 1985; Tew 1969). Shrub competition can be reduced using fires, herbicides, and mechanical treatment. Treatment of brush fields should be designed to retain the shrubs, but allow reintroduction of understory herbs. Sites supporting an adequate understory would not necessitate seeding. Control of wildfires has prevented natural burning of some brush fields, which tends to allow formation of closed stands of shrubs and suppression of understory plants. Some sites would benefit from burning, but may or may not require seeding.

Gambel oak is an important plant throughout many watersheds. It exists on steep slopes where ground cover is essential. Following burning, oak recovers well and provides needed ground cover. Gambel oak clumps that are burned and then chained or railed to improve seedbed conditions can be aerial seeded with good success.

An efficient means to suppress Gambel oak is twice-over anchor chaining, preferably with heavy links or with a Dixie or Ely chain. Chaining will break down both erect and short-growing shrubs. In addition, the density of shrubs can be reduced if desired. If single chained, seeding should precede chaining. With double chaining, seeding should occur between chainings to ensure proper seed coverage. Interspaces can be seeded and chained at the same time the brush is treated.

Offset disks, heavy pipe harrows, and brushland plows can be used to reduce some brush thickets. These methods of mechanical control are expensive, however, and the equipment can only be operated on level to moderately sloping sites, in open stands, or in short-statured oak. Excellent seedbeds are prepared, and small areas can usually be treated with these types of equipment.

Reestablishment of understory herbs is essential within Gambel oak stands. When competitive species are established, and grazing pressure is applied to Gambel oak thickets, the growth of new sprouts may be held in check (fig. 16) (Frischknecht and Plummer 1955; Harper and others 1985; Plummer and others 1970b; Stevens and Davis 1985). Treated oak stands that are not seeded with herbaceous plants readily resprout and regain dominance. In addition, the sprouts grow rapidly and become unavailable, and the stand may become impenetrable within a short time.

Understory species that are seeded in oak thickets must be shade tolerant because oak can resprout and form a dense canopy. Establishment of adapted understory species may reduce shrub regrowth, decrease the density of sprouting, and enable oak stands to remain open, supporting a better quality herbaceous understory. Forage production within oak clumps can be as much as three times greater than between clumps. Forage within clumps begins growth later in the spring but remains green longer into the fall than the same species growing between clumps (fig. 17). Soil moisture depletion has been found to be significantly reduced by removing oak top growth and introducing grasses (Tew 1966, 1967, 1969).

Clary and Tiedemann (1986) reported that more woody material is produced underground by Gambel

Figure 16—A stand of Gambel oak that was chained and seeded to smooth brome, intermediate wheatgrass, and tall oatgrass in 1954. Photo taken in 1993 demonstrating the ability of the seeded grasses to suppress or retard recovery of oak shoots.

Figure 17—Grasses seeded with oak clumps are more productive and retain greenness later into the season than similar plants established in openings.

oak than is produced above ground. Various types of mechanical treatments, fire, and herbicides have been used to kill or reduce oak. However, regardless of treatment, resprouting occurs from the massive root system.

Not all woody plants that dominate the mountain brush communities recover after fires. In addition, certain ecotypes of shrub species differ significantly in their response to fires. Gambel oak, serviceberry, maple, and sumac normally resprout after mechanical treatment and burning. However, duration and timing of the fire affects plant regrowth, particularly maple and sumac.

Antelope bitterbrush, cliffrose, and mountain snowberry may or may not recover after burning. These shrubs may show sprouting the first and second year after a burn, after which most die. Layering forms of antelope bitterbrush usually recover to some extent. Erect or upright growth forms are usually killed by burning. Some plants may resprout, but succumb by the second growing season. Ecotypes of antelope bitterbrush that naturally layer or grow with ponderosa pine and lodgepole pine are most likely to resprout and live after fires.

Mountain big sagebrush and curlleaf mountain mahogany are often killed by fire. New plants may develop from natural reproduction or from artificial seeding. Establishment of shrub seedlings is regulated by the presence and recovery of the understory herbs. If these two shrubs and other nonsprouting species are to be reestablished through natural seed dispersal, sites should not be planted with a dense understory of competitive herbs. Cliffrose, curlleaf mountain mahogany, chokecherry, and to a lesser extent, antelope bitterbrush, true mountain mahogany, and serviceberry respond well to chaining.

Planting Season

Seeding in the mountain brush zone should be conducted in late fall (October and November). Planting can be conducted even after snowfall and until snow becomes too deep to effectively operate equipment. In some seasons and on some sites, treatment can continue into January; however, the season often closes by mid-November or December. Spring plantings with rapidly germinating species can be successful if done immediately after snowmelt, but this is usually a very short period. Consequently, spring seeding is not recommended because of the unpredictability of moisture required to germinate and sustain new seedlings.

Planting Procedures

When treating large areas, aerial seeding has proven to be the most successful method. Chaining or pipe harrowing should follow seeding in order to cover the seed, scatter debris, and to create small water-collection and holding depressions. Seed dribblers and thimble seeders attached to crawler tractors can be used to seed selected species into the cleat marks. Grasses and forbs can usually be established on favorable sites by broadcasting seed just before leaf fall. Hand seeding small disturbed areas is practical. Drill seeding is often impractical because of heavy debris and steep terrain.

On bare, eroding hillsides, which frequently occur on southern exposures, furrowing and seeding with sidehill furrowers attached to a tractor is appropriate where slopes permit tractor operation. On slopes over 30 percent, broadcasting onto furrows, made on the contour by reversible moldboard plows or specially designed plows, is effective. Slopes cut by large gullies may require deeper and wider contour trenches. These must be spaced sufficiently close together to retain runoff from high-intensity storms. Deep furrowing or trenching is only recommended to control serious erosion problems.

Adapted Species and Mixtures

Mountain brush communities are located between aspen and juniper-pinyon communities, hence, many species common to higher and lower elevations mingle in this zone. Also, considerable variations occur in the amount of precipitation, slope, aspect, and soil to create a variety of sites for a large number of species. Mountain brush communities are potentially one of the most productive plant types. This type is a counterpart, in many respects, of ponderosa pine sites; consequently, similar treatment practices can often be used.

Species adapted to mountain brush communities are listed in table 13. Attempts to restore the diverse plant communities require use of a wide array of species. A considerable number of shrubs that occur in the mountain brush type are quite resilient and persist with intense grazing pressure. However, mountain big sagebrush, rubber rabbitbrush, antelope bitterbrush, cliffrose, mountain snowberry, Martin ceanothus, birchleaf mountain mahogany, and curlleaf mountain mahogany have been reduced and eliminated in some areas. These shrubs can normally be seeded with drills or single-row seeders. With the exception of big sagebrush and rabbitbrush, seeds of most shrubs must be placed into the soil. Broadcast seeding of big sagebrush and rubber rabbitbrush is recommended on open or bare surfaces. Direct seeding into herbaceous competition is not recommended for any shrub. Most sites receive sufficient moisture to assure shrub establishment if seed is properly planted.

Many native grasses and broadleaf herbs occur in this plant type and can be used to restore depleted sites. Seed availability may somewhat limit large restoration plantings, but seeds of many native species are becoming more available. Seeds of bluebunch wheatgrass, western wheatgrass, muttongrass, thickspike wheatgrass, streambank wheatgrass, big bluegrass, green needlegrass, needle-and-thread, Lewis flax, showy goldeneye, and Rocky Mountain penstemon are now more available and can be used in place of commonly used introductions. Intermediate wheatgrass, smooth brome, orchardgrass, hard sheep fescue, and crested wheatgrass have been widely planted throughout this type. These species are well adapted to this entire zone and have stabilized watershed disturbances and provided excellent forage. Intermediate wheatgrass and smooth brome are extremely competitive and have been used to stunt regrowth of Gambel oak and provide more accessible forage to grazing animals. Alfalfa, cicer milkvetch, and small burnet have been widely planted throughout this zone. All provide abundant high quality forage and have been used to stabilize livestock grazing and provide seasonal grazing to big game. Seeding of some introduced grasses, especially smooth brome, hard sheep fescue, and intermediate wheatgrass, has disrupted recovery of many understory herbs and has suppressed recruitment of big sagebrush and antelope bitterbrush (Monsen and others 1996).

Sites protected from livestock grazing normally recover if some residual species occur. Studies by Monsen and Harper (1988) demonstrate that native understory shrubs and herbs can be competitive, and are effective in suppressing invasion of juniper and pinyon and regulating density of Gambel oak.

Weedy species have not invaded the mountain brush type to any great extent, although poverty weed, various species of thistle, and a few other weeds occur. To date, they have not caused serious problems requiring intensive control measures.

Ponderosa Pine Communities

Ponderosa pine is the most widely distributed pine in North America (Fowells 1965) (fig. 18). In the Intermountain West, ponderosa pine occurs at approximately the same elevation and on sites with the same annual precipitation as does the mountain brush type. Mountain brush types are found on heavier soils than ponderosa pine, which prefers well-drained, coarser textured soils, with soil pH close to neutral, and more summer precipitation.

Twenty-two different plant associations occupied by ponderosa pine have been described by Steele and others (1981) for areas in central Idaho. These plant associations represent the primary ponderosa pine communities throughout the Intermountain region. Grazing, logging, weed invasion, and fires have created problems requiring restoration or revegetation. Logging activities have changed the composition of these plant communities. Road construction and logging disturbances have also created erosion, sedimentation, and runoff, causing degradation of downstream resources. Roads and related disturbances have also facilitated the spread of weeds that alter plant communities and interfere with restoration measures. Grazing has impacted many ponderosa pine/bunchgrass and shrub communities. Desirable understory species have been removed by grazing, which has also allowed invasion and expansion of weeds. Cheatgrass has spread throughout many of the ponderosa pine/bunchgrass associations and gained control of many disturbances. Yellow star thistle, rush skeletonweed, and medusahead also occupy sites once dominated by ponderosa pine/bunchgrass.

Invasion and spread of cheatgrass has increased fire frequency and size of wildfires throughout various ponderosa pine communities. More frequent burning has eliminated nonfire-tolerant trees, shrubs, and herbs, and further perpetuated the spread of cheatgrass and other undesirable annuals. Control measures are required to eliminate the annual grass, restore a competitive cover, and reestablish species eliminated by weed competition and burning.

Not all ponderosa pine disturbances have been invaded by weeds. In many situations understory shrubs and herbs have been eliminated or seriously weakened by grazing. Woody species important for winter grazing have been lost and must be restored. Grasses and broadleaf herbs have also been removed and require restoration to stabilize soil erosion and maintain a balance in species composition. Shrub and tree recruitment is dependent on seedbed conditions and composition of understory species.

Figure 18—A young stand of ponderosa pine with a mixture of understory species.

In many situations, disturbances within ponderosa pine sites occur on steep inaccessible sites, limiting treatment practices. Natural recovery is the most practical means of restoration. Natural recovery does occur throughout most areas where native herbs remain and have not been replaced by weeds. Protection and limited seeding should be utilized to restore these sites.

Removal of Competition

Many shrubs and herbs that occur with ponderosa pine are able to recover following burning, logging, or grazing unless the site seriously degraded. In these situations, seeding may be required. Cheatgrass, medusahead, and other weeds have invaded many lower elevation communities supporting ponderosa pine. These weedy species present serious management problems. They increase the incidence of wildfires and reduce establishment of natural and artificial seedlings. Annual weeds must be controlled to allow seedlings of other species to establish. On steep slopes, burning is the most practical method used to reduce weedy competition. Sites burned by wildfires or controlled burns should be seeded in the fall to control reinvasion of annual weeds. Adequate moisture is usually received to support new seedings if plantings are conducted the first year after burning when cheatgrass competition has been suppressed.

Recent invasion of rush skeletonweed in south-central Idaho in ponderosa pine/bunchgrass communities appears to be capable of upsetting natural successional changes. Its ecology is not well-understood, but control of this weed has become a major problem.

Plowing, disking, or spraying can be used to control dominant stands of annual grasses on large accessible areas. Seeding directly into annual grasses is not advisable. Cheatgrass sites can usually be successfully seeded following burns or during periods of drought that may diminish weeds. Burning does not reduce competition of medusahead, and additional control measures are required to assure planting success.

Broadcast seeding weed-infested sites following burning can be successful if seeds are covered by harrowing or chaining methods. Failure to cover seeds often results in spotty, irregular stands, although successful stands may occur in some years. Mechanical coverage is not always possible in many areas, and seeding on or before snowfall is advised.

Cheatgrass and medusahead occupy many ponderosa pine and associated shrub/bunchgrass sites. Many weedy areas once occupied by antelope bitterbrush have been interseeded or intertransplanted with this shrub. Plantings have been made into small scalps or clearings that are 30 x 30 inches (76 x 76 cm) in size. Weeds and weed seeds are removed by scalping and sidecasting the surface soil. Bitterbrush has been transplanted or planted into the small clearings. Many antelope bitterbrush interseedings were established using this technique amid weedy sites in central Idaho and Utah during the 1940s and 1950s. Mature stands of shrubs developed, but failed to persist. Individual shrubs reached maturity but slowly senesced. Although the antelope bitterbrush shrubs produced adequate seed crops during most years, natural recruitment failed to perpetuate shrub stands. Annual weeds were initially removed from portions of the area at the time antelope bitterbrush was seeded, but the weeds regained dominance of the understory. Competition from the understory prevented shrub seedling recruitment during the 40- to 50-year period since the sites were initially planted. Attempts to restore antelope bitterbrush in sites occupied by annual grasses must include replacement of the weeds with native understory herbs. If cheatgrass and medusahead are left as the understory, their presence will eliminate natural shrub seedling recruitment that is required to maintain the stand.

It is essential that native understory grasses and broadleaf herbs are reestablished to facilitate the natural recruitment of important shrubs. Large and extensive areas that once supported antelope bitterbrush and ponderosa pine are currently occupied with mixed stands of annual and perennial grasses. These sites should be managed or treated to restore the native understory species. As native plants are reestablished, interseeding with shrubs can be accomplished. Interseeding with shrubs into perennial native grasses will be required in many areas as the principal shrubs have been eliminated and a satisfactory seed source is not available. Once the understory is established, shrubs can be interseeded in narrow strips created by surface tillage, scalping, or following herbicide treatment. Reducing understory competition is normally required to establish uniform stands of antelope bitterbrush, snowberry, and most other shrubs. Although these species are able to establish by natural seeding into native herbs, planting large areas without some attempt to reduce understory competition is not advisable. It is essential to reestablish understory species prior to or as shrubs are planted. Planting or managing sites to establish and maintain a complete assembly of herbaceous and woody species is necessary. Attempts to establish only the shrub component of ponderosa pine associations have often been unsuccessful.

Weedy sites have commonly been seeded with perennial grasses including crested wheatgrass, intermediate wheatgrass, hard sheep fescue, and smooth brome. These species compete well and replace cheatgrass, medusahead, and other weeds; but they also prevent recovery of native herbs, and establishment and recruitment of most shrubs.

Reestablishment of antelope bitterbrush, big sagebrush, chokecherry, bitter cherry, and mountain mahogany is required on many disturbances. Sites occupied by these and other shrubs are important wintering areas and support concentrated wildlife populations. Animal browsing can and has prevented establishment and normal growth of small plantings. To be successful, shrub plantings must be large enough to limit browsing and allow plants to attain normal stature. In some special situations, populations of game animals may have to be reduced to allow establishment of seeded species.

Planting Season

Following burns or other treatments, seeds are usually fall sown. If seeds can be covered by chaining or using lightweight drags, planting should be conducted in late fall (October and November). Broadcast seeding on steep surfaces without any followup method used to cover the seed should be delayed until a snow cover has developed. Spring plantings are not advised because many sites, particularly south and west slopes, dry quickly. Early spring is the most preferred time to transplant.

Planting Procedures

Many tree-dominated sites occur on extremely steep slopes where machinery cannot be used. Typical areas usually requiring treatment are old-stock driveways, roads, logging disturbances, burns, or other areas where these practices have seriously impacted the vegetation. Most steep slopes can be aerially seeded with herbs, big sagebrush, and rubber rabbitbrush. Where possible, seed should be covered by harrowing or chaining.

In many situations, antelope bitterbrush and big sagebrush have been eliminated from areas as a result of natural fire and grazing. These and other shrubs can be interseeded into native bunchgrass stands if herbaceous competition is controlled for 1 to 2 years. Various interseeders can be operated on sites accessible to tractor-drawn equipment. Steep slopes normally require hand seeding.

Both big sagebrush and rubber rabbitbrush can be broadcast seeded in midwinter on native bunchgrass sites with excellent success. Seeds planted on or before snowfall germinate and establish amid grass competition. Many areas subjected to frequent burning lack a shrub cover, and these sites can be aerial seeded with big sagebrush or rubber rabbitbrush (Monsen and Pellant 1995).

Broadcast seeding beneath ponderosa pine is not as successful as planting amid aspen trees. Pine needles provide poor cover for the seeds. Seed germination and seedling establishment are quite erratic in these areas. However, most ponderosa pine and lodgepole pine types receive sufficient moisture each year to assure seedling establishment. Broadcast seedings on bare, well-drained, steep slopes normally result in poor stands. Many species simply cannot be established by broadcast planting on barren surfaces.

Anchor chaining can be used to cover seed on steep, long slopes by experienced operators (Monsen and Pellant 1995). Chains of various weights can be used with attached swivels to control the amount of soil disturbance. Contrary to some objections, chaining does not create small continuous depressions where water may collect and cause rilling or erosion. Chaining up and down long slopes is possible. Contour chaining is not necessary, even on bare or burned sites to control runoff. If properly used, chaining does not uproot or impact recovery of existing species. Chaining can be effectively used to till soils where water repellent soils form following burning. This is a major problem contributing to erosion on forested communities and open parks. The amount of soil tillage required to prepare a seedbed and cover seeds is usually helpful to "break up" water repellent soils and improve amount of infiltration.

In many situations, shrubs and trees must be established by transplanting. Seeding success with Woods rose, mountain snowberry, bitter cherry, maple, mountain ash, and chokecherry has been erratic. Yet, good success can be attained by seeding antelope bitterbrush, snowbrush ceanothus, redstem ceanothus, Martin ceanothus, mountain big sagebrush, and birchleaf mountain mahogany. These shrubs establish if good quality seed is fall sown, and the new seedlings are not subjected to excessive grazing and competition from herbaceous plants.

Adapted Species and Mixtures

Steele and others (1981) have identified various habitat types where ponderosa pine, lodgepole pine, and Douglas-fir exist with different components of understory shrubs and herbs. The distribution and occurrence of each habitat type has also been delineated. Species occurring in each habitat type or plant association should be included in any revegetation project. Since considerable differences in site conditions and plant composition occur among these types, it is not always advisable to plant species from one habitat type into another. Some grasses and shrubs occur in more than one habitat type and are more widely adapted than others. Also, certain species recover as pioneer plants and establish initially after a disturbance. Plantings of ninebark, redstem ceanothus, Utah honeysuckle, mountain lover, and cascara buckthorn do not survive well when planted on disturbed soils. These species grow better on soils that have not been degraded by erosion. Plantings of russet buffaloberry and most species of blueberry and manzanita fail to develop when planted in openings devoid of any overstory cover. These species should not be planted in open sites or areas that have lost the topsoil.

Although species of big sagebrush and rabbitbrush are well adapted throughout the mountain brush zone, they are restricted to specific sites. Mountain big sagebrush and rubber rabbitbrush should only be planted on sites where they naturally occur. Species suggested for planting are in table 13.

Juniper-Pinyon Communities

Distribution

Mitchell and Roberts (1999) stated that there are approximately 55.6 million acres (22.2 million ha) of pinyon and juniper in the Western United States. Substantial portions of the Intermountain region are occupied by juniper-pinyon and associated species (fig. 19). Acreage estimates vary considerably. West and others (1975) listed 15.5 million acres (6.2 million ha) in Utah, 13.1 million acres (5.2 million ha) in Nevada, and 1.4 million acres (0.6 million ha) in Idaho. In the Great Basin, data grid analysis from Lansat-1 satellite photography (Tueller and others 1979) indicated there are about 17.6 million acres (7.1 million ha) of juniper-pinyon. O'Brien and Woudenberg (1999) stated that there are more than 45.3 million acres (18.1 million ha) of forests composed mostly of pinyon and/or juniper in the Intermountain West.

Singleleaf pinyon occurs throughout Nevada to central Utah where pinyon takes over and extends into Colorado. Utah juniper is found in association with both singleleaf pinyon and pinyon. On drier sites where conditions are too arid for the pinyons, Utah juniper occurs in pure stands covering vast areas. Rocky Mountain juniper occurs at the upper edge of the singleleaf pinyon occupying small scattered areas. Western juniper dominates the low foothills in eastern Oregon and Washington, existing on sites similar to those occupied by Utah juniper in the Intermountain region.

Figure 19—Numerous areas in central Utah support similar age stands of pinyon and juniper, growing with only scattered amounts of understory species.

Juniper-pinyon ranges from 10,000 ft (3,280 m) elevation on the crest of the Sierras (West and others 1975) to a low of 3,200 ft (1,050 m) along the Utah-Arizona border (Woodbury 1947). Pinyon tends to favor higher elevations, and Utah juniper becomes more dominant at lower elevations. Annual precipitation in the juniper-pinyon type ranges from 8 to 22 inches (200 to 560 mm), with the best stand development occurring between 12 and 17 inches (300 and 430 mm).

Ecological Changes and Status

From the late 1800s to the present, distribution and density of many pinyon and juniper communities have been significantly altered. A majority of the juniper-pinyon stands in the Great Basin prior to settlement were confined to specific areas, and supported a diverse understory of perennial grasses, forbs, and shrubs. Fire, combined with perennial understory competition, controlled the spread and thickening of existing juniper-pinyon stands. The understory vegetation controlled or regulated the incidence and spread of fires, which, in turn, regulated the presence and distribution of juniper and pinyon. Heavy grazing by livestock over many years resulted in community changes and the eventual loss of the perennial understory (fig. 20) and, in some locations, establishment of exotic annuals that now dominate the understory (Gruell 1999). Grazing and a lack of fire have resulted in an extensive increase in tree density and expansion into new areas. O'Brien and Woudenberg (1999) reported that 53 percent of the pinyon and juniper trees in Utah and 67 percent in Nevada are between 40 and 120 years old, and only 20 percent in Utah and 9 percent in Nevada are older than 200 years. This data dramatically demonstrates the great increase in trees following the introduction of livestock and reduction of fire incidence. Adjoining semiarid grass and shrublands underwent similar changes as desirable species were eliminated or reduced in density and vigor by grazing. The absence of fire and the loss of dominant grasses and other understory species by livestock allowed for an increase in juniper and pinyon trees, and substantial tree invasion into many adjoining grass and shrublands (Aro 1971; West 1984b, 1999; Woodbury 1947).

Figure 20—Stands of pinyon and juniper frequently provide cover for wildlife, but lack suitable seasonal herbage.

Increase or invasion of trees combined with significant changes in the understory from perennial to annual communities resulted in unstable soil conditions and erosion (Farmer and others 1995; Roundy and Vernon 1999). Grass and shrub communities use and transpire considerably less moisture than juniper and pinyon, which are active all year (Roundy and Vernon 1999). This unchecked water use has the potential to dry up springs and reduce quantity and quality of water in streams. Archaeological sites have been lost or damaged by erosion in depleted juniper-pinyon sites (Chong 1993). In addition, critical fall, winter, and spring livestock and wildlife ranges have been seriously degraded. Deer and elk numbers have been shown to decline as tree density increases (Short and others 1977). Suminski (1985) reported that declines in deer numbers were highly correlated to closing canopy cover of juniper and pinyon expansion into areas formerly devoid of trees, and the corresponding decline in understory production. Sage-grouse (Commons and others 1999) respond adversely to increased density and invasions of pinyon and juniper. Loss or alteration of riparian areas through community changes, erosion, and lowering of water tables has occurred, affecting the productivity and stability of these sites.

Not all juniper-pinyon sites support similar compositions of understory species (Rust 1999; Thompson 1999). A variety of herbaceous and woody plants exist in different amounts, depending on site and climatic conditions (Goodrich 1999). In addition, the composition and age structure is regulated by changes in climatic and biotic events including wildfires.

Over the past 45 years, some depleted juniper-pinyon stands have been artificially seeded to enhance species composition, improve habitat, and correct watershed conditions. However, not all juniper-pinyon stands merit treatment and artificial seeding. Sites that are ecologically stable and have not been so dramatically altered that natural successional changes may occur, should not be candidates for artificial treatment. In some situations, stable tree communities may be altered to satisfy high-value resource needs, but few situations would justify converting stable communities to support other species. Some juniper-pinyon woodlands have been converted to pasture lands for livestock foraging. In some situations, these practices have been used to stabilize livestock grazing problems. Although conversion from woodlands to herblands is attainable, careful management is required to maintain the desirable herbs. Introduced grasses have been successfully established throughout many juniper-pinyon woodlands and provide substantial forage for grazing animals. Introduced species generally provide considerable competition to limit tree reinvasion, but tree reincroachment is not prevented on all sites seeded to introduced herbs. Grazing practices, in conjunction with site conditions, will influence recovery of native species, including woody plants.

Species composition of juniper-pinyon communities may be altered to a different seral status with or without the introduction of a new complex of species attained by seeding. In some situations, juniper-pinyon woodlands can be converted by burning (Goodrich and Reid 1999; Greenwood and others 1999) or chaining to reduce tree density. This is possible if sufficient native understory exists, and is capable of recovery following treatment (Stevens 1999a).

To date, most juniper-pinyon conversion projects have utilized artificial seeding to ensure the rapid reestablishment of understory shrubs and herbs. If treated sites lack the desired understory species, seeding is normally used to ensure their establishment. To date, substitute species are commonly used to seed many sites because seed of many native species is not consistently available.

Juniper-pinyon sites that have been altered by extensive grazing and exclusion of wildfires must be examined to determine the restoration measures that can be used to reestablish desired vegetation, leading to the creation of a more natural system. Most sites that have been heavily grazed for long periods no longer support even minor amounts of understory perennial species (Poulsen and others 1999). On these sites, either juniper or pinyon trees, or both, have increased and dominate (Madany and West 1983). Trees provide extensive competition and preclude the invasion or establishment of small seedlings of most desirable understory species (Naillon and others 1999).

It is essential that some trees be removed to allow for the establishment of other species. Trees offer so much competition that seed germination and seedling emergence and establishment is prevented. Removal of all trees is not essential, but tree competition must be sufficiently diminished to allow many slower developing species time to fully establish. Interseeding into existing vegetation has proven successful in some community types, but not in juniper-pinyon.

Juniper-pinyon sites that have been void of understory species for many years will most likely lack a sufficient seedbank (Naillon and others 1999; Poulsen and others 1999). On these sites, natural seeding will not occur even if trees are removed. Understory shrub and herbaceous species that are weakened by heavy grazing and competition and from tree encroachment normally do not bear seed, but may persist for years before eventually succumbing. Under these conditions, undisturbed stands of juniper-pinyon may exist for many years with little seed being added to the natural seedbank. Removal of competitive trees can, in very specific situations, result in a slow, erratic recovery of associated native species. Unless sites are artificially seeded, natural recovery is often ineffective.

Many juniper-pinyon sites support scattered, but important, amounts of annual weeds including cheatgrass, bur buttercup, red brome, and various mustards. If trees are removed and sites are allowed to recover naturally, annual and perennial weeds will flourish and quickly assume dominance (Gruell 1999). Weeds can be highly competitive and restrict the reestablishment of desirable natives. Because conversion to annual weeds will occur rapidly, seeding must not be delayed beyond the year of tree removal.

Juniper-pinyon restoration programs should be designed to allow for restoring native vegetation and creating stable communities. Converting juniper-pinyon communities to assemblages of introduced species is not advisable (Stevens 1999a; Walker 1999). The seeded community should be able to respond to wildfires and sustain some grazing. In many situations, juniper-pinyon sites must be managed to allow wildfires to occur and thereby regulate species composition. In some situations, wildfires may not be acceptable or cannot be managed without extensive damage to shrubs and other adjacent resources. In these situations, chaining or other artificial treatment may be used as a substitute to regulate plant composition.

Removal or controlled use of livestock from many depleted juniper-pinyon-dominated areas will not facilitate the recovery of native vegetation, stabilize the soil, and return these areas to their presettlement conditions (Goodloe 1993, 1999). Severely depleted juniper-pinyon sites recover very slowly with the removal of grazing. In some other vegetative types, improvements can be expected by removing livestock grazing, but desired responses are slow to occur in many juniper-pinyon stands. Principal reasons are the absence of a seed source and the competition exerted by pinyon and juniper. To return most juniper-pinyon areas to a more natural state, tree competition should be reduced, a suitable seedbed created, and sites properly seeded.

Chaining or other mechanical treatments used to reduce tree density are substitutes for natural tree control most frequently attained by wildfires. The objective of most improvement projects is not to remove all trees, but to allow recovery of the understory species and to facilitate artificial seeding (Stevens 1999a). Creation of a diverse understory is normally required to enhance resource values and help control the spread and growth of trees and annual weeds. Tree removal, by whatever means, is simply a technique used to change the seral status of many sites (Stevens 1999b).

Removal of Competition

There is a need to enhance watershed conditions and water quality, increase spring flow, improve understories, and improve big game, nongame, and livestock habitat in the juniper-pinyon woodlands (Roundy and Vernon 1999). A large number of acres of juniper-pinyon woodlands have been treated by chaining and railing. When comparing results from early projects with today’s plant materials, equipment, techniques, standards, and results, some mistakes were made in the past. However, most older chainings and seedings are now exhibiting desirable improvements in watershed stability (Roundy and Vernon 1999) provided by more natural plant associations. Results from poorly designed and managed projects should not prevent further treatment projects. Decisions should be based on recovery and stability of native plant communities and the use of today’s plant materials, equipment, and techniques. Guidelines have been developed for chaining and seeding (Fairchild 1999; Nelson and others 1999).

Removal of competing trees can be accomplished in a number of ways. Prescribed fire can be an effective practice in some areas. Twice-over anchor chaining, with 90-lb (41-kg) links, in opposite directions have been used extensively in juniper-pinyon control and thinning (Plummer and others 1968; Stevens 1999b). Use of cable or a chain of lighter links is satisfactory where it is desired to leave more trees and shrubs. Once-over chaining may be adequate when sufficient understory remains, trees are sparse and mature, and seeding is not required. Cabling is less effective than chaining in removing trees and creating a seedbed.

Anchor chains are pulled behind two crawler tractors traveling parallel to each other. For maximum tree removal, chains cannot be dragged while stretched taut, but must be dragged in loose, J-shaped, U-shaped, or half-circle patterns. The half-circle configuration provides the greatest swath width and lowest percentage tree kill. It is primarily used in mature, even-age stands and when a low percent tree kill is desired. Tree kill increases as the width of the J- or U-shaped pattern decreases. As the proportion of young trees increases, chaining width should decrease to remove the greatest number of young trees, if this is the objective (Stevens 1999b).

Success in removing trees varies with species composition, tree age structure, and density. Trees in mature, even-age stands can be uprooted more effectively and efficiently than in uneven-age stands (Van Pelt and others 1990). Young trees less than 4 ft (1.2 m) tall generally are not killed with single or double chaining because the chain rides over the plants without causing damage (fig. 21). Young pinyon are much more flexible than are young juniper, resulting in less kill of small pinyon.

Chaining has commonly been confined to slopes of less than 50 percent (Vallentine 1989). In Utah, successful chaining has been accomplished on slopes up to 65 percent with both chainings being downhill. First and second chainings can be done in the fall, with seeding taking place between the two chainings. Another technique is to chain once during the summer months. Trees are then allowed to dry out before seeding, and the second chaining is done in the fall. Dry trees break up easily and are scattered over the area when this technique is used.

Figure 21—Young pinyon and juniper trees normally are not uprooted with chaining, and can recover quickly as older trees are removed.

It is advantageous to leave downed trees in place and not pile or burn them. Some advantages include: (1) retention and detention of surface water, preventing erosion and increasing infiltration; (2) increased ground cover; (3) improved wildlife habitat; (4) inceased big game and livestock movement onto the treated areas; (5) decreased livestock trailing; (6) more even distribution of livestock and big game which, in turn, provides for more even use; (7) improved seeded and natural seedling establishment (fig. 22); and (8) no cost for piling and burning.

Planting Season

Late fall until midwinter (October through January) is the preferred planting period. Seedings should only occur when seed can be properly covered. Delaying seeding until late fall or midwinter reduces seed depredation by rodents and birds. Fall and winter plantings provide adequate time for stratification of planted

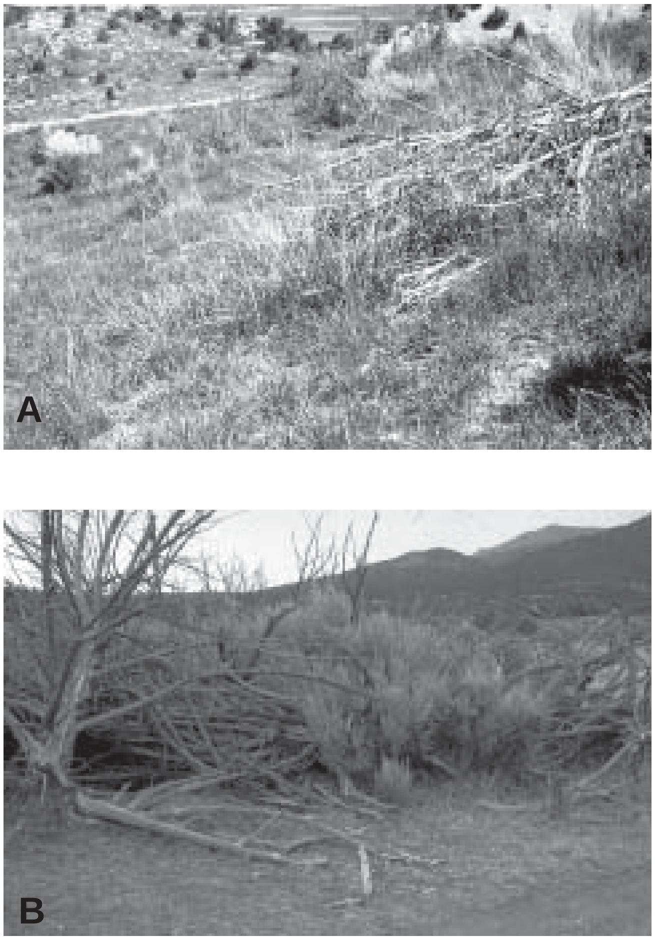


Figure 22—Tree limbs provide ideal microsites for seedling establishment of: (A) grasses and (B) shrubs.

seeds, and ensures that seeds are in the ground when temperature and soil moisture conditions are most favorable (early spring) for germination and seedling establishment.

Planting Procedures

Seeders attached to fixed-wing aircraft and helicopters are designed to broadcast seed uniformly. The majority of juniper-pinyon chainings and burns in the Intermountain West have been aerially seeded. Most grasses, forbs, and small seeded shrubs such as sagebrush and rabbitbrush can be seeded successfully with both fixed-wing aircraft and helicopters. Helicopters generally are better adapted to seed small or irregular areas. Downdraft from helicopters can somewhat separate seed by size and weight. There is a tendency for lighter seed to drift beyond the strip or zone where heavier seeds concentrate. Chaining has proven to be the most effective practice available to prepare a seedbed and cover seed following fire or chaining. If double cabling or chaining is employed, seeding should occur before the final treatment. Seeding prior to the first chaining is not recommended. The final chaining normally provides good seed coverage. Interseeding should occur prior to chaining when one-way chaining is employed.

When downed trees do not interfere, seed can also be covered using drags or a pipe harrow. Single disk harrows, or similar light-weight machinery, can be used to cover seeds in open, debris-free areas. Care must be taken to ensure that seeds are not covered too deep and seedbeds are not too loose. Chaining, or equivalent treatments, are required to cover seed when burned sites are broadcast seeded. If mechanical coverage is not used, seeding is best done by placing seed on top of a blanket of snow.

Rangeland drills can be used to seed many species on large open areas. Again, care should be taken to ensure that seeds are properly covered. As a general rule, most seed should be covered no more than three times their own thickness, or to a depth of about ¼ to ⅜ inch (0.6 to 1 cm). Some species do, however, benefit from seeding on a disturbed soil surface.

Seeds that are in short supply or those that require a firm seedbed can be seeded with a Hansen Seed Dribbler or thimble seeder mounted on the deck of a crawler tractor. Seed is metered onto the crawler tracks, then embedded in the soil by the tractor's tracks.

Planting Adapted Species and Mixtures

Tremendous variation exists in soils and biotic condition within the juniper-pinyon type and in any given area. Consequently, a number of species adapted to specific sites and conditions should be used (fig. 23). The primary objective in any restoration project should be to restore ecologically adapted communities. This objective is currently more attainable as native seeds become increasingly more available. Planting practices have been developed to seed diverse species. Table 14 lists species adapted to pinyon-juniper communities that receive less than 11 inches (280 mm) annual precipitation. Table 15 lists species adapted to sites that received 11 to 15 inches (280 to 380 mm) of precipitation, and table 16 lists species that are adapted to sites that receive over 15 inches (380 mm) of annual precipitation. Within the juniper and pinyon vegetative type, small to rather large stands of fourwing saltbush and other salt desert species can be found. These areas generally have soils that contain more clay, may have a hardpan, and have a slightly higher pH. Species adapted to juniper-pinyon sites with considerable fourwing saltbush (salt desert shrublands)

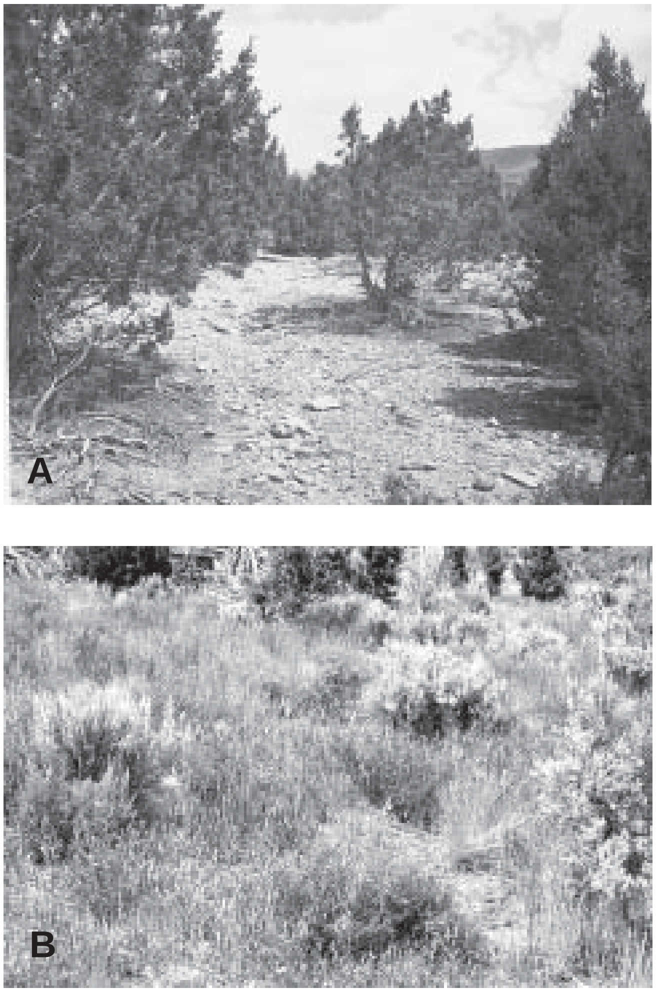


Figure 23—(A) A depleted stand of pinyon and juniper prior to chaining and seeding. (B) Similar area eight years after treatment.

are listed in table 17. Care must be taken to ensure that aggressive species do not dominate the mixture, and once established, do not dominate the seeded and indigenous communities. Crested, desert, intermediate, and pubescent wheatgrass, smooth brome, and hard sheep fescue will outcompete most seeded and native species, thereby attaining dominance.

Numerous native species have and are being developed for restoration of juniper-pinyon communities (McArthur and Young 1999). Sufficient amounts of seed are available from wildland collections and cultivated fields to provide adapted ecotypes of a number of species. Sufficient seed can usually be obtained during a 1- to 2-year period. Seed of bluebunch wheatgrass, western wheatgrass, thickspike wheatgrass, streambank wheatgrass, basin wildrye, bottlebrush squirreltail, Indian ricegrass, Sandberg bluegrass, big bluegrass, green needlegrass, needle-and-thread, Lewis flax, various species of penstemon, western yarrow, globemallow, and other herbs are normally available. Seed lots of big sagebrush, black sagebrush, rubber rabbitbrush, antelope bitterbrush, cliffrose, mountain mahogany, ephedra, fourwing saltbush, shadscale, and winterfat are commonly collected and marketed in sufficient amounts to seed large tracts. Additional grasses and broadleaf herbs are being reared under cultivation and will become more available at cheaper prices in the future.

Benefits and Features of Chaining

Because of the controversy that has developed regarding rehabilitation or restoration projects, the following information about the proper use of chaining in juniper-pinyon communities is provided.

Juniper-pinyon communities are unique and important sites. These areas normally support big game and other wildlife during critical spring, fall, and winter months. Often the sites are important watersheds. Although they may not store and discharge large amounts of water, unstable areas often contribute sediment and affect downstream water quality. Restoration procedures, currently employed to treat unstable sites, have been developed to restore wildlife habitat, provide livestock forage, and stabilize watershed conditions. Most restoration projects are designed to improve or stabilize a number of resource values. For this reason, restoration measures must be carefully developed for each situation.

Restoration of most disturbances should be designed to regain the original composition of species and allow the communities to function naturally. Treatments should allow the recovery of suppressed understory species, and reintroduction of species that have been displaced. Designing treatments to restore only a specific resource, such as soil protection, livestock forage, or wildlife habitat, may not be ecologically sound or advisable. Following is a description of some features of anchor chaining:

1. Chaining is an effective method for restoring juniper-pinyon communities.

It is apparent that trees must be removed to reduce competition and allow new understory seedlings to establish. Various practices have been evaluated as methods to reduce or control trees. Fires, hand cutting, herbicides, hula-dozing, and railing have all been used, but chaining is most functional. It provides adequate tree control, creates desired seedbeds, and accommodates seeding.

Chaining can be effectively used to regulate or manipulate plant composition without destruction of understory species. Chain link size, modifications to links, and operation of the crawler tractor will determine the number and size of trees that are removed and the effects on understory species. Types and size of chains and chaining practices can be regulated to retain most existing understory species, yet sufficiently reduce tree competition to facilitate seeding and promote natural recovery of understory species.

Through extensive testing and development of alternate techniques and equipment, chaining has proven to be the least destructive technique to existing vegetation and soil. Compared with other methods of mechanical treatment (plowing, disking) or use of herbicides or fire, this practice can be selectively used to reduce tree density in desired locations without disruption of understory plants and nontarget areas.

Soil conditions, including watershed stability, can be improved with chaining. Many treatment practices, including burning, leave bare soil, and sites are subjected to erosion for a number of years following treatment. Chaining leaves considerable litter on the surface, which improves watershed protection by retaining and detaining surface runoff and increasing infiltration. Debris is also deposited in gullies, draws, and waterways, thereby reducing erosion and sedimentation within drainages.

Chaining improves watershed and vegetative conditions. Its primary advantage is that the practice can be used at almost any season of the year. Plowing, spraying, and burning must be conducted at specific times, depending on soil moisture, stage of plant growth, and access. Treatment by these methods is often completed at a time when sites are subjected to erosion or when unfavorable seedbed conditions occur. In many situations, burning or other methods of plant control require followup treatments to reduce erosion or limit weed invasion. Chaining can be conducted at the most appropriate season to benefit soil stability, create a desirable seedbed, plant seed, and reduce invasion of weeds. Currently, no other treatment provides the flexibility afforded by chaining.

Chaining can be used to help control weeds that normally exist within depleted juniper-pinyon stands. Since chaining does not disrupt existing perennial understory species, desirable perennials recover quickly following reduction in tree competition and provide immediate competition to potential weeds. Adding species by seeding also increases competition to weedy plants. Soil nutrients and site productivity can be maintained by chaining. Surface litter and plant debris are maintained onsite, whereas burning removes nutrients, litter, and debris. Soil profiles are not disrupted with chaining as they would be with plowing or disking.

2. Chaining can selectively reduce desired density and most age classes of trees.

Chaining is a technique that can be used to retain selected trees, if desired. The amount or number of trees removed can be regulated by widening or narrowing the operating distance between the tractors, or changing speed or direction of operation. The weight or size of the chain used and the number and position of swivels located in the chain can also be used to regulate the extent of tree removal. However, operational procedures can be simply modified by positioning and regulating the speed of the crawler tractors.

Different types of equipment are not required to treat highly variable sites. Prior to chaining, the area can be inventoried, and a chain of appropriate size and length can be selected. Once a chain size is selected, operation of the tractors can be used to regulate the number of trees that are removed. Hula dozing or cutting of individual trees also provides considerable flexibility, but costs and treatment time are normally prohibitive. The practice of chaining can be very site specific, and can be easily regulated to affect specific community types, aspects, or acreage. Compared with burning, this practice can be specifically targeted to small, irregular tracts. The degree of tree removal using chemical sprays or burning is difficult to control. Areas treated with either of these practices often results in complete removal of all vegetation, although stands or patches may be left that are untreated. However, it is much more difficult to remove only a certain fraction of the trees by burning or chemical spraying without also affecting the understory.

Since chaining can be conducted during almost any season, the extent of trees or understory removed can be determined by treating on different dates based on plant growth and soil moisture conditions. Chaining, during early winter when trees are brittle and snow covers the understory, generally results in removal of most trees and some shrubs, including big sagebrush, without damage to understory herbs. Chaining during the growing season, when woody species are more flexible, normally leaves more shrubs undamaged. Chaining late in the growing season, when soil moisture has been depleted, results in more complete uprooting of trees and shrubs than if sites are chained in early spring.

Chains with attached swivels and couplings are available to most public agencies and private users. Transportation and setup costs are not prohibitive. Individual chains require little maintenance and repairs are infrequent. Compared with other machinery, repair costs are minimal and little investment is needed for tools or repairs.

3. Chaining can provide suitable seedbeds for many species and can be used to cover seed on diverse sites. Various practices used to control trees—spraying, burning, hula dozing, and hand-cutting—do not prepare a seedbed or aid in actual seeding. Chaining can, however, provide satisfactory seedbeds on even, steep, and irregular, terrain, and on critical watersheds. Under normal chaining conditions, suitable seedbeds are created to plant seeds of a number of species with different seedbed requirements. Chaining scarifies the soil, creating numerous microsites where seeds are planted at various depths. Seeds can be broadcast before or after chaining to take advantage of the different planting depths, surface compaction, and soil mixing that occurs. Planting before or after chaining determines which species may initially establish and become prominent in the plant community.

Natural seeding of native species can be enhanced by chaining, especially when chaining occurs after seeds mature. Chaining can also promote sprouting of some species, and if done at the correct season, favors their recovery and spread. Chaining can also be used to diminish or control weeds.

Chaining and seeding can be conducted at the most appropriate season for enhancing establishment of the planted species. Within most of the Great Basin, fall seedings have proven to be the most ideal time to plant. Spring seedings should only occur prior to mid-March and only with species that germinate and establish quickly. In southern Utah, southern Nevada, and northern Arizona, seeding just prior to the mid-July summer storms has resulted in good success if the storms come.

Satisfactory seedbeds can be prepared with chaining on rough, steep, and irregular sites. Attaining uniform and competitive stands on irregular terrain and variable soil conditions is extremely difficult with most conventional seeding practices. Chaining produces the most uniform stands on poorly accessible sites of any technique now available.

Although burning or spraying can be used to control tree competition, an additional technique is needed to prepare a seedbed and to plant seeds. Seeds may be broadcast on fresh burns or sprayed sites; however, many species require some degree of seed coverage.

Chaining provides all degrees of soil coverage, resulting in the establishment of a diversity of species. Chaining favors soil moisture accumulation, and can be conducted when conditions are most favorable for seed germination and seedling establishment. Chaining and seeding can be accomplished when sites are bare or covered with snow, without accelerating runoff and loss of soil moisture. Although some land managers fail to recognize the importance of seeding at specified periods when soil moisture is most favorable, this is one of the most critical issues determining planting success. Chaining offers an option to quickly and effectively treat small and large diverse sites.

4. Chaining does not destroy resource values. Any plant conversion or regulation practice can impact a number of wildland resources. Most revegetation or restoration measures are designed to remove existing weedy, woody, and herb species, and to reestablish natural plant succession. Removal of existing trees creates an abrupt and often dramatic change in plant density, structure, and age class. Recovery of the native species can frequently take many years to provide a visible, mature assembly of plants. During the recovery period, the impacts can be quite apparent. When properly done, chaining will not degrade or destroy soil or watershed resources. It is a practice designed to modify plant composition, stabilize erosion, provide suitable seedbeds, and cover seed. Selection of appropriate treatment practices should be based on restoration objectives.

Basic Guidelines for Juniper-Pinyon Chaining Projects

Site Considerations

Selection of treatable areas: Treat only problem sites where the opportunity for success exist. Base decisions on ecological status of the community.

Areas to be treated: No more than 50 percent of the total area should be treated at one time. Natural travel lanes, resting and thermal cover areas, snags, older chronological record trees, archeological sites, corridors that connect nonchained areas, and areas with high visual values should not be treated.

Design of chained area: Chaining should be designed to provide maximum mosaic of treated and nontreated sites that fit within topographic conditions and provide maximum aesthetic and edge effect. Treatments should match natural community zones. Almost all nonchained areas should interconnect with continuous, live, mature tree corridors at least 30 ft (9.2 m) wide.

Accessible slopes: Areas with slopes as steep as 60 percent can be effectively and safely chained. First and second chaining can be in the same direction, which may be downhill.

Maximum size of openings: Size of clearing should not exceed 100 yards (91 m) at its widest points.

Vegetative Considerations

Age class and stand structure: Highest tree removal success will occur within even-age mature tree stands. A large percent of trees will survive chaining in young and uneven-age communities. Presence of large trees usually indicates high site potential.

Tree density: Tree density and size of trees will, in part, determine link size, length of chain, and tractor requirement costs of treatment.

Treatment of downed trees: Uprooted trees should be left in place. Debris should not be concentrated in windrows or pushed into piles. Dry trees should not be burned.

Selection of seeded species: Species and accessions that are planted must be site adapted and provide an ecologically compatible community. Species selection and seeding rates will depend on presence and composition of existing species and seedbank. Seed mixtures should consist of a diverse number of species, including a majority of native species. Restraint should be used in seeding competitive, exotic grasses.

Methodology

Timing: Reduction of tree competition, preparation of a seedbed, and seeding generally requires two chainings. The first chaining may be conducted anytime during summer or fall. The second chaining should occur at the most advantageous time for seeding, which, in most cases, will be late fall or early winter.

Chain type: Smooth chains provide good control of mature trees, moderate soil and understory species disturbance, and seed coverage. Trees that are uprooted are normally left in place. Ely chains provide good control of mature and intermediate-aged trees and can be operated to remove some shrubs and other understory species. Uprooted trees often are accumulated in piles. The Dixie chain is not recommended for treatment of dense tree stands. This chain performs best in open scattered stands and can be used to uproot small trees and understory shrubs. This modified chain eliminates more plants and provides greater soil scarification than other types of chains.

Weight of chain: Chains with individual links that weigh 40 to 60 lb (18 to 27 kg) should be used where the objective is to minimize disturbance of understory species. Heavier links of 60 to 90 lb (27 to 41 kg) are used when trees are dense and larger, and where little understory exists and maximum soil tillage is desired.

Length of chain: Chains 300 to 350 ft (91 to 107 m) long are the most commonly used lengths. Chains can be up to 450 ft (138 m) long. Size of crawler tractor, weight of chain, density and size of trees, and topography will determine chain length.

Swivels: Swivels are used to allow the chain to turn freely and prevent chain twisting and balling. One swivel is required at either end of the chain and it is recommended that one or more be placed within the chain, especially when using a Dixie or Ely chain. Swivels also regulate the amount of digging or soil tillage.

Size of crawler tractor: Crawler tractors that are rated D8 or larger should be used. Weight and length of chain, density and size of trees, percent slope, and amount and size of rocks will affect tractor power requirements. Properly powered tractors are a must.

Field operations: Trees are most effectively uprooted when tractors are not directly parallel to each other, but rather operated in a J shape, with one tractor ahead of the other. Tree removal and soil tillage increases as tractors are positioned closer together. The further the tractors are spread apart the lower the percent of tree kill and the less understory vegetation and soil is disturbed.

Seeding techniques: Seed is most effectively distributed by broadcasting from fixed-wing aircraft and helicopters between the first and second chainings. Drills can only be used on more level areas with few downed trees, shrubs, or rocks. Seed dribblers or thimble seeders can be mounted on each crawler tractor, and seeds can be planted during the first or both chaining operations.

Summary

Where seeding is to occur, competition from existing trees must be reduced to allow the new seedlings to establish. Twice-over anchor chaining in opposite directions with 60 to 90 lb (27 to 41 kg) links is usually the most satisfactory treatment (Plummer and others 1968). Use of a cable or a chain with lighter links is satisfactory where it is desirous to leave more trees. Once-over chaining may be adequate when sufficient understory exists, tree competition removal is attainable, and seeding is not planned. Cabling is less effective than chaining in removing trees and covering seed. It also disturbs less understory.

Anchor chains are pulled behind two crawler tractors traveling parallel to each other. Chains cannot be dragged stretched taut, but must be dragged in a loose J-shaped, U-shaped, or half-circle pattern. The half-circle configuration provides the greatest swath width and lowest percentage of tree kill, and should only be used in mature, even-age stands. Tree kill increases as the width of the J- or U-shaped pattern decreases. The J-shaped pattern is the most desirable. As the proportion of young trees increases, chaining width is usually decreased to achieve satisfactory thinning.

Success in removing trees varies with species composition, age structure, and density of trees. Mature trees can be killed more effectively and efficiently than trees in uneven-age stands. Young trees, less than 4 ft (1.2 m) tall, generally are not killed with single or even double chaining, (fig. 21) because the chain rides over them. Small junipers are uprooted and killed more effectively than are small pinyons that are more flexible. Chaining is commonly conducted on slopes of up to 50 to 60 percent (Vallentine 1989). In Utah, successful chaining has been accomplished on 65-percent slopes.

First and second chaining can follow each other in the fall with seeding occurring between chainings. Another technique is to chain once during the summer. Trees are allowed to dry before seeding, and the second chaining is done in the fall. The dry trees break up easily and are scattered over the area in a uniform pattern. It is advantageous to leave downed trees in place and not pile or burn them. Leaving trees in place: (1) reduces surface runoff, (2) increases ground cover, (3) provides cover for wildlife, (4) encourages big game movement onto the treated area, (5) provides shade for livestock, (6) decreases livestock trailing, (7) improves seedling establishment (fig. 22), and (8) eliminates cost of piling and burning.

Late fall or winter (October through February) is the preferred planting period. Seeding should not be attempted in frozen soil. Seedings should occur when it is possible to plant and cover the seed properly. Late fall and winter seedings can result in reduced rodent depredation, yet provide adequate stratification of planted seeds. Fall-planted seeds remain in the ground until conditions are the most ideal (early spring) for germination and establishment.

With double cabling, seeding should occur between the two chainings. Fixed-wing aircraft and helicopters can broadcast seed uniformly. Helicopters generally do a better job of distributing seed over small or irregular areas. Where downed trees do not interfere, seed can also be covered successfully using drags or a pipe harrow. Single disk harrows or similar light machinery can also be used to cover the seed. Care must be taken to ensure that seeds are not covered too deep and seedbeds are not too loose. Chaining or equivalent treatment is required to cover seed after burning.

On large, somewhat even, open areas that are relatively free of debris and large rocks, drills can be used to plant many species. Care should be taken to ensure that seeds of most species are properly covered. As a general rule, seed should be covered at least but not much more than three times their own thickness or to a depth of $\frac{1}{4}$ to $\frac{3}{8}$ inch (0.6 to 1 cm). There are, however, species that require surface seeding on disturbed soils and a few that require deep seeding.

Seeds of shrubs and forbs that are in short supply or those that require a firm seedbed can be successfully seeded with a Hansen seed dribbler or thimble seeder that is mounted on the deck of a crawler tractor. Seed is metered out on the crawler tracks, then pushed by the weight of the crawler into the cleat marks. Excellent stands can be obtained with this procedure.

The tremendous variation in edaphic and climatic condition in the pinyon-juniper type and within a site requires that species and accessions adapted to specific sites be seeded (fig. 23). Tables 14 through 17 list adapted species and suggested mixtures.

Sagebrush Communities

Sagebrush is one of the most widespread shrub genera in the Intermountain West. Extensive stands of sagebrush grow on low foothill ranges, adjacent valley slopes, within stands of mountain brush and aspen, and in subalpine zones above 10,000 ft (3,048 m). Sagebrush is also an important component of the southern desert shrub type where it grows in association with blackbrush and spreading creosotebush. This wide range of occurrence in differing climates and soils necessitates the use of varied treatments to improve disturbances. Treatment depends on how much sagebrush is to be retained or reestablished. Big sagebrush is a natural component in many communities and is desirable on most big game and livestock ranges within its area of distribution (fig. 24). Sage-grouse rely on sagebrush year around for food and shelter (fig. 25). However, where understory species have been removed by grazing and where big sagebrush has usurped the site and excluded understory species, stands should be thinned to permit reestablishment of understory grasses and forbs.

Figure 24—Wyoming big sagebrush communities are essential to pronghorn antelope and other wildlife.

Eight major sagebrush communities are encountered in the Intermountain region. The big sagebrush complex occupies one of the largest areas and produces perhaps the greatest amount of forage of any shrub. Three big sagebrush subspecies are generally recognized (Shultz 1986; Stevens 1987a): basin big sagebrush, mountain big sagebrush, and Wyoming big sagebrush. Other major sagebrush types are black sagebrush, low sagebrush, threetip sagebrush, silver sagebrush, and alkali or early sagebrush. Of minor importance are foothill big sagebrush, subalpine sagebrush, pygmy sagebrush, Bigelow sagebrush, stiff sagebrush, and bud sage (Shultz 1986; Stevens 1987a).

Figure 25—Big sagebrush provides sage-grouse with cover, forage, and brood-rearing areas.

Other shrubs usually occur within most sagebrush communities.

Previously, most site improvement practices conducted in the sagebrush communities have been designed to reduce shrub density and reestablish herbaceous understory. In many situations, extensive wildfires have eliminated species of sagebrush. Extensive and prolonged grazing has also reduced both understory species and shrub cover, which has allowed weeds to establish. Sagebrush seedling recruitment has subsequently been halted, and stands have slowly declined as individual plants succumb with age. In many situations, planting sagebrush is now required.

Big sagebrush communities are easily disturbed, especially on drier sites. Few understory species occur in the drier regions, and disturbances recover slowly. Annual weeds have invaded and now dominate many big sagebrush communities (Billings 1990; Young 1994). The occurrence of cheatgrass has dramatically altered species composition and restoration methods (Monsen 1994). Cheatgrass is so competitive that it prevents natural recovery of most native herbs and shrubs (Billings 1994). Cheatgrass competition must be reduced to allow other species to reestablish. In addition, cheatgrass produces a dry, highly flammable fuel that results in more frequent wildfires than are generated from native plant communities. Repeated fires further degrade the sites, eliminating nonfire-tolerant species, such as sagebrush, and perpetuate annual grass. The fire cycle must be broken to stabilize conditions and allow species to establish and recover from seedings or natural improvement. Aggressive control measures coupled with well-designed seedings are required to improve weed infested sites.

Many sagebrush sites currently support some annual weeds including cheatgrass. Inappropriate grazing practices cause continued decline of native perennials, allowing expansion of weeds. Transition may occur slowly, depending on climatic conditions and degree of grazing pressure. Natural recovery usually cannot occur unless grazing is completely discontinued. Certain species may recover with some carefully managed grazing practices, but sites that contain only scattered remnant native plants are not able to recover even with minimal use. Where there is some perennial understory in place, removal of grazing may be the most effective and economical means of restoring sites occupied by different species of sagebrush. Many sites may require an extended period of time for all species to fully recover. Consequently, it is often advisable to protect many arid and semiarid shrublands to prevent further degredation, control weed invasion, and effectively restore diverse communities. Allowing sites to deteriorate to the point that artificial seeding is required is not advisable.

Methods and techniques used to treat different species of sagebrush are quite similar, although some differences in control and seeding measures among different sagebrush communities are recommended.

Removal of Competition: Control of Sagebrush

Many stands of big sagebrush have been depleted of almost all understory herbs, which allows shrub density to increase beyond desirable levels. Where this has occurred, the shrub overstory must be reduced to faciliatate seeding and allow establishment of reintroduced herbs. Complete removal of shrub overstory is not required or recommended, but competition must be diminished to facilitate seedling establishment. In some situations, complete removal of shrubs has been advocated to accomplish conversion to stands of introduced or native grasses, with the objective of enhancing seasonal grazing for livestock. This practice is not recommended in most situations.

Anchor chaining is a useful practice where it is desirable to release suppressed understory species. Anchor chaining is the least expensive mechanical treatment to reduce thick stands of sagebrush. This treatment ensures that enough sagebrush can be left to satisfy most game requirements and maintain species diversity. Chaining can be used on a variety of sites including rocky surfaces and terrain with 60-percent slopes. The Dixie chain was designed especially for treating sagebrush stands. Eighteen-inch lengths of 40-lb (18 kg) rails welded across the chain links greatly increase elimination of sagebrush and create a better seedbed. The Dixie chain removes sagebrush more effectively than a smooth or Ely chain.

Pipe harrowing accomplishes many of the same objectives as does chaining, but has the advantage of operating more economically on small areas. Disk plowing to a depth of 2 or 3 inches (5 or 7.5 cm) generally removes most shrubs, but disking is more costly and more destructive to other vegetation. Disk plowing can be used on comparatively level terrain and on less rocky sites than is practicable for chaining. Brush “beaters” and root plows also may be used on such sites.

Controlled burning can be the least expensive and most effective treatment for removing sagebrush plants on large tracts where there is enough fuel to carry fire. Burning often removes or kills all sagebrush plants. Consequently, throughout the Wyoming sagebrush communities, limiting burning, if possible, to smaller areas is often recommended. Natural recruitment and artificial seeding of sagebrush are not always successful following complete removal of all sagebrush plants over large areas. If cheatgrass occurs in the understory, burning should be done after cheatgrass seeds are ripe and the foliage has dried, but before cheatgrass seeds fall from the plant. Most seeds left on the plant will be consumed by fire. Some cheatgrass seeds usually escape, but the resulting competition may not be severe enough to suppress establishment of seeded species.

Stands of sagebrush can be eliminated by spraying with 2,4-D in ester formulations at 1 or 2 lb (0.4 or 0.75 kg) (acid equivalent) per acre (Blaisdell and others 1982). A practice that has gained considerable favor is to spray early in the summer and then seed adapted species in fall or winter. This treatment, however, is not widely suited to use on some ranges because it often kills too much of the sagebrush stand and eliminates associated forbs. The herbicide “Spike” can be used to reduce density or remove big sagebrush without harming the understory. Spike should only be used when there is an acceptable understory because areas treated with Spike cannot be seeded for at least 3 years following treatment. Mechanical methods of eradication are usually preferred because they can be regulated to eliminate desired amounts of big sagebrush, create a good seedbed, and preserve valuable herbs that are present.

Shrub Enhancement

In many situations restoration measures are required to enhance or restore sagebrush plants and associated understory species. Many burns have eliminated all sagebrush plants. These will require seeding. If annual weeds dominate the understory, the herbaceous competition must be removed by burning, disking, or use of herbicides. Shrubs and herbs can then be seeded into the burned areas or into clearings or strips formed by mechanical tillage or chemical fallow.

Big sagebrush plants are most often capable of invading weak stands of native grasses, and forbs. Broadcast seeding sagebrush without any site preparation can be successful if weeds are not present. Broadcast seeding sagebrush directly onto sites supporting Idaho fescue, Sandberg bluegrass, and bluebunch wheatgrass following burning can be highly successful. Broadcast seeding sagebrush onto existing stands of native grasses is less successful if competition has not been reduced by burning. However, adequate stands of shrubs may establish, although timing and amount of moisture is much more important.

Planting Season

If weather permits, planting in winter is best; however, seedings may be conducted from late fall through early winter. Mid October or early November is sufficiently early to start. Planting may continue through December, January, and February, or until the ground has frozen or the weather prohibits further planting. Aerial seeding sagebrush on snow has proven highly successful. Snow cover can enhance sagebrush seed germination and seedling establishment. Sites receiving a snow cover that persists until early spring normally support sagebrush emergence. Consequently, delaying seeding until a uniform blanket of snow has accumulated is advisable.

Planting Procedures

On large areas, aerial broadcasting grasses, broadleaf herbs, and big sagebrush (fig. 26) seeds by fixed-wing plane or helicopter is recommended. Hand broadcasting is efficient on small, isolated tracts. Anchor chaining is economical and effective for covering broadcast seeded herbs and sagebrush on large disked or plowed areas, burns, or herbicide-treated range. The rangeland drill or other single-disk drills can satisfactorily plant sagebrush sites. Drilling requires one-third to one-half less seed than broadcasting. Browse seed, including sagebrush, should be planted in alternate rows from grasses and forbs, with either the rangeland drill or browse seeder. Because sagebrush seed requires very shallow to surface planting, it is best to pull the drop tubes from between the furrow openers and place it so the seed falls behind the furrow openers onto the disturbed soil.

Most species of sagebrush can be successfully seeded with good success, although special consideration must be given to control herbaceous competition. The condition and quality of sagebrush seed is of particular concern in most seeding projects. Seeds of most sagebrush taxa mature in late fall or early winter after many revegetation projects would

Figure 26—Five years after chaining treatment, a mixture of native and introduced species occupy a pinyon and juniper site.

be seeded. Consequently, fresh seed is not always used. One- or 2-year-old seed is most commonly planted. Seed lots of most sagebrush taxa may remain viable for 2 to 4 years depending upon storage conditions (Stevens and Jorgensen 1994). Older seed lots with low viability may be seeded if sufficient amounts are sown. Seeds should be properly stored and tested to assure high quality seeds are used whenever possible.

Sagebrush plants produce numerous small seeds. When harvested, seed lots usually contain a considerable amount of leaves and floral debris. During seed processing, most large sticks are removed, but small leaf and floral tissue is left with the seed. Seed lots having a purity of 8 to 18 percent are commonly sold. The condition of the seed lot can influence the way seed is planted. If the seed lot is chopped before stems are removed by cleaning, the material may not flow through some drills. If the collected material is first screened to remove sticks and then chopped or processed with a debearder, the seeds and debris can be planted much easier. The seed debris is very lightweight and, if not properly cleaned to remove stems, may not flow uniformly through most conventional drills. Consequently, a carrier or seed of other species may be added to cause the material to flow freely and uniformly. Seed lots that are cleaned to a purity exceeding 12 to 15 percent will most often flow very well. Seed lots with high purity (generally over 20 percent) consist of many small seeds. Most seeding equipment or machines are not capable of precisely metering the seed; consequently, the seed must be diluted to be uniformly planted. It is not recommended to clean seed lots above 15 to 20 percent purity for use with standard seeding equipment of if seeded alone.

Sagebrush seed is frequently mixed with seeds of other species to aid in dispensing the sagebrush seed and diluting the seeding rate. This is a useful technique, but sagebrush should not be directly sown with aggressive herbs. Sagebrush can be sown separately in alternate rows with herbs using most conventional drills if the seed is properly cleaned and seeded at the appropriate depth.

Seeds of sagebrush are almost exclusively collected from wildland stands. In many cases, the identity of the taxon is not known. More than any other wildland species, sagebrush seeds are collected and planted over a broad range of sites. Failure to correctly identify specific species, subspecies, and plant-adapted ecotypes can result in poor seeding success.

Seeds of sagebrush taxa are very small, often exceeding 1 million per pound (2.2 million per kg) (Shaw and Monsen 1990) and require light to germinate (McDonough and Harniss 1974a,b). However, the response to light varies among seed lots and with environmental conditions (Bewley and Black 1984; Meyer and others 1990b). Seeds must be planted on or near the soil surface to promote germination and ensure establishment. It is often difficult to plant sagebrush seed near the soil surface using conventional drills. Most seeding equipment is designed to place seeds at deeper depths. When seeded with other species that require deep placement in the soil, sagebrush should be planted in a separate operation or seeded in separate rows. Sagebrush seeds can be dispensed through conventional drills, but seed should not be planted at the bottom of the furrow. Seed tubes attached to the furrow opener can be removed and positioned so the end of the tubes extend behind the furrow openers, which allows the sagebrush seed to be dropped behind the furrow opener on the disturbed soil surface. A “sagebrush seeder” employing a gang of truck tires and a drill box has been developed (Boltz 1994) and is being used with good success. Seed is metered out ahead of the gang of tires and then compressed into the soil.

Sagebrush seeds require adequate moisture to germinate. Goodwin (1956) reported that the highest field germination occurred when the soil was saturated. Weldon and others (1959) found that germination of big sagebrush declined by 60 percent when water potential of the soil medium was reduced to –0.80 MPa. The soil surface of most planting sites dries quickly, adversely affecting seedling establishment. The presence of surface litter and retention of a snow cover benefit sagebrush seedling establishment. Meyer (1990) found greater numbers of big sagebrush seedlings within areas where snow collected compared to open surfaces. Sagebrush seeds were able to germinate beneath the snow in a moist environment, and were protected from spring frosts, as young seedlings have little frost tolerance. Natural seedlings of big sagebrush normally establish near mature shrubs, and around and under downed pinyon-juniper trees and litter piles. The existing shrubs and downed trees obviously entrap snow and provide more favorable seedbed conditions than exposed sites. Seeding sagebrush in large, open disturbances has usually been unsuccessful because snow does not collect or is not retained for more than a few days. Within these areas, soil surfaces dry rapidly, and favorable conditions do not exist for seed germination or seedling establishment.

Meyer and Monsen (1992) found that germination response among sagebrush collections correlated to the habitat from which the seed is produced. Seed collections of mountain big sagebrush from severe winter sites had a larger dormant seed fraction and slower germination rates than collections from mild winter sites. Collections from severe winter sites require up to 113 days to germinate, while collections from mild winter sites require as few as 6 days. Habitat-correlated variation appears to be an adaptive feature that prevents precocious germination, and promotes germination when frost damage potential is low and when the best chance of success occurs. Planting unadapted seed lots can undoubtedly lessen the chance of seedling establishment.

Sagebrush seedling establishment is related to the presence and composition of understory grasses and broadleaf herbs. Sagebrush seedlings are generally unable to compete with annual grasses, particularly cheatgrass (Evans and Young 1987a). Dense stands of perennial native and introduced grasses have been reported to reduce sagebrush seedling establishment and growth (Blaisdell 1949; Holmgren 1954). However, sagebrush seedings have frequently been able to invade many seeded areas (Blaisdell and others 1982). In general, sagebrush seedlings are less likely to reestablish and spread throughout areas receiving less than 12 inches (30 cm) of annual moisture than sites receiving greater amounts.

The relationship of sagebrush seedling establishment to native understory grasses and broadleaf herbs is not well understood. However, natural spread of sagebrush seedlings into established stands of understory herbs is frequently observed. In addition, seeding sagebrush directly into established stands of native herbs has also been successful.

Sagebrush seedlings establish satisfactorily using surface-type seeders such as a Brillion seeder (Monsen and Meyer 1990). Seedlings also establish well by aerial or broadcast seeding on a rough surface. Aerial seeding following chaining has been highly successful through the juniper-pinyon and big sagebrush communities. Broadcast seeding onto snow over disturbed soil in early or late winter also produces good stands (fig. 27). Most species of sagebrush can be interseeded or spot seeded into some existing competition (Monsen and Stevens 1987; Stevens 1980b). Interseeding in rows or strips is a practical method of establishing shrubs and providing a seed source for further spread.

Figure 27—Big sagebrush seedlings have successfully established from midwinter aerial seeding on sites covered by snow.

Adapted Species and Mixtures: Considerations in Selecting Species To Be Seeded

Extensive areas of sagebrush, particularly species of big sagebrush, have been seeded with introduced grasses to reestablish a herbaceous understory that was eliminated by previous mismanagement. Conversion of sagebrush shrublands to introduced forage grasses has provided a stable and productive forage base for livestock, enhanced watershed conditions, and has helped to control weed invasion. Wildlife resources have been enhanced occasionally; in most cases they have been dramatically reduced. Native species and community recovery have been prevented, and multiple-use management has been reduced or eliminated by converting shrublands to stands of introduced grass.

Converting or altering sagebrush communities must be done carefully to assure that desired resource values are retained or achieved. Numerous species are available to seed sagebrush sites. However, the communities that ultimately develop from mixed seedings must be recognized and appropriate seed mixtures utilized.

Revegetation efforts in the Wyoming big sagebrush and some basin big sagebrush habitat types are often only partially successful. These sites frequently receive inadequate moisture to sustain new seedlings. If seedings are completed in years of normal precipitation, planted species usually survive.

Attempts have been made to introduce other more palatable, shrub species and convert the existing shrub composition to more preferred and palatable species to Wyoming big sagebrush and basin big sagebrush communities. Few other woody plants naturally grow with these two shrubs. Antelope bitterbrush has been extensively planted throughout these sagebrush communities with limited success. In most instances, antelope bitterbrush should not be indiscriminately planted in “offsite” circumstances.

Sources of fourwing saltbush and winterfat have been collected from native stands occurring intermixed with both Wyoming and basin big sagebrush communities. These selections have been planted on broad areas throughout the big sagebrush types. Some individual selections demonstrate good longevity, but little natural spread has been recorded. No population of fourwing saltbush has been identified that is widely adapted to the Wyoming big sagebrush communities. Numerous Intermountain collections of fourwing saltbush have been planted in southern Idaho, Utah, and Nevada, where Wyoming big sagebrush occurs. To date, some sources have established and produced seeds but no seedling recruitment has occurred. A number of sources from southern Utah, Arizona, New Mexico, and Texas have survived for less than 10 years when seeded in the northern portion of the Intermountain region. Ecotypes of fourwing saltbush that naturally occur intermixed with basin big sagebrush have established and persisted well if planted on sites similar to the area of collection. In most situations, however, it has not been practical to seed different species of shrubs on Wyoming big sagebrush types.

In situations where the density of fourwing saltbush, winterfat, or other shrubs is being increased by artificial seeding, it is imperative that an adapted seed source is planted. A number of cultivars of different native shrubs have been developed for use in the big sagebrush type (McArthur and others 1984b; Monsen and others 1985a; Welch and McArthur 1979a). Each cultivar has regional areas of adaptation and is not universally adapted to all conditions where big sagebrush occurs. Various attempts have been made to plant “Rincon” fourwing saltbush, “Hatch” winterfat, “Lassen” antelope bitterbrush, and “Hobble Creek” and “Gordon Creek” big sagebrush throughout the big sagebrush zone. These cultivars are adapted to specific locations, and plantings should be confined to these situations.

Most big sagebrush rangelands are subjected to wildfires, particularly sites that support an understory of cheatgrass. Burning reduces the density and recruitment of many species, particularly shrubs. It is advisable that species that are seeded into sagebrush-cheatgrass rangelands are able to withstand fires and recover by natural seeding. To date, ecotypes of fourwing saltbush and winterfat that have been planted in these areas have not survived fires, particularly on sites that burn frequently.

Few native forbs are available in sufficient amounts to seed large disturbances. Seed of blue aster, Palmer penstemon, western yarrow, globemallow, and Lewis flax are available to seed moderately sized disturbances. All available sources are adapted to specific site conditions. Broadleaf forbs are essential to arid shrublands, and development of additional sources is necessary.

Selections of alfalfa and small burnet have been developed and used to improve forage diversity, extend grazing periods, and enhance forage quality throughout the big sagebrush type. Both species are well adapted to sites receiving more than 12 inches (304 mm) of annual precipitation. Mountain big sagebrush and some basin big sagebrush and Wyoming big sagebrush stands receive this amount of precipitation. Stands of highly preferred species have not been maintained when small amounts of seed have been planted. Small burnet and alfalfa have frequently been planted at only 0.5 to 1.0 lb (0.2 to 0.45 kg) per acre within the big sagebrush types. These broadleaf herbs receive heavy use by all classes of animals, which may eliminate the plants from the seeded area. When highly preferred species are planted in mixtures, enough seed (2.5 to 4 lbs [1.2 to 1.8 kg]) should be seeded to establish a large enough population to reduce damage from concentrated grazing. Sufficiently large tracts should be seeded to lessen concentration of animals and heavy browsing of the more preferred species.

Many introduced and native species that have been seeded in the sagebrush types exhibit a wide range of adaptability. Crested wheatgrass, desert wheatgrass, intermediate wheatgrass, pubescent wheatgrass, Sandberg bluegrass, and bottlebrush squirreltail are widely adapted to the different habitat types of Wyoming and to basin big sagebrush. Bluebunch wheatgrass, Indian ricegrass, streambank wheatgrass, thickspike wheatgrass, needle-and-thread grass, and Russian wildrye are more sensitive to particular soil types occupied by these two shrubs, but are still widely used. Great Basin wildrye is more restricted to particular habitat types, and should only be seeded in areas of natural occurrence.

Desert wheatgrass, crested wheatgrass, intermediate wheatgrass, pubescent wheatgrass, Canby bluegrass, streambank wheatgrass, thickspike wheatgrass, and hard sheep fescue have been widely seeded in sagebrush communities. Numerous sites have been converted from a shrub-dominated community to an exotic perennial grass type. Desert wheatgrass has proven better adapted to more arid sites. Crested, pubescent, and intermediate wheatgrass, and hard sheep fescue are more suited to upland situations with southern smooth brome being suited to sites with higher amounts of precipitation. ‘Hycrest’ crested wheatgrass, a cross between desert and crested wheatgrass, and ‘Douglas’ wheatgrass express excellent establishment traits and are able to compete well with annual weeds. These two selections are not as drought tolerant as desert or crested wheatgrass. ‘Douglas’ wheatgrass is the least drought tolerant. ‘Hycrest’ wheatgrass has been widely planted, however, extensive stands have been lost in drought years. Desert, crested, ‘Hycrest’, intermediate wheatgrass, smooth brome, and hard sheep fescue have not proven compatible with most native herbs. When seeded in most sagebrush communities, these species will gain dominance and restrict recovery of native herbs. The lack of species diversity adversely affects wildlife habitat, and does not provide the seasonal herbage or watershed values as mixed communities do. Dominant stands of crested, desert, pubescent, intermediate wheatgrass, smooth brome, and hard sheep fescue have, in many situations, prevented shrub seedling recruitment. Loss of sagebrush and other woody species slowly occurs in many situations when these grasses have been planted. Wildlife habitat and other resource values have been adversely affected. Seeding crested, desert, or intermediate wheatgrass and hard sheep fescue throughout the sagebrush communities should be evaluated to be sure management objectives will be achieved. Use of native herbs is desirable where diverse communities are required.

Basin Big Sagebrush

Basin big sagebrush (fig. 26, 27) is one of the most abundant shrubs in Western North America (McArthur and others 1979a). This plant occurs on plains, valley and canyon bottoms, and foothill ranges. It is most prevalent on deep, well-drained, fertile soils with a pH ranging from slightly acidic to highly alkaline. Within the Intermountain West, basin big sagebrush can be found from 3,000 to 7,000 ft (914 to 2,140 m) elevation, with annual precipitation ranging from 9 to 16 inches (23 to 41 cm).

A majority of the irrigated farmlands, dry farms, and dryland pastures within the Intermountain West were once dominated by basin big sagebrush. A large number of native and introduced grasses and forbs do well on these lands. The productive potential of the basin big sagebrush type is reported to be higher than that of the Wyoming big sagebrush type but less than the mountain big sagebrush type (Winward 1980).

Basin big sagebrush is not readily eaten by livestock or big game when it occurs with other, more preferred species (Hanks and others 1973; Sheehy and Winward 1981; Welch and others 1981). However, it does contain high levels of protein (McArthur and others 1979a; Welch 1981). The herbage is digestible (Welch 1981), and plants withstand heavy browsing. Deer and sheep use this shrub seasonally. This species is critical on deer winter ranges, especially during extended and deep snow accumulation and cold periods. Sage-grouse also use this subspecies throughout the entire year (Call 1979).

Removal of Competition

The question arises of how much basin big sagebrush is enough. Should it be controlled, reduced, or seeded? The value of the shrub cover should be carefully evaluated before attempts are made to reduce shrub density. This subspecies occurs in differing densities, with various types and amounts of associated species, and in differing climates and soils. Various range improvement treatments are thus required for satisfactory control. Complete or near complete elimination of basin big sagebrush can be accomplished with plowing, burning, or use of herbicides. Anchor chaining can be used to reduce shrub density. The extent to which the shrubs are killed by chaining is determined by the number of times a site is chained, the type of chain used, and the method and season of treatments. Similar results can be accomplished with a pipe harrow.

Disk chains and various types of disk plows have been developed that can be used to uproot and thin or remove dense stands of sagebrush. Disks can be adjusted to regulate the percent of plants uprooted. Disking and plowing can, however, result in kill of associated, desirable vegetation. Fire can be effective in eliminating or reducing basin big sagebrush. This shrub has essentially no fire tolerance. For fire to move through basin big sagebrush stands, there must be sufficient understory to carry the fire. Density of basin big sagebrush generally must be reduced to obtain satisfactory establishment of seeded understory species (fig. 28). Once a basin big sagebrush area is disturbed, it is imperative the area is seeded the same year (during the appropriate season) so undesirable species do not establish.

Planting Season

Fall and early winter planting is recommended; however, plantings at low elevations may be extended into midwinter or until frozen ground prevents tillage. Seeding on top of snow over areas that have been disturbed has proven successful (fig. 27). Spring plantings are not advised within this shrub type.

Planting Procedures

Seeding large areas can be best accomplished by aerial seeding using either a fixed-wing aircraft or helicopter. This should be followed by some method of seed coverage. Hand broadcasting is effective in planting small, isolated tracts. The rangeland drill, and other types of heavy duty drills, can be used to seed areas where debris and rocks are absent and the ground is fairly level. Species can be interplanted into sagebrush stands using a scalper and seeder combination (Stevens and others 1981b). The Hansen seed dribbler and thimble seeder are also effective equipment that can be used to seed many forbs and shrubs.

Adapted Species and Mixtures

A number of species, accessions, and varieties are adapted to and recommended for seeding areas formerly inhabited or occupied by basin big sagebrush (table 18). Species recommended for seeding mixed fourwing saltbush-basin big sagebrush sites are listed in table 17. A number of introduced grasses and

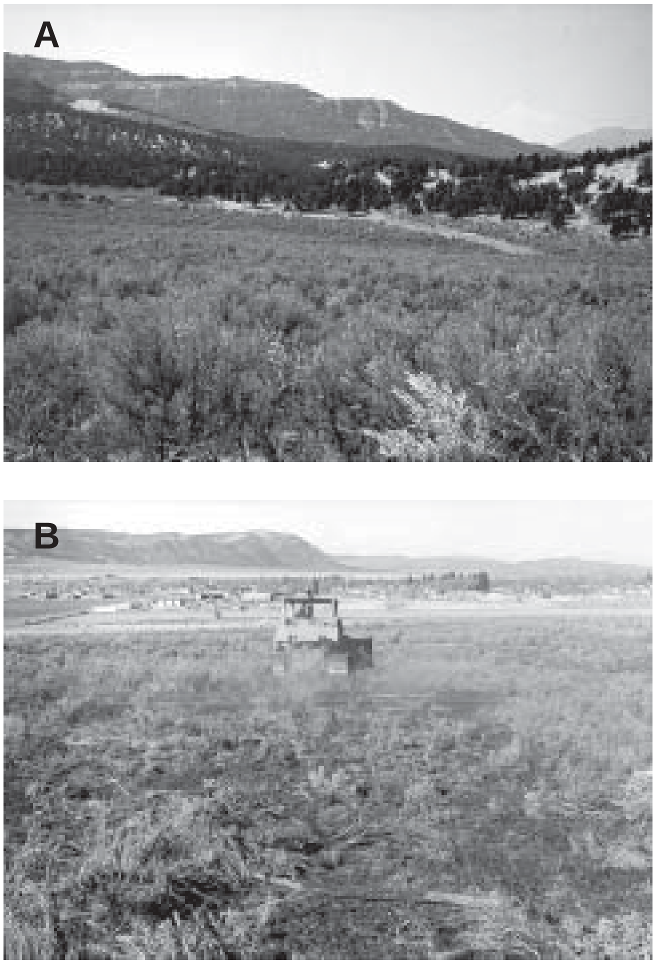


Figure 28—(A) Dense stands of basin big sagebrush often develop that lack understory species essential to wildlife. (B) Thinning stands of big sagebrush can be accomplished using a disk-chain to facilitate seeding of herbaceous species.

broadleaf herbs have been developed to revegetate these communities. In addition, some of the principal native grasses and some broadleaf herbs are available. The objectives of the project and availability of seed of adapted species will determine what is planted.

Mountain Big Sagebrush

Throughout the Intermountain West, mountain big sagebrush (fig. 29) is found at elevations from 3,500 to 9,800 ft (1,060 to 3,000 m) and occurs from foothills to subalpine zones. Annual precipitation ranges from 12 to 30 inches (300 to 760 mm). Soils on which mountain big sagebrush grows range from slightly acid to slightly alkaline (McArthur and others 1979a), and are generally well drained. Soil moisture is usually favorable throughout the growing season.

A large number of grass, forb, and shrub species grow in association with this shrub (Winward 1980), and usually produce an abundance of forage. Livestock, big and small game, and upland game birds prefer mountain big sagebrush (McArthur and others 1979a; Welch 1981). Open stands with good, diverse understory are essential to sage-grouse and must be used in treatment projects to maintain sufficient shrub density and cover for sage-grouse. It is essential that desirable understory species and woody species associated with mountain big sagebrush be retained or reestablished as part of the revegetation effort.

Removal of Competition

The use of herbicides, plowing, and disking are effective techniques in reducing competition, but often are not recommended for renovating mountain big sagebrush stands, particularly areas supporting big game and sage-grouse. These techniques usually kill most associated herbs and existing shrubs. Because mountain big sagebrush provides palatable and nutritious forage for wildlife throughout the year, it is not advisable to eliminate this shrub. Sage-grouse strutting, wintering, and chick-rearing areas can be seriously altered if mountain big sagebrush and associated native forbs are removed.

Mechanical treatments, including once- or twice-over chaining or pipe harrowing, will normally eliminate enough mountain big sagebrush to reduce competition, create a suitable seedbed, and preserve valuable forbs. If annual weeds dominate the understory and sagebrush density is extremely high, more aggressive

Figure 29—Mountain big sagebrush frequently grows in association with Gambel oak and an assembly of grasses and broadleaf herbs.

methods are required to reduce the competition. However, in many situations, thinning of mountain big sagebrush may be all that is required.

When herbicides are used, mountain big sagebrush should be treated at an earlier stage of growth than the other big sagebrush species. As leaves appear, it is especially susceptible to herbicides. It can be sprayed in early spring prior to the emergence of most understory species. If sprayed at a later date (late spring and early summer), mountain big sagebrush is less susceptible, and herbicides can be more detrimental to understory herbaceous species.

In stands where the associated herbaceous vegetation has been depleted by grazing or other causes, mountain big sagebrush can increase in density and size (Winward and Tisdale 1977). Early spring burns that occur soon after the snow starts to melt generally do not completely eliminate a stand. Burns at these dates will likely create a mosaic of shrubs and herbs. Herbicides can also be sprayed in similar patterns to create mosaics. Size and shape of areas treated must be designed to maintain or improve wildlife habitat, particularly for sage-grouse.

Planting Season

Late fall and early winter plantings are recommended. At higher elevations, plantings can be terminated by early heavy snowfall. Sites should not be spring planted. Sagebrush reduction or thinning operations in areas with healthy understory herbs may not require seeding. Areas that lack desirable herbaceous plants and those that are plowed or disked require seeding. Table 19 lists species that are adapted to the mountain big sagebrush type. The most successful seedings are those that include a mixture of species and are conducted in the fall just prior to snowfall.

Planting Procedures

Aerial broadcasting by fixed-wing plane or helicopter is recommended for seeding herbs and sagebrush seeds on large areas. Hand broadcasting or broadcasting with spreaders mounted on ground transport units are effective methods for seeding small tracts. Anchor chaining or pipe harrowing are economical and effective methods for covering broadcast seeds on depleted sites and large disked or plowed areas, burns, or herbicide-treated ranges. Mountain big sagebrush can be successfully seeded by broadcasting from aerial or ground units. This shrub can spread well by natural seeding. Chaining or other surface-manipulation practices will enhance natural spread. Seedlings of mountain sagebrush are competitive and able to establish and persist with some herbs; consequently, mixed plantings are normally successful.

Antelope bitterbrush, mountain snowberry, Stansbury cliffrose, mountain mahogany, sakatoon serviceberry, and chokecherry occur intermixed with mountain big sagebrush. These species should be drill seeded to assure seeds are placed in the soil at appropriate depths. The Hansen seed dribbler is very effective in seeding most shrub and forb species. This seeder is normally mounted on the truck or crawler tractor used to chain or pipe harrow mountain big sagebrush sites. Browse seeds can also be seeded in alternate rows with grasses and forbs with rangeland drills or modified browse seeders.

Adapted Species and Mixtures

Mountain big sagebrush communities normally support a diverse composition of species, and plantings should be designed to reestablish the entire community structure. Small but important stands of serviceberry, chokecherry, mountain mahogany, mountain snowberry, antelope bitterbrush, and Stansbury cliffrose are desirable and should be reestablished within mountain big sagebrush restoration projects where appropriate. It is important that understory herbs are reestablished along with the shrubs on depleted sites. Table 19 lists the primary species adapted to mountain big sagebrush sites.

Wyoming Big Sagebrush

This subspecies can be found throughout the Intermountain West on xeric sites, foothills, valleys, and mesas between 2,500 and 7,000 ft (760 and 2,100 m). Annual precipitation varies from 7 to 15 inches (180 to 280 mm). Soils on which Wyoming big sagebrush occurs are usually well drained, gravelly to stony, and may have low water-holding capacity. Soils are shallow, usually less than about 18 inches (46 cm) deep. Fewer herbaceous species are associated with Wyoming big sagebrush than with basin or mountain big sagebrush (Winward 1980). Native bunchgrasses are often important understory species in Wyoming big sagebrush communities. In some areas, this sagebrush may be used extensively throughout the year by livestock, big game, and upland game birds.

Removal of Competition

Following disturbance, Wyoming big sagebrush generally does not reestablish as rapidly as mountain big sagebrush. Cheatgrass has often displaced Wyoming big sagebrush and associated understory species. Control and eradication measures must be designed to replace this weed if plantings of perennial herbs and sagebrush are to be successful.

Stands of Wyoming big sagebrush normally do not produce abundant seed crops each year. Natural spread onto disturbed sites can be delayed until years when seeds are produced and favorable moisture conditions occur to support new seedlings. Attempts to seed this shrub in semiarid sites have not always been successful because of adverse climatic conditions. The amount and timing of late winter and early spring precipitation is critical for sagebrush seed germination and seedling survival, particularly on areas that receive less than 10 inches (250 mm) annual precipitation. Lack of spring and summer moisture often limit seedling survival. Wyoming big sagebrush can be successfully seeded on sites that receive 10 to 12 inches (250 to 300 mm) precipitation.

Natural spread of Wyoming big sagebrush has often been restricted by cheatgrass. This annual grass is extremely competitive and limits shrub regeneration. Seedings of crested, desert, pubescent, and intermediate wheatgrass have, in many areas, also prevented natural recovery of this shrub.

Removal of Competition

Usually sites supporting Wyoming big sagebrush receive low amounts of precipitation, and weed control is essential for the establishment of all seeded species. Where cheatgrass occurs in dense stands, plowing or spraying may be required to adequately control this weed. In many situations, cheatgrass and other annual weeds exist intermixed with Wyoming big sagebrush and perennial herbs. Under these conditions the annual weeds can provide sufficient competition to prevent natural recruitment of native plants, including Wyoming big sagebrush. Cheatgrass competition must also be reduced to assure establishment of seeded species. Control measures used should not destroy existing perennial herbs. Interseeding shrubs and/or herbs into cleared strips or spots is a satisfactory method of interplanting. This technique can be used to reintroduce desirable plants and ultimately create parental stock from which natural recruitment may occur. However, annual weeds must be controlled to allow natural spread.

Weed-infested sites can be burned after cheatgrass seeds are ripe and the foliage has dried, but before the seeds fall. Burning during this period consumes most seed; however, some seeds usually escape, but the resulting competition may be reduced enough to allow establishment of seeded species. Cheatgrass can recover quickly following burning, and sites must be planted in the fall months after the burn. Waiting to seed beyond one season allows weeds adequate time to fully recover. Seeding burned areas that remain heavily infested with annual weeds is not advised. Burning will kill existing Wyoming big sagebrush, but fires normally will not seriously impact many existing perennial herbs. If burns are relatively small, shrub recruitment by natural seeding may occur, depending on the success attained in replacing annual weeds with native perennial herbs.

Reduction in density of Wyoming big sagebrush may be required where thick stands of this shrub have developed, but the shrub can easily be controlled by disking, plowing, burning, or use of herbicides. Shrub density can also be regulated by anchor chaining or pipe harrowing. Either practice can be modified to attain different levels of control. Treating in midwinter when stems are cold and brittle results in higher kill than late fall or early spring treatments when plants are more flexible. Significant differences in kill can also be attained by using different weight chains and modifying methods of operation (operating at different speeds, adjusting width and spacing of tractors, once- or twice-over chaining). Brush beaters are also effective in removing mature shrubs, but use is restricted to level terrain and sites free of rock. Herbicides can be used to remove Wyoming big sagebrush, but the treatment often kills too much of the shrub stand and eliminates valuable forbs.

Planting Season

If possible, planting in winter is advisable, but late fall through early winter has been generally successful. Planting may continue through December, January, and February, or until the ground has frozen, preventing operation of equipment. Planting on snow over disturbed soil is acceptable. Newly disturbed sites should be seeded in the fall or winter months following disturbance.

Planting Procedures

Seeding practices described for mountain and basin big sagebrush sites apply to treatment of Wyoming big sagebrush communities. Extensive areas occupied by Wyoming big sagebrush occur on relatively level terrain where conventional drills can operate; consequently, large areas have been planted with rangeland drills coupled together in gangs of two to five drills drawn with a single tractor.

Broadcast seeding followed by anchor chaining or pipe harrowing is an appropriate practice for seeding extensive areas in a very short time. Most herbs and Wyoming big sagebrush can be seeded in this manner. In some situations, reestablishing sagebrush on large barren areas created by wildfires has been difficult to accomplish. Studies by Meyer (1994) indicate that sites receiving winter snow that persists until early spring (March) significantly favor shrub seedling establishment. Young and others (1990) reported destruction of soil surface morphology caused by various disturbances destroys seedbed conditions, diminishing seedling establishment. Soils throughout many Wyoming sagebrush communities have been altered by grazing, weed invasion, and frequent fires. In addition, loss of shrub cover and surface litter over extensive areas results in poor seedbed conditions. Large open sites often do not receive a winter snow cover and soil surfaces dry rapidly, reducing emergence and survival of small seedlings.

Standing cover and surface litter provided by mature shrubs or perennial grasses significantly improves seedbed conditions for Wyoming big sagebrush seedlings. Attempts to modify seedbed conditions by diking, pitting, or deep furrow drilling have not improved shrub seedling success; however, use of the “sagebrush-seeder” has improved sagebrush establishment and survival over conventional drilling practices. The sagebrush-seeder deposits and firms seed onto the soil surface without further modification of the seedbed (Boltz 1994). Although this practice does not ensure planting success in all situations, it is advisable to use this equipment or other surface seeders when planting small seeds of sagebrush.

Adapted Species and Mixtures

Within Wyoming big sagebrush areas, where annual precipitation is near 10 inches (250 mm) or less and soils are light textured, Sandberg bluegrass, Indian ricegrass, bottlebush squirreltail, and Bluebunch wheatgrass may be used if plants occur naturally. Thurber needlegrass, western wheatgrass, and sand dropseed are other recommended native grasses. Not all species are universally adapted to all Wyoming big sagebrush sites. Crested and desert wheatgrass, Russian wildrye, and pubescent wheatgrass are the primary introductions adapted to this shrub type. Areas receiving more than 12 inches (300 mm) of annual precipitation will support bluebunch wheatgrass, western wheatgrass, alfalfa, small burnet, and intermediate wheatgrass. Winterfat, antelope bitterbrush, fourwing saltbush, or other shrubs seeded on Wyoming big sagebrush sites should be confined to areas where these species naturally occur. Attempting to convert Wyoming big sagebrush to other native shrub species is not advisable. Seeds of certain native broadleaf herbs, including Lewis flax, Palmer penstemon, Utah sweetvetch, and gooseberryleaf globemallow, may be sufficiently available to be included in large seedings. These species are only recommended for sites in which they naturally exist. Attempts to seed them in more arid or offsite conditions are not advised. Near pure stands of fourwing saltbush occur in some Wyoming big sagebrush areas. In some locations, the two shrubs can be intermixed. Soils in which fourwing saltbush occur are generally deeper, possess more clay, and have a slightly higher pH. Species recommended for seeding Wyoming big sagebrush sites are listed in table 20. When fourwing saltbush is intermixed with Wyoming big sagebrush, adapted species for seeding vary and are listed in table 17.

Plantings of forage kochia (fig. 30) have demonstrated adaptability to much of the Wyoming big sagebrush type (Stevens 1985b). This introduced shrub establishes well amid considerable competition from annual weeds (McArthur and others 1990a; Monsen and others 1990; Monsen and Turnipseed 1990; Stevens and McArthur 1990), provides excellent wildlife habitat, and forage, and restricts the spread of annual weeds (Monsen and others 1990). This shrub is also effective in controlling wildfires when planted as greenstrips or fuel breaks in weed infested rangelands (Pellent 1994). Currently, this low half-shrub is a useful species for planting semiarid sites where seedling establishment of other species is difficult to attain. Completely replacing sagebrush with forage kochia is not advised. Forage kochia furnishes excellent winter forage for livestock under controlled grazing conditions, but it does not provide the habitat required for sage-grouse and other wildlife.

Black Sagebrush

Black sagebrush is highly palatable to livestock, big game and sage-grouse. The species generally occurs between 4,900 and 8,000 ft (1,500 and 2,400 m), but can be encountered at lower elevations. A majority of the black sagebrush communities occur on calcareous soils, derived from limestone. There are, however, extensive areas where black sagebrush occurs on

Figure 30—Forage kochia and fourwing saltbush have been successfully seeded into weed-infested sites that once supported Wyoming big sagebrush.

volcanic soils. Black sagebrush is encountered with horsebrush, greasewood, shadscale, ephedra, pinyon-juniper, big sagebrush, and in salt desert shrub communities. In general, it grows in pinyon-juniper communities and at lower elevations; however, it is also encountered on rocky soils at higher elevations. Low sagebrush is often confused with black sagebrush. Low sagebrush, however, normally grows with pinyon-juniper, mountain brush, white fir, aspen, and spruce-fir communities.

Annual precipitation of black sagebrush sites range from 7 to 18 inches (180 to 460 mm). Because of the low moisture-holding capacity of most soils, only a small portion of the annual precipitation is available. Black sagebrush may occur on warmer and well-drained soils, and on more xeric sites than Wyoming big sagebrush. Salt desert shrub species normally occur on sites that are too xeric or saline for black sagebrush.

Removal of Competition

Generally, stand reduction should not be attempted in black sagebrush types. This is due to low precipitation, poor moisture-holding capacity of the soil, and the small number of beneficial grasses, forbs, and shrubs that can be successfully seeded. Black sagebrush is a very important forage species and should be retained, not eliminated or altered. Some black sagebrush areas have been invaded by Utah juniper, singleleaf pinyon or pinyon. Removal of the trees by anchor chaining can result in substantial recovery of residual black sagebrush plants and original understory species. Where stands of black sagebrush have been eliminated by a combination of grazing and burning, cheatgrass and red brome have frequently invaded and dominate. These annual weeds can be controlled using practices described for Wyoming big sagebrush.

Black sagebrush does recover well when sites are protected from extensive grazing. Seedlings of this shrub are extremely competitive, and natural recruitment proceeds well if disturbances are protected. Interseeding black sagebrush into disturbances can certainly speed up natural recruitment processes. Once established, black sagebrush plants compete well with annual weeds. Through protective management, weakened stands of black sagebrush can displace annual weeds and regain dominance.

Seeded grasses, including desert, crested, and Siberian wheatgrass, have not persisted well amid stands of black sagebrush. Although some native grasses and broadleaf herbs occur intermixed with this shrub, black sagebrush is extremely competitive and may not allow for the development of extensive stands of grass. Disturbances within the black sagebrush type that have been seeded to drought-tolerant grasses have reverted to a shrub cover within 10 to 20 years.

Planting Season

When seeding is attempted, every effort should be made to conserve and utilize available soil moisture. Late fall or early winter seedings are recommended. Seeding should be delayed until some winter moisture has been received. Seeding into water catchments, holding basins, or deep furrows can improve seedling establishment. Broadcast seeding black sagebrush with a mixture of native and introduced grasses has not diminished shrub seedling establishment.

Adapted Species and Mixtures

Species with potential for seeding disturbed sites in the black sage type are listed in table 21. Desert, crested, and Siberian wheatgrass, and Russian wildrye are introduced species that have established in black sagebrush sites. These species have not persisted in all areas, particularly as black sagebrush recovers. Western wheatgrass, Indian ricegrass, bluebunch wheatgrass, and needle-and-threadgrass are native species common in this shrub type. They persist better with black sagebrush than do most introduced grasses, but may occur as subdominant understory species. All can be seeded with good success. There are generally few forbs that are associated with black sagebrush. Attempts should not be made to seed shrub species that do not naturally occur with black sagebrush.

Low Sagebrush

Low sagebrush can be found growing on more moist sites, and generally at slightly higher elevations than black sagebrush. Soils in which low sagebrush occurs are dry, rocky, and often alkaline, some have shallow clay pans, and most are not well drained. Sites may be subjected to spring flooding. Areas of occurrence ranging from 2,300 to 11,500 ft (700 to 3,500 m) (McArthur and others 1979a) and receive 9 to 20 inches (230 to 510 mm) of annual precipitation.

Low sagebrush is an important and useful species, and attempts to convert this shrub type to introduced herbs is not advised. If the associated understory has been removed, the potential for herbaceous vegetation improvement through seeding is fairly good on most low sagebrush areas. Species adapted to the low sagebrush types are listed in table 22. Seeding should occur in the fall or early winter prior to snowfall. Low sagebrush has not been as widely seeded as other species of sagebrush; however, direct seedings are usually quite successful.

Some reduction of low sagebrush may be required to reestablish seedlings of displaced species, but elimination of this shrub is not recommended. If necessary, density of low sagebrush can be reduced with anchor chains and pipe harrows. These two pieces of equipment are also useful for covering seed. Plowing, disking, fire, and herbicides are effective techniques for killing low sagebrush, but are not recommended. These techniques cause major damage and can kill existing shrubs, forbs, and grasses. Seeding should be done in the fall or early winter prior to snowfall.

Threetip Sagebrush

Within the Intermountain West, threetip sagebrush occurs in northern Utah, northern Nevada, and southern Idaho. It can be found between the lower, warmer dry sites dominated by Wyoming big sagebrush and the higher, cooler mountain big sagebrush type (Schlatterer 1973). Soils are quite variable, but are usually moderately deep, ranging from fine loam to very gravelly. Annual precipitation ranges from 10 to 20 inches (250 to 500 mm) and elevations from 3,000 to 9,000 ft (900 to 2,750 m) (Beetle 1960).

A number of forbs, grasses, and other shrubs grow in association with threetip sagebrush. The potential for reestablishing herbaceous species through seeding is fairly high, but not as great as in mountain big sagebrush areas. Threetip sagebrush may resprout from the base following fire, defoliation, or other disturbances. Practices can be used to initially reduce woody competition and allow understory species to establish, yet favoring the recovery of the sage. Threetip sagebrush sites should be seeded with adapted and available species (table 23) at the same season as described for mountain big sagebrush, using similar practices. Best seeding success has been achieved by seeding in the late fall just before snowfall .

Threetip sagebrush communities normally support a wide array of herbaceous and woody species. Sites usually are not invested with annual weeds. Areas disrupted by grazing normally recover with protection. Threetip sagebrush plants usually produce abundant seeds each year, facilitating natural recruitment. Stands of threetip disrupted by burning or extended periods of grazing can be restored by broadcast seeding. Aerial seeding of fresh burns or broadcasting prior to chaining or pipe harrowing are quite successful. Seeding threetip sagebrush with herbaceous species has also been successful.

Mountain Silver Sagebrush

Throughout the Intermountain region, mountain silver sagebrush occurs in valleys, plains, foothills, and mountains up to 10,000 ft (3,050 m). Precipitation ranges from 18 to 30 inches (460 to 760 mm) annually. Soil texture ranges from loam to sandy loam. Many sites are poorly drained, with some having seasonally high water tables. Some sites often collect a heavy snow pack that remains late into the spring. As snow melts, the soil is saturated for a period of time.

Two other silver sagebrush subspecies occur in the west: Bolander silver sagebrush occurs primarily in the Sierra-Nevada Mountains, and plains silver sagebrush occurs principally east of the Continental Divide (Shultz 1986). Timberline sagebrush grows in association with silver sagebrush, especially when there is heavy snow pack. Subalpine big sagebrush also occurs on more open areas with silver sagebrush.

Considerable variations of understory species occur among mountain silver sagebrush sites. Consequently, care should be taken when selecting species to seed within a particular mountain silver sagebrush community. Mountain silver sagebrush communities should not be altered or converted to other species. However, where disturbances have occurred, mountain silver sagebrush density can be reduced with anchor chains, pipe harrows, disks, and disk chain if necessary. Fire and herbicides are also effective means for reducing silver sagebrush. Species that are adapted to the mountain silver sagebrush, timberline sagebrush and subalpine big sagebrush areas are listed in table 24.

Ecotypes of mountain silver sagebrush demonstrate excellent establishment features. Some ecotypes compete well with annual weeds. Natural spread of mountain silver sagebrush into weed infested sites often occurs. This shrub resprouts following burning, and may be used to seed areas occupied by flammable annual weeds.

Alkali or Early Sagebrush

Alkali sagebrush occurs at elevations between 5,900 and 8,000 ft (1,800 and 2,450 m). It occupies extensive areas along the foothill ranges from south-central Montana southward into Wyoming, northern Colorado, Utah, Nevada, Idaho, and Oregon (Blaisdell and others 1982). Alkali sagebrush usually occurs on heavy textured and poorly drained soils. This shrub is unlike most other woody sagebrushes, with the exception of low sagebrush or silver sagebrush, as it is able to grow on wet sites. It is frequently mixed with antelope bitterbrush, and basin big, threetip, and low sagebrush, particularly in south-central Idaho. Yet, when growing with these shrubs, it usually occurs in separate and distinct patches.

Alkali sagebrush is useful forage for game birds, livestock, and big game animals. It is important habitat for sage-grouse and provides forage for sheep and antelope, especially as spring herbage. Rehabilitation or conversion of alkali sagebrush-dominated communities should not be initiated until the impacts on these game birds are considered.

Alkali sagebrush sites normally support a diverse understory of grasses and herbs. Sites that have been well managed support Idaho fescue, bluebunch wheatgrass, and Letterman needlegrass. It is not uncommon to encounter mixed communities of alkali sagebrush and antelope bitterbrush.

Areas that are heavily grazed usually lack a satisfactory understory of herbs. In these situations, the density of alkali sagebrush increases significantly. Once this occurs, the native herbs are slow to reestablish. Alkali sagebrush-dominated areas in south-central Idaho have been rested from grazing for over 30 years without much community change or improvement.

Removal of Competition

Improvement of alkali sagebrush ranges can be attained by artificial measures. Grasses and broadleaf herbs can be interseeded into clearings created by burning or disking. Alkali sagebrush can also be effectively controlled with chaining, disking, or spraying; however, chaining is the most effective treatment (Monsen and Shaw 1986). Complete removal of the existing shrubs is neither necessary nor desirable. A reduction of 25 to 50 percent in density of the shrubs is sufficient to allow seedling establishment of additional species. Alkali sagebrush stands exposed to burning or chaining recover quickly, often within 3 to 5 years. Consequently, it is essential to immediately seed after these treatments. However, thinning by chaining, burning, spraying, or disking can result in a rapid improvement of understory herbs (Monsen and Shaw 1986). Following burning or chaining, alkali sagebrush plants recover quickly by sprouting. This shrub normally produces a good seed crop each year. Clearing techniques, including chaining or disking, usually improve the seedbed and result in rapid recovery of new shrub seedlings.

Burning of alkali sagebrush stands is usually not difficult if conducted at the right season. Sites dominated by this shrub may lack a dense understory. If so, fires may burn erratically leaving a mosaic pattern. If an understory does exist, seeding following burning is not required. Most associated plants recover following burning and chaining.

Alkali sagebrush begins growth much earlier than either basin big sagebrush or low sagebrush. Plants normally flower a month before low sagebrush. Consequently, if herbicides are used to control alkali sagebrush, treatment should be completed much earlier than would be scheduled for basin big sagebrush.

Planting Season

Fall seeding is normally recommended, although some sites receive sufficient moisture to support early spring plantings.

Planting Procedures

Aerial seeding followed by anchor chaining is a satisfactory means of planting. Sites that are burned may be aerially seeded or drill seeded. Areas that have been burned may be drill seeded using a rangeland drill or similar type drill that is capable of operating on sites supporting considerable standing litter and debris.

Rocky outcrops often occur amid alkali sagebrush communities and can restrict the methods used to seed an area. Anchor chaining is normally the most practical and effective method of seeding rocky sites.

Adapted Species and Mixtures

Species recommended for rehabilitating alkali sagebrush sites are similar to those used for basin big sagebrush (table 18) or low sagebrush sites (table 22). Idaho fescue, bluebunch wheatgrass, and Letterman's needlegrass are also adapted to these sites.

Alkali sagebrush plants spread well by natural seeding. Attempts to improve a site by seeding understory herbs normally results in the overall recovery of the shrub. This shrub is not difficult to establish by direct seeding. Seedlings are quite competitive and can be established in combination with some herbs. Seeds are relatively large compared with those of most other sagebrushes, and are easily cleaned and planted with most equipment.

Budsage

Budsage is locally important in the Intermountain West (fig. 31). This species is found on dry, often saline,

Figure 31—Salt desert shrub communities support an important group of woody species including bud sagebrush, shadscale, winterfat, spiny hopsage, and fourwing saltbush. Maintaining these communities and preventing weed invasion is essential because these sites are difficult to restore.

plains and hills. It is well adapted to xeric conditions and is often associated with shadscale saltbush, black greasewood, and other salt-tolerant shrubs (fig. 31). In some places it can be found growing in association with black sagebrush and basin big sagebrush. Budsage sites are generally not recommended for rehabilitation because of arid conditions that prevail. If a site is disturbed, few species can be recommended for seeding. Attempts made to seed this species have not been very successful because of poor quality seed and harsh planting conditions. Seeds are small and seedlings do not grow rapidly. Stands of bud sagebrush should be protected and carefully managed to avoid loss.

Salt Desert Shrub Communities

Salt desert shrub communities occur throughout the Western United States, Canada, and Mexico. Chenopod shrubs dominate many of these communities, providing a diverse group of species (McArthur and Sanderson 1984) (fig. 31). Some species that occupy the salt desert shrublands are encountered in both cold desert and warm desert communities described by Shreve (1942). Various species of sagebrush exist in association with certain salt desert communities, but they normally grow at higher elevations and on better drained soils. Generally, salt desert species occur on heavy textured lowland soils containing some salt in the subsoil. Not all sites have a developed carbonate layer, and salt content may vary throughout the soil profile.

Salt desert communities occupy harsh and somewhat unique sites, including waste places, temperate salt marshes, deserts, and semidesert regions (Goodall 1982; McArthur and Sanderson 1984). Salt desert shrublands occur as extensive rangelands occupying broad valleys throughout southeastern Oregon and southern Idaho, southward through the Great Basin into southern California and western Arizona (Oosting 1956). Precipitation is low, normally less than 10 inches (250 mm), and erratic. Locally, physical differences in topography, soils, and aspect produce distinct patterns in the distribution of different plant communities. It is important to recognize that quite different vegetative associations occur throughout the salt desert shrublands, reflecting the effects of soil conditions, water accumulation, evaporation, and salt deposition. Accumulation of salts create zonal patterns of vegetation around playa lakes and areas where flooding or runoff may occur (Billings 1980). Where salt content is excessive, samphire glasswort and iodine bush dominate. Shadscale, greasewood, gray molly, winterfat, blackbrush, Nevada ephedra, and spiny hopsage exist on sites with less salt.

Differences in site conditions must be considered in any vegetative improvement projects. Salt desert shrublands may be difficult sites to restore or revegetate. Seasonal precipitation is not only low but very erratic, and planting success is closely regulated by availability of soil moisture in the spring and early summer. Restoration or revegetation measures must be developed to properly treat different communities and site conditions.

It is important that rehabilitation procedures selected apply to the specific plant association being treated. To date, disturbances within the salt desert shrublands have generally been seeded with crested wheatgrass, desert wheatgrass, Siberian wheatgrass, Russian wildrye, Great Basin wildrye, and bottlebrush squirreltail (Plummer and others 1968). Although attempts have been made to reestablish native shrubs and associated herbs, erratic success has resulted. Most revegetation projects have relied on the use of grasses, using species capable of developing uniform stands under adverse establishment conditions. Although native shrubs have evolved to populate these sites, natural and artificial seedings generally do not provide reliable seedling establishment each year. Recent studies with some semiarid shrubs demonstrate that by selecting adapted ecotypes (Meyer and Monsen 1990; Shaw and Haferkamp 1990), proper seedbed preparation (Stevens and others 1986), and aggressive weed control (Monsen and Pellant 1989), a number of species can be seeded with good success. Recent development of native and introduced ecotypes has also provided additional plant materials for seeding salt desert disturbances (McArthur and others 1982; Stevens and McArthur 1990; Stevens and others 1977; Welch and McArthur 1986).

Shadscale-Saltbush

Shadscale-saltbush communities occur over 50,000 square miles (129,00 km^2) ranging from Canada to Mexico, and from 1,500 to 7,000 ft (450 to 2,100 m) in elevation (Hanson 1962). These species dominate broad valley bottoms and adjacent foothills where they merge with big sagebrush and juniper-pinyon. Shadscale is the most common and abundant shrub of the salt desert shrubland (Blaisdell and Holmgren 1984). Shadscale is found in heavy soils with soluble salts ranging from 160 to 3,000 ppm and pH of 7.4 to 10.3 (Hanson 1962). On highly alkaline soils, shadscale occurs in nearly pure stands. Annual precipitation on these areas is generally less than 10 inches (250 mm), with many areas receiving from 3 to 8 inches (80 to 200 mm). Both pure and mixed stands of shadscale occur in the Colorado River drainage in western Utah (fig. 31), and throughout Nevada, eastern Oregon, southern Idaho, and southwestern Wyoming. Community composition may be predominantly shadscale or other saltbush species. Numerous shadscale communities have been described by various investigators (Hutchings and Stewart 1953; Stewart and others 1940; Wood 1966). West and Ibrahim (1968) described four habitat types with distinctly different floristic composition and soil features in southeastern Utah. Shadscale exists as nearly pure stands with large open spaces among plants in valley bottoms. On higher slopes it exists in fairly complex mixtures with other low shrubs and some grasses (Hutchings and Stewart 1953).

Shadscale plants can be completely killed by fires. Vest (1962) reported that shadscale is more sensitive to extended periods of drought than any other of the salt desert shrubs. Extensive stands have also been killed by periods of heavy precipitation and seasonal periods of flooding or soil saturation.

Although heavy or improper seasons of grazing can diminish stands of shadscale, this species is reported to replace palatable shrubs and grasses where grazing has been excessive (Blaisdell 1958).

Most successful range improvement projects in shadscale-saltbush communities have occurred where annual precipitation exceeds 8 inches (200 mm) (Bleak and others 1965; Plummer 1966; Plummer and others 1968). Techniques and plant materials are limited at the present time to ensure consistent, acceptable, long-term success in areas that receive less than 8 inches (200 mm) of precipitation. The presence of juniper or pinyon in a shadscale community indicates that adequate precipitation is generally available to successfully seed the area.

Normally, areas with Gardner or mat saltbush are too dry or saline for successful seeding. However, treatments may be successful in shadscale or mixed shrub communities, which include fourwing saltbush, winterfat, black greasewood, blackbrush, basin big sagebrush, spiny hopsage, horsebrush, and juniper. Bud sage is often codominant or subdominant with shadscale. Disturbed shadscale areas are usually occupied by Russian thistle, cheatgrass (fig. 32), and halogeton. It is important to revegetate these disturbances to reduce erosion and to check the increase of undesirable annuals, poisonous plants, and noxious weeds, and to control wildfires.

Natural recovery of large stands of shadscale has frequently occurred following fires. In some situations, plants appeared 3 to 4 years after disturbance, indicating seeds survive in the soil and may remain viable for a number of years. Shadscale seedlings are able to compete with some herbaceous competition, but recent trials indicate seedlings are susceptible to competition.

Figure 32—Shadscale communities are often invaded by cheatgrass following wildfires, creating serious problems in restoration of this native shrub.

Removal of Competition

Disturbance of the perennial plant cover may threaten soil stability (Bleak and others 1965; Plummer 1966). Typically, perennial plant density is low with major openings existing between individual shrubs. Annual and perennial weeds have often invaded disturbances and sites where plant density is low or where shrubs have been burned by wildfires. Weeds have also established on sites where shrub density has not been diminished. Weed invasion and persistence fluctuates annually, creating the potential for large and disruptive fires.

Where cheatgrass brome (fig. 32) has become established and gained control, removal of weedy competition should follow the same general procedure as outlined in guides for seeding into cheatgrass, red brome, and medusahead types. Likewise, where halogeton and Russian thistle have established, the treatments described in this chapter for seeding into low annual weed communities would be appropriate.

If a reduction in shrub density is desired, this can be accomplished by anchor chaining, shallow plowing, and disking, or with disk-chains, pipe harrows, and scalpers of various types (McArthur and others 1978b). Shrubs within this type are generally very brittle and easily removed. Destruction of shrub cover **should not be done** unless specific objectives would justify conversion to a different community.

Control of annual weeds is a major problem throughout most of the salt desert communities. Annual weeds have invaded many sites and restrict natural recruitment of native species. The annual weeds also flourish following a wildfire or other disturbance. Once in place, the weeds dominate and prevent establishment of artificial seedings. Cheatgrass is highly competitive and produces abundant seed crops, providing a seedbank that persists for more than one season. Any attempt to plant these disturbances requires removal of existing plants and elimination of the seedbank. Single treatments, including mechanical tillage or application of herbicides, are not always successful.

Planting Season

If soils are not frozen, midwinter seeding is recommended. Disking, drill seeding, or other disturbances when soils are wet can cause surface crusting, which prevents emergence of most seedlings. Generally, low-elevation sites can be seeded from late fall until early spring. Spring planting should be completed before winter moisture has diminished and soil surfaces are dry.

Planting Procedures

Unless weeds are present, drill seeding can usually be accomplished with little reduction of existing cover (Plummer 1966). Where the objective is to improve ground cover and increase production by leaving perennial vegetation and adding some additional species, direct seeding with the rangeland drill is especially successful. If shrubs are seeded, they should be planted in alternate rows separated from seeded grasses. Good results can be obtained when the drill makes wide furrows, permitting the maximum amount of precipitation to be collected in the depressions. However, a drill can often compact the furrow, which may interfere with seedling emergence. The use of scalpers, pitters, and land imprinters to create depressions where moisture will collect, combined with broadcast seeding, has resulted in improved establishment (Ferguson and Frischknecht 1981; Fisser and others 1974; Giunta and others 1975; Hull 1963b; Knudson 1977; Lavin and others 1981; Stevens 1980b, 1981; Wein and West 1971; Wight and White 1974). Furrows and pits are useful for collecting and conserving moisture on heavy soils with slow infiltration rates (Bleak and others 1965). Anchor chains and pipe harrows are not recommended for seed coverage where existing stands of shadscale occur, as the brittle shrubs will be seriously damaged. If shadscale shrubs have been destroyed by burning or other disturbances, chaining or harrowing can be used to cover broadcast seeds.

Adapted Species and Mixtures

Species that are adapted to the shadscale type are listed in table 25 (Bleak and others 1965; Ferguson and Frischknecht 1981; McArthur and others 1978b; McKell and VanEpps 1981; Monsen and Plummer 1978; Plummer 1966, 1977; Plummer and others 1968).

Seeding shadscale onto sites where wildfires or other disturbances have removed the shrub has frequently been attempted. Erratic stands have often developed from direct seedings, yet new shadscale plants appear over a number of years, eventually producing good stands. If a seedbank has been developed in the soil, natural recovery of shadscale has occurred following burns at a number of locations. Natural seedlings compete well with other species, and mature individuals develop in 3 to 5 years. Heavy and continuous grazing has weakened and killed existing plants. Weakened plants may fail to produce normal seed crops, slowing the recovery process. Natural recovery following extended periods of destructive grazing can be slow or may not occur. Weed invasion can also prevent shrub recruitment.

Natural recovery of shadscale can be expected on recent burns if weeds are absent and a seedbank has accumulated in the soil. Seeding shadscale or other species may not be required. If weed invasion is apparent, planting is usually necessary to ensure shrub recovery. Seeding introduced perennial grasses following wildfires is often recommended to stabilize soils and control weed invasion. However, plantings of crested wheatgrass on upland foothills and plains has prevented shadscale recovery. This practice should be avoided if conditions suggest shadscale is capable of recovery.

Seed lots of shadscale obtained from native collections often have less than 40 percent viability. A large percentage of the seed fails to develop, and many empty utricles are formed. In addition, the hard utricle prevents germination. Once the utricle is fractured or opened, seeds germinate rapidly. Procedures have not been developed to open the utricle and permit uniform germination. Seed from various native stands germinate more freely than others, and collections from north-central Nevada, southern Idaho, and eastern Utah have germinated better than collections from most other areas. This demonstrates the practicality of improving stand establishment through controlled breeding and selection.

Plantings of forage kochia (fig. 30), an introduced half-shrub, have demonstrated adaptability to and can establish in the shadscale type (McArthur and others 1990a). This plant is competitive as a seedling (Monsen and Turnipseed 1990; Stevens and McArthur 1990) and has established very well when seeded amid sites occupied by annual weeds. This introduced shrub provides useful herbage, competes well with annuals, and has significantly reduced the incident of wildfires where cheatgrass has invaded. Converting shadscale communities to forage kochia is not advised, but existing disturbances currently occupied by cheatgrass

(McArthur and others 1990a), Russian thistle, or halogeton (Stevens and McArthur 1990) can be converted to a more manageable and productive cover with forage kochia. In addition, this shrub can be used to control the further spread of weeds and restrict further decline in site productivity and erosion. Forage kochia is able to outcompete summer annuals because of its early spring growth, rapid germination, and growth of numerous small seedlings.

Black Greasewood

Black greasewood occupies considerable acreages on salty valley bottoms. This plant also occurs on salt-bearing shale outcrops in canyons and on foothills (fig. 33). Sites vary in respect to soil texture and availability of ground water. Some areas are wet with high water tables, and others are dry with well-drained soils.

Black greasewood occurs in pure or mixed stands. The plant contains oxalic acid and can cause poisoning, particularly when grazed in the spring (USDA 1968). Livestock can safely consume moderate amounts of greasewood when it is eaten in conjunction with other forage. Black greasewood is not known to be poisonous to game animals and, in fact, has some forage value. However, forage production and ground cover can often be increased by establishing additional species within greasewood stands.

Removal of Competition

Some stands of black greasewood have been converted to herbaceous species for livestock pastures or cultivated fields. Many black greasewood sites can be relatively productive areas, and increases in forage production can economically support development costs. Introduced perennial grasses are commonly seeded to provide spring/fall pastures.

Many black greasewood sites have been invaded by cheatgrass and summer annuals. These sites frequently burn, which decreases shrub density and diminishes understory herbs. Where control of annual weeds and fire suppression is a major concern, planting introduced perennial grasses has been justified. Reestablishment of the native understory is attainable in many situations, although seed availability currently limits restoration programs.

Many black greasewood sites are important for maintaining wildlife habitat and soil protection. Streams and riparian zones often align this plant type. Consequently, restoration measures are often required to restore the understory vegetation. Complete elimination of all shrubs is not necessary or advisable. Shrub density should only be decreased to facilitate planting understory species. Converting this woody community to other shrub species is not advisable in most situations.

Figure 33—Black greasewood sites often exist with a limited cover of understory herbs, and are subject to invasion by annual weeds, including cheatgrass.

Black greasewood is not very competitive with seeded herbs. However, some thinning of the shrubs is usually required to reduce competition and facilitate seeding. A heavy offset disk, disk-chain (fig. 34), pipe harrows, brushland plow, or similar equipment can be used to remove top growth and eliminate plants. Pipe harrowing, chaining, mowing, beating, or use of the land imprinter effectively reduce top growth, and leave litter on the ground as mulch. These treatments do not kill or remove all greasewood plants. Top growth of greasewood can be removed with fire when

Figure 34—Mechanical tillage is often used to reduce competition from black greasewood and establish understory species.

there is sufficient fuel to carry a fire. Greasewood can be satisfactorily controlled with 2,4-D (Cluff and others 1983b; Roundy and others 1983).

Soil crusting in the black greasewood type is a major problem. Mulching helps to reduce crusting and provides improved seedling emergence and establishment. Every effort should be made to leave mulch on the soil surface.

Planting Season

If the surface is dry or moist, February is the preferred time for planting because the soil crusts less following tillage or seeding than in late fall or early winter. However, planting from late fall (mid-October) through January can produce good stands. Seeding in March and early April is normally successful if soils are dry and firm. Spring tillage or seeding dries the soil surface and prevents seed germination and seedling establishment.

Planting Procedures

Broadcasting by aerial or hand-seeding techniques, followed by anchor chaining or pipe harrowing, are suitable and practical procedures. Anchor chaining and pipe harrowing after seeding are usually preferred treatments, as litter is scattered over the soil surface. Drilling or imprint seeding can be used unless numerous woody stems are left on the soil surface. Surface planting using a Brillon seeder often prevents surface compaction and crusting, and produces adequate stands.

Adapted Species and Mixtures

Even though few species (table 26) are adapted to the akaline soils of greasewood communities, good opportunities exist for improving forage production, ground cover, and soil stabilization. Bottlebrush squirreltail, western wheatgrass, and Great Basin wildrye are the principal native grasses adapted to this shrub type. “Fairway” and “Ephraim” crested wheatgrass, and Russian wildrye are all well-adapted introductions and useful forage species. Russian wildrye provides excellent forage during late spring and summer periods and helps control reinvasion of weeds. Although greasewood is not eliminated by the presence of seeded herbs, shrub density can be controlled by the presence of understory species and seasonal grazing practices.

Winterfat

Winterfat occurs in the pinyon-juniper, basin big sagebrush, Wyoming big sagebrush, and salt desert communities and in pure stands. It occurs from Canada to the Great Basin and Rocky Mountain States to California, Mexico, and eastward to Texas and North Dakota (Blaisdell and Holmgren 1984). This shrub is abundant on low foothill ranges, dry valley bottoms, and plains, growing on subalkaline soils (Gates and others 1956; Shantz and Piemeisel 1940). It is not uncommon to find this shrub in nearly pure stands over extensive areas (Branson and others 1967).

Winterfat may frequently dominate upland or foothill sites, normally growing with some understory grasses in these situations. Blaisdell and Holmgren (1984) conclude that winterfat appears as a dominant species in three major salt desert shrub communities: winterfat-low rabbitbrush, winterfat-low rabbitbrush-grass, and winterfat-grass. It also exists as almost pure stands or intermixed with shadscale on alluvial soils on broad valley bottoms and lower valley slopes. Indian ricegrass, galleta, and black sagebrush are frequently associated with winterfat. Throughout the salt desert communities, winterfat is second only to shadscale in importance.

Salt desert shrub communities occur on soils with extreme salinity, alkalinity, or both (West 1982) where precipitation is mostly under 6 inches (15 cm). This combination of factors creates climatically and physiologically dry soils (Billings 1945). Winterfat differs from some other salt desert shrubs in that it grows on soils relatively low in salt and sodium (Naphan 1966). Although it may occur on coarser textured soils with low water holding capacity, it also occupies fertile, moist sites.

Winterfat is highly palatable and nutritious. Its tolerance to winter grazing is remarkable. Even so, persistent and continuous overgrazing, especially in spring and summer, has reduced its density on many ranges, and in places, has completely eliminated stands. Low rabbitbrush, snakeweed, shadscale saltbush, and such annuals as Russian thistle, cheatgrass, red brome, and halogeton now occupy extensive areas that were formerly dominated by winterfat (Stevens and others 1977a). Spring and summer grazing essentially eliminates seed production.

Winterfat can survive through extensive moisture shortage. It has an extensively fibrous and deep taproot. During prolonged drought, growth is negligible and plants may even appear to be dead. However, the woody crowns often survive. With moisture, it has a remarkable ability to recover. The more successful range improvement projects have occurred where annual precipitation is in excess of 8 inches (200 mm).

Removal of Competition

Winterfat has been eliminated by grazing or other disturbances and replaced by cheatgrass, red brome, Russian thistle, and halogeton. These sites frequently burn and further reduce shrub density and understory herbs. Techniques described in the chapter for treating these annual communities should be employed. Where control of annual weeds and fire suppression is a major concern, planting of introduced perennial grasses has been justified. However, reestablishment of natives can occur in many situations.

When winterfat stands have been invaded by or replaced with low rabbitbrush, rubber rabbitbrush, and snakeweed, the density of these species must be reduced to facilitate seeding. A Dixie chain or pipe harrow can effectively reduce competition from these species and prepare a favorable seedbed. Plowing or disking will kill and eliminate winterfat plants that may be present. Working the soil when it is damp or wet will cause soil crusting and prevent seedling emergence.

Planting Season

The most ideal time for seeding winterfat and associated species is in the fall before the soil freezes. Where summer storms occur, particularly in the southwest, seeding prior to these storms has resulted in good success.

Planting Procedures

A major factor in successful seeding is seed coverage. Winterfat seeds are encircled by two cottony, hairy bracts. Seed should not be removed from these bracts. Winterfat seed does best when it is surface seeded. The bracts, when embedded in soil, help to anchor the seed to the soil and provide for successful germination and seedling establishment. Aerial broadcasting onto disturbed sites or with slight disturbance with chaining or pipe harrowing can be successful. Drill seeding can be successful when a picker wheel or chaffy seed dispenser is incorporated in the seedbox. Seed should be deposited behind the furrow openers and in front of the drag chain. Winterfat should be seeded in alternate rows separated from grasses. The use of scalpers, pitters, and land imprinters that form depressions for moisture collection has resulted in good seedings.

Adapted Species and Mixtures

Ecotypic variations exist in winterfat. Generally, low-growing, drought-tolerant forms are found in valley bottoms with heavier soils. Tall-growing, more woody types occur on more upland sites with higher precipitation, generally associated with ponderosa pine and pinyon-juniper (Stevens and others 1977a). When seeding winterfat, it is imperative that adaptive ecotypes be selected and seeded.

Species adapted to seeding onto winterfat vary with climatic and edaphic conditions. Winterfat most often occurs in association with other species. Species recommended for seeding are listed by associated species in table 13 (mountain brush-ponderosa pine); tables 14 to 16 (juniper-pinyon); table 17 (fourwing saltbush); table 18 (basin big sagebrush); table 20 (Wyoming big sagebrush); table 25 (shadscale saltbush); and table 28 (cheatgrass, red brome, and medusahead).

Fourwing Saltbush

Fourwing saltbush is widely distributed over the west in foothills and desert ranges. It reaches well into the Great Plains on the east and nearly to the Pacific Ocean on the west, from Canada on the north and south into Mexico. It occurs from below sea level in the Mojave Desert to over 8,000 ft (3,280 m). It is found in pure stands and in scattered stands associated with shadscale saltbush, Gardner saltbush, juniper-pinyon, basin big sagebrush, and Wyoming big sagebrush.

Over its wide range of distribution, fourwing saltbush exhibits extensive variations in growth form, seed production, germination, establishment, drought tolerance, cold tolerance, grazing, palatability to livestock, and adaptability to soil type.

Removal of Competition

Fourwing saltbush has been eliminated or reduced in density on many sites by overgrazing and/or fire. Grazing has also depleted or eliminated associated understory species. Cheatgrass brome, red brome, and spring and summer annuals have invaded and occupy the understory of many fourwing saltbush areas.

The objective of most seedings has been to establish perennial understory and retain and increase fourwing saltbush density. This requires removal of grazing pressure, reduction of competitive annuals, and seeding of adapted understory species and fourwing saltbush. Treatment used to reduce competition will vary with density and composition of existing understory communites and associated perennial species. Techniques are described in the chapter for treating the various community conditions. These are listed by major species types: juniper-pinyon, basin big sagebrush, Wyoming big sagebrush, annual weedy grasses, and lowland annuals.

Planting Season

Late fall seedings are most often recommended; however, in the Southwest, when summer storms occur, seeding prior to these storms is generally recommended.

Planting Procedures

Fourwing saltbush seed requires that the seed be planted at least 1/4 inch (6 mm) deep, preferably in a firm seedbed. When drill seeding, this species does best seeded separately from grasses. Broadcast seeding will accomplish this, but provisions must be made to ensure the seed is covered. Seeding through a Hansen seed dribbler or thimble seeder mounted on a crawler tractor can result in superior establishment.

Adapted Species and Mixtures

Ecotypic variations in fourwing saltbush require that only seed sources adapted to the planting site be seeded. Sources from warmer, more southern climates cannot be moved to cooler, northern areas. Likewise, lower elevation sources cannot be moved to higher elevations. When this occurs, few seedlings generally survive.

A large majority of the fourwing saltbush seed that is produced and harvested comes from Texas, New Mexico, Arizona, southern Utah, Nevada, and California. These ecotypes should not be seeded in northern Colorado, Utah and Nevada, southern Idaho, Wyoming, or eastern Oregon. Species adapted to fourwing saltbush sites are listed by associated species. Table 17 lists species adapted to areas where fourwing saltbush occurs in assocation with juniper-pinyon, basin big sagebrush, and Wyoming big sagebrush; table 25, shadscale saltbush; table 27, blackbrush; and table 28, areas where cheatgrass, red brome, and medusahead dominate.

Blackbrush Communities

Blackbrush grows on fairly large tracts in the Colorado river drainage, Arizona, and New Mexico. In some locations, it occurs with few associated species (Bowns and West 1976). In some areas, spreading creosotebush, desert peachbrush, silver buffaloberry, Utah serviceberry, basin big sagebrush, and various cacti, yuccas, and Utah juniper grow in association with blackbrush. Annual precipitation ranges from 6 to 16 inches (150 and 400 mm). Seedings are usually not successful where annual precipitation averages less than 9 inches (220 mm). Blackbrush is a valuable shrub for livestock (fig. 35) and deer. It should not be disturbed, nor should attempts be made to convert it to another vegetative type.

Cheatgrass and red brome grow under the crowns of blackbrush plants. In wet years, these annuals may be so abundant that once they dry out, fires may burn across large acreages. Since blackbrush is not fire tolerant, these burned areas automatically become annual cheatgrass and red brome ranges and, therefore, special problem areas. Unless such disturbances are seeded, the annual grasses may persist for many years.

Removal of Competition

Control of plant competition is required only in areas where red brome and cheatgrass brome have invaded. Seeding is recommended following wildfires as a means of controlling the spread of the annual grasses. Once annuals have gained control, these plants must be significantly reduced in density to allow shrubs and native herbs to recover. Because the chief aim in improving blackbrush areas is the retention of blackbrush, and because blackbrush is not tolerant of fire, burning to control the annual grasses should be avoided. Disking or spraying with ground equipment can be used to treat specific sites, while avoiding scattered shrubs.

Planting Season

Storm patterns favor late June to early July seedings, just prior to summer storms (Jordon 1981, 1983). Fall and winter seedings can, however, be successful. Work can continue from November through February. Pendleton and others (1995) reported that natural emergence of blackbrush seedlings in southern Utah occurred between December and February. In addition, these authors found that blackbrush seeds require 4 to 6 months of stratification to break seed dormancy. Consequently, fall seeding is required to assure stratification and emergence of blackbrush seedlings. Occasional low temperatures seldom delay

Figure 35—Domestic livestock often graze blackbrush sites, but these areas are also important to big game animals.

ground treatment or planting for more than a few days. Rodents gather and feed on planted seeds and graze young sprouts, causing considerable damage and loss of a high percent of all seeds and seedlings (Longland 1994). As a precaution against undue loss of seeds to small rodents, plantings may be delayed until December when rodents are less active.

Planting Procedures

Probably the best method of seeding herbaceous species is aerial broadcasting followed by anchor chaining or pipe harrowing. This method is particularly applicable on rocky areas, where it is difficult to drill. Chaining can be detrimental to blackbrush plants and should not be used where these shrubs are present. In rock-free areas, where the rangeland drill or other disk-type drills can be used, good stands can be attained with these machines. Planting seeds of blackbrush in alternate rows with herbaceous species is recommended. Shrub seeds can also be sown using a seed dribbler or thimble seeder mounted on crawler tractors.

Adapted Species and Mixtures

Because temperatures are much warmer in this type than in more northern shrublands, a mixture of adapted species that can tolerate heat is required (table 27). Seed mixtures may be modified according to difference in climate and availability of seed. Seed of adapted native grasses is currently quite limited, and is not always sufficient for planting large acreages. Indian ricegrass and squirreltail are adapted native species for which seed is most available. In areas that have a fair amount of summer rainfall, sand dropseed can be planted.

Pendleton and others (1995) found that natural recruitment and artificial seedings are quite successful during years when sites receive adequate spring and winter moisture. Environmentally accepted methods are not currently available to control seed depredation by rodents, yet planting few seeds per spot and planting in discontinuous rows or furrows decrease seed gathering. In addition, planting open areas or sites free of cover tends to enhance seedling establishment, as rodents seek some protective cover. Seeding during periods when rodent populations are low can increase seedling survival.

Seeds of blackbrush are limited and expensive, which restricts their use on large-scale projects. Big sagebrush, desert bitterbrush, Apache plume, fourwing saltbush, and winterfat can be included in seedings in the blackbrush type where these species naturally occur.

Cheatgrass Brome, Red Brome, and Medusahead Communities

Cheatgrass brome, red brome, and medusahead dominate large areas of depleted foothill and valley rangelands (Mack 1981; Piemeisel 1938; Stewart and Young 1939; Young and Evans 1970, 1971; Young and others 1968). These grasses germinate in fall or spring and demonstrate phenomenal ability to utilize space and soil moisture to the exclusion of perennial grass and herb seedlings (Evans 1961; Hull and Hansen 1974; Robertson and Pearse 1945). The competitive influence exerted by these plants enables them to dominate vast areas for many years.

Piemeisel (1951) reported that sites in southern Idaho infested with cheatgrass and other annuals continued to support a weedy cover for over 50 years, even when protected from grazing. Natural reestablishment of desirable perennials occurs slowly on sites where annual weeds exist. On most sites, particularly arid rangelands where native seedbanks have been depleted, changes in plant composition will not occur unless aided by revegetation (Hull and Holmgren 1964; Monsen and Kitchen 1994; Monsen and McArthur 1985; Young 1983). Annual grasses, particularly cheatgrass brome, are extremely difficult to control, but must be significantly reduced in density prior to seeding other species.

Cheatgrass (fig. 36) now dominates former brush and tree types in the following approximate order of decreasing importance: big sagebrush (fig. 28, 30), juniper-pinyon (fig. 20), blackbrush, shadscale saltbush (fig. 32), and mountain brush (Monsen and McArthur 1985). Cheatgrass has recently invaded

Figure 36—Cheatgrass now dominates extensive areas previously occupied by Wyoming big sagebrush, increasing wildfire and fire suppression problems throughout the West.

southern desert shrub regions. Major areas of concern, where restoration is needed, are within the blackbrush and associated shrub types where red brome may also occur (fig. 37). Both annual grasses spread quickly and gain control soon after the perennial cover is disturbed. Wherever red brome dominates, it should be treated in much the same way as cheatgrass brome.

Different methods are required to revegetate sites infested with annual grasses than would be required if these annuals were not present. Consequently, the annual weeds have been considered as a separate major vegetative type.

Both cheatgrass and red brome provide a short grazing season for livestock and game animals. Forage production varies greatly between wet and dry years (Klemmedson and Smith 1964; Stewart and Young 1939). Seeds and new shoots provide valuable sustenance for chuckars, partridge, Gambel quail, and mourning doves. Both grasses are grazed in spring and fall by livestock and big game.

As with other annuals, production of cheatgrass, red brome, and medusahead is often negligible in dry years. All three species are serious fire hazards, particularly in wet years. Areas dominated by these two bromes and medusahead frequently burn and gradually extend their areas of dominance (Pickford 1932; Wright 1985; Wright and Klemmedson 1965; Young and Evans 1978b). Because they become a fire hazard in wet years, produce little forage in dry years, and prevent reestablishment of native species, attempts should be made to replace these annuals with adapted perennials. These two bromes can persist as minor components in perennial stands (fig. 32) (Astroth and Frischknecht 1984; Barney and Frischknecht 1974). They are, however, able to take advantage of any reduction or weakness in the perennial stand. For this reason, any major increase in establishment of either of these grasses immediately indicates damaging use, or at least a weakening of the perennials.

Medusahead has invaded many western rangelands (Major and others 1960), particularly low sagebrush sites (Young and Evans 1971). This annual grass exhibits characteristics similar to those of cheatgrass, and usually occurs in similar climatic zones. Where both occur together, medusahead has sometimes been able to replace cheatgrass. It has been able to advance into clay or heavy textured soils, particularly on sites lacking a competitive plant cover (Young and Evans 1971). Well-drained or coarse-textured soils are usually not inhabited by this grass. Plants normally occur in closed, dense patches. Medusahead (fig. 38) is a highly competitive winter annual. An abundance of seed and litter builds on the soil surface. This creates serious fire management problems, as highly flammable foliage is present every year (Bunting 1985). Medusahead seeds are not consumed by ground fires as readily as cheatgrass seeds, and intense and slow-burning fires are required to destroy accumulated seeds. Medusahead is a poor forage plant. Sites dominated by this weedy annual must be treated in a manner similar to cheatgrass sites, using competitive perennials. Once a perennial cover is established, the grass can be controlled, but not eliminated.

Cheatgrass, medusahead, and red brome possess a number of traits that must be recognized before restoration practices are initiated. Cheatgrass has spread to occupy a wide array of habitats throughout the Western United States (Mack 1981) and has quickly developed habitat-adapted populations. Although red

Figure 37—Red brome is a serious invader in more arid environments than those occupied by cheatgrass or other annual weeds. It is as competitive as cheatgrass and has created similar fire problems.

Figure 38—Medusahead is an annual grass that is rapidly expanding its area of occupation, and is now found on sites once dominated by cheatgrass.

brome and medusahead occupy less diverse habitats, populations of all three species are well suited to the variety of sites they occupy. Plants of all species are able to respond to differences in annual climatic conditions, and to mature and produce some seeds each year, even during years of relatively high stress (Rice and Mack 1991). Generally, plants produce an abundant seed crop. Seed germination patterns vary among populations of cheatgrass, although a high percent of seeds will germinate if moisture is available (Hull and Hansen 1974). Hulbert (1955) reported that recently harvested seeds of cheatgrass from eastern Washington and southern Idaho were conditionally dormant at summer incubation temperatures, but became nondormant with autumn temperatures. Young and others (1969a) reported that freshly harvested seed from western Nevada were nondormant. Beckstead and others (1993) concluded that high summer dormancy has evolved with populations growing in climates with plentiful summer rain, as opposed to nondormant populations occurring in areas with less chance of premature germination from summer rains.

Most studies demonstrate that seed of cheatgrass fully afterripens and germinates in response to fall rains. Seeds that are partially covered with litter or soil readily germinate and become established. Medusahead and red brome seeds also fall germinate at similar periods as reported for cheatgrass. Seeds that do not fall germinate are left on the soil surface and will carryover until the following spring (Evans and Young 1972b; Wicks and others 1971; Young and others 1969a). Regular spring germination is common in many regions with little carryover beyond this date (Mack and Pyke 1983). Young and Evans (1975) found that seeds from western Nevada were induced into secondary dormancy under winter conditions, which delayed germination, resulting in substantial carryover until the second year. Hull and Hansen (1974) reported similar results from seeds of northern Utah. Consequently, a sufficient reservoir, or seedbank remained from year to year (Wright 1985).

Plants of cheatgrass, red brome, and medusahead are highly competitive. The number of seedlings germinating and becoming established varies from year to year. Regardless of the number of seedlings to appear, the plants can extract all available soil moisture throughout their rooting depth. One large plant may be as competitive as a large number of small, individual plants (Monsen and McArthur 1985). Thus, reducing the density of seedlings may not significantly reduce the overall effect on soil moisture.

Cheatgrass, red brome, and medusahead are winter annuals. Seeds may germinate either in fall or spring months, depending on weather conditions (Bunting 1985). Seeds that germinate in the fall produce plants that overwinter and resume growth in the early spring (Young and Evans 1973). Seeds that germinate in the spring do so prior to most seeded or native perennials (Buman and others 1988). In addition, seedling vigor and rate of growth is superior to that of most perennials (Harris 1967); therefore, they provide serious competition to newly developing seedlings of other species. To eliminate or reduce density of these weedy annuals, any treatment must effectively control live plants and both fall- and spring-germinated seeds (Monsen 1994).

Removal of Competition

Burning before seeds shatter is an economical treatment, particularly on rocky rangelands. To be most effective, burning should be done before seeds are dispersed (Hull 1944; Pechanec and Hull 1945). Fires must burn slowly or hot enough to consume seeds left on the soil surface. Most fires destroy only a portion of the seed, particularly medusahead seed. Cheatgrass is often infested with smut (Fisher 1937), which may destroy over 95 percent of the seeds. Scheduling treatments to coincide with smut outbreaks may not always be practical, yet sites that are heavily infested can be treated to good advantage with fire.

Deep furrow drilling or other methods to control these annuals may be required to reduce competition within the seeded area. Plowing, shallow disking, or pipe harrowing young plants before seeds mature can be effective on areas that are accessible to tractor drawn equipment. Except on small tracts, disking or plowing is more costly than burning. Offset disks, disk chains, pipe harrows, and disk harrows are satisfactory implements for removing competition.

Ogg (1994) summarizes the status and potential use of herbicides to control annual grasses. More than 20 herbicides are registered for use. Cheatgrass seedlings are easily killed with herbicides. The main problem is to develop methods that selectively control the weed, but retain desirable plants. Pronamide applied late in the fall will selectively control cheatgrass without damage to slender wheatgrass, tall wheatgrass, western wheatgrass, crested wheatgrass, intermediate wheatgrass, creeping foxtail, or orchardgrass. Currently, labeling permits grazing of treated grasses (Ogg 1994). Evans and others (1967, l983) reported that Paraquat, a contact herbicide, could be applied in the spring followed by spring seeding.

Glyphosate is a foliage-active herbicide that will control cheatgrass when applied at rates as low as 0.3 kg/ha. This herbicide can be applied early in spring when cheatgrass growth is quite active, with little damage to dormant perennials. This herbicide can be effectively used where extensive stands of cheatgrass occur. Glyphosate can also be used to spray strips that are about 3 ft (1 m) wide to allow interseeding of other species. Cheatgrass plants can be fall or spring treated if these plants are actively growing. Spraying and seeding can be done in one operation if care is given to prevent overturning soil from the seeding operation onto sprayed plants.

Drilling seeds in scalped furrows 16 to 32 inches (40 to 60 cm) wide with an interseeder eliminates competition for one or two seasons and allows sufficient time for new seedlings to establish (Monsen 1980a,b; Nyren and others 1980; Stevens 1994). The scalps create good barriers against the spread of wildfires in the same season. On hillsides too steep for machinery, shoveled scalps 3.3 ft^2 (l m^2) remove competition sufficiently for planting shrubs (Giunta and others 1975).

No single method is completely effective for eliminating live plants and seeds of annual grasses. To be most effective, disturbances should be treated before these annuals have gained dominance.

Planting Season

Late fall (mid-October) through February is recommended for seeding. Planting in winter is preferable, especially on sites in the southern desert shrub type. If herbicides are used, planting must be scheduled following recommendations for the specific herbicide. Sites should not be seeded in the summer or early fall months. Burned areas are frequently planted immediately after wildfires regardless of the date of the burn. This is a mistake and should not be done. Early seeding does not reduce the reestablishment of the annual grasses. Seeds planted too early in the season may germinate after a light rainfall, only to succumb as soils quickly dry.

Planting Procedures

Aerial broadcasting, using fixed-wing aircraft or helicopters, followed by anchor chaining or pipe harrowing, can be widely used on both rocky and rock-free sites. This treatment is especially useful on extensive burns. Selected areas referred to as “greenbelts,” or “fuel barriers,” can be planted to help contain range fires. Small areas can be broadcast seeded with a cyclone seeder or by hand, but seeds must be covered afterward. Failure to cover the seed, or planting out of season, will often result in failure of the project. Ash and litter remaining on the soil following burns cannot be expected to adequately cover seeded perennials.

Drilling is successful on plowed, machine-scalped, and burned areas. The rangeland drill, with its disks regulated to make deep, wide furrows, can satisfactorily interseed perennial grasses into cheatgrass stands. The drill can also plant forbs and shrubs on burned cheatgrass ranges. Depth bands should be used on the disks to insure that drills do not plant too deep in loose seedbeds. Both the browse seeder and the rangeland drill can be used to plant browse seeds in alternate rows with herbs. The browse seeder, equipped with wide scalpers, has been the most satisfactory planter used for seeding into cheatgrass. Recently developed drills with multiple seed boxes can plant individual species in separate drill rows. In addition, press wheels have been added that firm the seedbed and improve seedling establishment. It is important that sites are correctly seeded, as annual grass will quickly recover and occupy openings. Seeded plants must compete with the weeds, and should be established in the most optimal sites.

Adapted Species and Mixtures

Cheatgrass sites must be planted with perennials to reduce the reestablishment of the annual grass. If perennials are not established the first season after treatment, cheatgrass will regain dominance. If perennial seedlings survive the first growing season, they will usually attain dominance. The time required for seeded plants to develop a mature stand is dependent on annual climatic conditions. The perennial grasses usually require at least two growing seasons to fully establish. Seeded stands generally reach full maturity 4 to 6 years after planting. Treated areas must be carefully managed to ensure development of the seeded species.

Individual species and mixtures recommended for use in cheatgrass, red brome, and medusahead areas are essentially the same as those recommended for whatever vegetative type existed prior to invasion of the annual weeds. Some species are more competitive and have the potential to establish and spread in annual grass communities (table 28). Included in this group are Sandberg bluegrass, Lewis flax streambank wheatgrass, bottlebrush squirreltail (Stevens 1998), crested wheatgrass, desert wheatgrass, and rubber rabbitbrush (fig. 30). At higher elevations, muttongrass, sheep fescue, intermediate wheatgrass, pubescent wheatgrass, and small burnet compete and increase well with annual grasses. Other species can also compete with the annuals, but may require a longer period to attain maturity and dominate the site. Some examples are western yarrow, Pacific aster, Thurber needlegrass, bluebunch wheatgrass, and needle-and-threadgrass.

Lowland Annual Weed Communities

There are two types of lowland annual weed communities; those that prosper in the spring, and those that develop in the summer (fig. 39).

Figure 39—Interplanting and interseeding shrubs and herbs on sites infested with annual weeds have been successful methods of facilitating establishment and spread of the desired species.

Spring-Growing Annuals

Spring-growing annuals germinate early (February through April), grow rapidly, and flower before summer arrives. Major spring-growing species found on valley and foothill ranges in the Intermountain West are bur buttercup, tumble mustard, blue mustard, tansy mustard, prickly lettuce, fiddleneck, and African mustard. These annuals can be found in pure or mixed stands, mainly in the sagebrush zone. Abandoned farmlands, sheep bedgrounds, feeding areas, and sites where the native vegetation has been severely depleted are typical areas for these weeds. Annual precipitation throughout these areas varies from 9 to 16 inches (230 to 410 mm), and soils are generally basic.

Spring-growing annuals germinate early, sometimes under snow cover. To establish desirable perennials in communities of spring-growing annuals, the following should be done: (1) eliminate the annual seed source, (2) use perennial species that exhibit early germination or that have vigorous seedlings that are able to compete with the established annual seedlings, and (3) seed at the most opportunistic time.

Removal of Competition

Most spring-growing annuals can be controlled by shallow disking using offset disks, pipe harrows, disk chains, or anchor chains. Seeds of most weed species are small and germinate on or near the soil surface. Plowing or deep disking can be used to bury these seeds in areas where elimination of other species is not a concern. Weeds can be removed with broadleaf herbicides applied prior to seed maturation. Most spring-growing annuals are not as competitive as cheatgrass, and desirable species can be established by reducing competition. Some weed-infested sites can improve if livestock grazing is better regulated; however, many sites will require control measures to promote recovery.

Planting Season

Areas dominated by spring-growing annuals generally are best seeded in the fall or winter. Seeds of many perennial species exhibit dormancy, which can be overcome by fall or winter seeding. Fall, winter, and spring seedings generally require reduction or removal of weedy species and their seeds. Control measures should be designed not only to reduce competition, but to conserve soil moisture and aid in seedbed preparation and planting.

Spring seedings are not recommended. By the time soil surfaces dry enough to operate planting equipment, annuals have germinated and soil moisture has nearly been depleted. Consequently, sufficient soil moisture is not available to support germination and establishment of new seedlings.

Planting Procedures

Seedling establishment can be enhanced by seeding into scalps or furrows created to remove the annual weeds. Various types of equipment are available that make scalps or furrows and plant seeds into the cleared depression (Larson 1980). Scalps 4 to 8 inches (10 to 20 cm) wide are generally sufficient for seeding adapted grasses. Strips of this width can be created using offset disks on the rangeland drill or other commercial drills. Shrubs and perennial forbs do better with wider clearings. Scalps should be at least 12 to 24 inches (30 to 60 cm) wide for shrubs. The more competition, or potential competition (seed), that is removed, the greater chance for success.

Adapted Species and Mixtures

Species seeded into spring-growing annual communities can face considerable competition until they are well established. Seeded areas should not be grazed until there is a good, healthy stand of the seeded species. This generally requires at least 2 to 4 years of nonuse. One should not expect stand density to be exceptionally high the first 2 to 4 years. However, some sites do respond rapidly.

Species recommended for seeding are those recommended for seeding the vegetative type that existed prior to disturbance. These include juniper-pinyon (tables 14 through 16), fourwing saltbush (table 17), basin big sagebrush (table 18), Wyoming big sagebrush (table 20), black sagebrush (table 21), low sagebrush (table 22), shadscale saltbush (table 25), black greasewood (table 26), and blackbrush (table 27).

Summer-Growing Annuals

Major summer-growing annuals are Russian thistle and halogeton. Two species of Russian thistle have been identified (Welsh and others 1987). Both grow with halogeton and are widespread on lower elevation ranges (Beatley 1973; Evans and Young 1980). These plants are most abundant on abused, deteriorated areas in the salt desert shrub and basin big sagebrush types. Soils are basic, and annual precipitation usually ranges from 5 to 16 inches (130 to 410 mm). Most improvement can be gained on areas that receive more than 9 inches (230 mm) of annual precipitation. Areas that receive less than 9 inches (230 mm) of precipitation may, however, warrant treatment. Russian thistle and halogeton are early spring germinators, but do not grow much until midsummer. When both species grow rapidly (Cook and Stoddart 1953; Dwyer and Wolde-Yhannia 1972; Evans and Young 1972a, 1980).

Removal of Competition

Chaining, disk chaining, disking, scalping, or pipe harrowing generally eliminate sufficient competition so adapted perennials can be established. Deep furrow drills can also be used to clear strips adjacent to the seeded furrow to assure establishment of seeded species.

Burning is not effective in removal or control of these summer annuals. Both species generally remain green until late summer and are not easily burned. Abundant seed crops are formed each year, and primary control measures must be developed to eliminate or remove weed seeds. Broadleaf herbicides can be used to kill established plants, but sufficient seed persists in the soil to germinate the following season. To be most effective, mechanical or herbicide treatments should be conducted when weeds are young, generally each summer. However, sites cannot be seeded at this date, and planting should be delayed until the fall. Weeds quickly reinvade treated areas, and sites should be fall seeded to prevent weed invasion.

These weeds invade and increase rapidly following disturbances. It is important to seed new disturbances as soon as possible. Sites should not be allowed to remain open or occupied by these weeds because a seedbank will quickly develop. Disturbances that have been occupied by these weeds for a number of years may require 1 to 2 years of fallowing to exhaust the seedbank. Once perennial herbs or shrubs have reestablished, weeds can be controlled.

Because early season competition from these two annuals is usually not serious, perennial species that germinate early and quickly develop a root system that can be most successful. If environmental conditions are adequate and seeded species become established, Russian thistle and halogeton density can be reduced substantially.

Planting Season

Fall seedings are essential in summer-growing annual communities.

Planting Procedures

Most disturbances can be seeded with a number of methods. Sites can be aerial seeded, and seeds covered with a drag, harrow, or similar implement. Drill seeding is a primary method of planting, and deep furrow drills are commonly used to remove weeds in a narrow strip or scalp. Interseeding using the Hansen seeder or similar equipment is particularly effective in reestablishing desired species.

Many species established from interseedings will naturally spread by seedling recruitment into the weedy areas. Russian thistle density fluctuates from year to year, allowing for invasion of other species.

Adapted Species and Mixtures

Summer-growing annuals have established and become dominant over areas in a number of vegetative types. Species recommended for seeding summer-growing annual communities are essentially the same as those recommended for seeding the vegetative type that existed prior to when the annuals gained control. These include juniper-pinyon (tables 14 through 16), fourwing saltbush (table 17), basin big sagebrush (table 18), Wyoming big sagebrush (table 20), black sagebrush (table 21), low sagebrush (table 22), shadscale saltbush (table 25), black greasewood (table 26), and blackbrush (table 27).

Table 1—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding subalpine herblands and upper-elevation aspen openings.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Grasses and sedges						
Barley, meadow	P,E,L	X	X	EX	EX	ME
Bentgrass, redtop	P,E	X		ME	ME	PO
Bluegrass, big	E,L	X	X	ME	ME	ME
Bluegrass, Canada	P,E,L		X	ME	ME	ME
Brome, meadow	P,E		X	EX	EX	ME
Brome, mountain	P,E,L	X	X	EX	EX	EX
Brome, smooth (northern)	P,E,L		X	ME	EX	EX,NC
Brome, subalpine	E,L		X	ME	EX	EX
Fescue, sulcata sheep	P,E,L	X	X	PO	EX	ME
Fescue, tall	P,E		X	EX	EX	ME
Foxtail, creeping	P,E,L		X	ME	EX	EX
Foxtail, meadow	P,E,L		X	ME	ME	EX
Hairgrass, tufted	P,E,L	X	X	PO	ME	ME
Needlegrass, subalpine	E,L	X		ME	ME	ME
Oniongrass	P,E		X	ME	ME	PO
Orchardgrass	P,E,L		X	EX	EX	ME
Oatgrass, tall	P,E		X	ME	EX	ME
Reedgrass, chee	E,L		X	PO	PO	EX
Sedge, ovalhead	E,L	X	X	PO	ME	EX
Timothy	P,E		X	EX	EX	PO
Timothy, alpine	P,E,L	X	X	ME	ME	ME
Wheatgrass, intermediate	P		X	EX	EX	EX,NC
Wheatgrass, slender	P,E,L	X	X	EX	EX	ME
Forbs						
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	ME
Aster, leafybract alpine	E,L	X		PO	PO	PO
Aster, Pacific	P,E,L	X	X	PO	ME	ME
Aster, smooth	P,E,L	X	X	PO	PO	EX
Bluebell, tall	E,L	X		PO	PO	EX
Cinquefoil, gland	E,L	X		ME	ME	ME
Columbine, Colorado	E	X		PO	ME	ME
Cowparsnip	E,L	X		ME	ME	ME
Crownvetch	P,E,L		X	ME	ME	ME
Fleabane, Bear River	E,L	X		ME	ME	ME
Fleabane, Oregon	E,L		X			
Geranium, sticky and Richardson	P,E,L	X	X	PO	PO	ME
Goldeneye, showy	P,E,L	X	X	ME	EX	ME
Goldenrod, low	E,L	X	X	ME	EX	ME
Groundsel, butterweed	E,L	X		ME	ME	ME
Helianthella, oneflower	P,E	X		ME	ME	ME
Ligusticum, Porter	P,E,L	X		ME	ME	ME
Lomatium, Nuttall	P,E,L	X		ME	ME	ME
Lupine, mountain	E,L	X		ME	ME	EX

(con.)

Table 1 (Con.)

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Lupine, silky	E,L	X		ME	ME	EX
Meadowrue, Fendler	L	X		PO	ME	ME
Painted-cup, sulphur	L	X		ME	ME	EX
Penstemon, Rocky Mountain	P,E,L	X	X	PO	ME	ME
Penstemon, Rydberg	P,E	X	X	PO	ME	ME
Penstemon, Wasatch	P,E	X	X	ME	ME	ME
Sage, Louisiana	P,E	X	X	PO	ME	ME
Solomon-plume, fat	E,L	X		PO	PO	ME
Sweetanise	P,E,L	X		ME	EX	ME
Valerian, edible	E,L	X		PO	PO	EX
Vetch, American	L	X	X	ME	ME	ME
Violet, Nuttall	P,E,L	X		ME	EX	ME
Yarrow, western	P,E,L	X	X	ME	EX	ME
Shrubs						
Cinquefoil, shrubby	E,L	X		PO	PO	EX
Currant, sticky	E,L	X		PO	PO	EX
Currant, wax	E,L	X		PO	PO	EX
Elderberry, red	E,L	X		PO	ME	EX
Rabbitbrush, low	P,E,L	X	X	ME	ME	EX
Rabbitbrush, mountain rubber	P,E,L	X	X	ME	ME	ME
Rabbitbrush, Parry	P,E,L	X	X	ME	ME	ME
Rose, Woods	E,L	X	X	PO	PO	EX
Sagebrush, big mountain	P,E,L	X	X	ME	ME	ME
Sagebrush, big timberline	P,E,L	X		EX	EX	EX
Sagebrush, silver	P,L	X		ME	ME	ME
Snowberry, mountain	E,L	X	X	PO	PO	EX

	Soil seeding rate	
Growth form	**Well drained**	**Moist**
	Pls lb/acre[c]	
Grasses	4 to 6	4 to 6
Forbs	6 to 8	6 to 8
Shrubs	1 to 2	1 to 2

---

[a] Species status: P = pioneer; E = early seral; L = late seral.

[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.

[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 2—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding wet and semiwet meadows.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Grasses and sedges						
Barley, meadow	P,E,L	X	X	EX	EX	ME
Bentgrass, redtop	P,E	X	X	ME	ME	PO
Brome, mountain	P,E,L	X	X			
Brome, smooth (northern)	P,E,L		X	ME	EX	EX,NC
Foxtail, meadow	P,E,L		X	PO	ME	EX
Hairgrass, tufted	P,E,L	X	X	PO	ME	ME
Oatgrass, tall	P,E		X	ME	EX	ME
Sedge, ovalhead	E,L	X		PO	ME	EX
Timothy	P,E		X	EX	EX	PO
Wheatgrass, tall	P,L		X	EX	EX	EX
Wildrye, Great Basin	E,L	X		PO	PO	ME
Forbs						
Aster, alpine leafybract	P,E,L	X	X	PO	PO	PO
Aster, blueleaf	P,E,L	X	X	PO	PO	ME
Aster, Pacific	P,E,L	X	X	PO	ME	ME
Cinquefoil, gland	P,E,L	X		ME	ME	EX
Clover, alsike	E,L		X	ME	ME	ME
Clover, strawberry	P,E,L		X	ME	ME	ME
Geranium, sticky and Richardson	P,E,L	X		ME	ME	EX
Medick, black	P,E,L		X	EX	EX	ME
Milkvetch, cicer	P,E,L		X	ME	ME	EX
Sainfoin	E		X	ME	ME	PO
Sage, Louisiana	P,E	X	X	PO	ME	ME
Sweetanise	P,E,L	X		ME	ME	ME
Valerian, edible	E,L	X		PO	PO	EX
Yarrow, western	P,E,L	X	X	ME	ME	ME

	Soil seeding rate	
Growth form	**Well drained**	**Moist**
	Pls lb/acre[c]	
Grasses	4 to 5	3 to 4
Forbs	5 to 7	6 to 8

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 3—Ecological status, use index, and competitiveness for shrubs recommended for transplanting in wet meadows.

Species	Ecological status[a]	Use index for:		Competitiveness[b] as a seedling in the presence of:		Mature plant
		Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	
Grasses and sedges						
Birch, water	P,E,L	X		ME	ME	EX
Cinquefoil, bush	E,L	X		ME	ME	EX
Dogwood, redosier	E,L	X		PO	ME	EX
Honeysuckle, Utah	E,L	X		PO	PO	EX
Rose, Woods	E,L	X	X	PO	PO	EX
Willows (see table 11)	P,E,L	X	X	PO	PO	EX

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor.

Table 4—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding inland saltgrass sites.

Species	Ecological status[a]	Use index for:		Competitiveness[b] as a seedling in the presence of:		Mature plant
		Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	
Grasses						
Dropseed, sand	P,E,L	X	X	ME	ME	ME
Fescue, tall	P,E,L		X	EX	EX	PO
Foxtail, meadow	P,E,L		X	ME	EX	ME
Sacaton, alkali	P,E,L	X	X	PO	PO	ME
Wheatgrass, fairway crested	P,E,L		X	EX	EX	ME
Wheatgrass, 'NewHy'	P,E,L		X	ME	ME	EX
Wheatgrass, streambank	P,L	X	X	ME	ME	EX
Wheatgrass, tall	P,L		X	ME	ME	EX
Wildrye, Russian	P,E,L		X	PO	PO	EX
Wildrye, Salina	P,L	X		PO	PO	ME
Forbs						
Aster, Pacific	P,E,L	X	X	PO	ME	ME
Clover, strawberry	P,E,L		X	ME	ME	ME
Medick, black	P,E		X	EX	EX	PO
Summercypress, Belvedere	P,E		X	EX	EX	PO
Sweetclover, yellow	P		X	EX	EX	PO
Shrubs						
Buffaloberry, silver[c]	E,L	X		PO	PO	EX
Greasewood, black	E,L	X		PO	PO	EX
Honeysuckle, tatarian[c]	E,L	X		PO	PO	EX
Plum, American[c]	E,L	X		PO	PO	EX
Rabbitbrush, rubber	P,E	X	X	ME	ME	ME
Saltbush, fourwing	P,E,L	X	X	ME	ME	ME
Saltbush, Gardner	P,E,L	X	X	ME	ME	ME
Willow, purpleosier[c]	E,L		X			EX

Growth form	Soil seeding rate Wet and dry soils
	Pls lb/acre[d]
Grasses	6 to 8
Forbs	2 to 3
Shrubs	1 to 2

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor.
[c] Established most successfully by tansplants.
[d] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 5—Distribution and rooting characteristics of select native sedges and rushes for riparian sites. Information, in part, is from Lewis (1958a) and Monsen, in Platts and others (1987).

Species	Areas[a]	Habitat	Abundance	Characteristic	Comments
Bulrush, saltmarsh	Mtn. B.	Lake edge, streambank, alkali sites	Abundant	Rhizomatous	Dense patches, spreads rapidly.
Bulrush, tule	Val.-Mtn. B.	Lake edge	Abundant	Rhizomatous	Tall, rank, dense patches, restricted to water's edge.
Rush, Baltic	Val.-Asp.	Wet and semiwet meadows	Abundant	Rhizomatous	Principal species for stabilization. Use adapted ecotypes, spreads aggressively, persists with grazing.
Rush, Drummond	LPP-Alp.	Wet and dry meadows	Common	Caespitose	Spreads after disturbance, occupies infertile soil.
Rush, longstyle	Sage-SF	Wet meadows and streams	Common	Rhizomatous	Moderately palatable rush, long style.
Rush, swordleaf	Sage-SF	Streams and wet meadows	Abundant	Strongly rhizomatous	Moderately palatable, wide elevational range.
Rush, Torrey	Val.-PJ	Streams, wet meadows, seeps, alkali tolerant	Common	Strongly rhizomatous	Spreads onto disturbances.
Sedge, analogue	PP-SF	Bogs and wet meadows	Frequent	Long, creeping rootstock	Excellent cover, widely distributed, calcareous soils.
Sedge, beaked	Val.-SF	Streams, water's edge, standing water	Abundant	Culms from stout, long rhizomes	Principal species for streambank, stabilization, low palatability.
Sedge, black alpine	SF-Alp.	Well-drained meadows	Frequent	Creeping rootstock	Good cover for wet areas.
Sedge, blackroot	Alp.	Open, dry meadows	Common	Caespitose	Vigorous, abundant.
Sedge, Douglas	PF-Asp.	Dry meadows, alkali tolerant	Abundant	Creeping rootstocks, long culms, increases under grazing	Adapted to compact soils, low palatability.
Sedge, downy	Alp.	Dry and wet meadows	Abundant	Rhizomatous	Vigorous, spreads rapidly.
Sedge, golden	Val.-SF	Marsh, wet	Frequent	Caespitose, long rootstock	Widely distributed, good ground cover.
Sedge, Hepburn	Alp.	Open meadows	Abundant	Densely caespitose	Short stature, open cover.
Sedge, Hood	Mtn. B.-SF	Open parks, drainageways	Abundant	Densely caespitose	Excellent ground cover, useful forage.
Sedge, Kellogg	Mtn. B.-SF	Wet meadows, marshes	Abundant	Caespitose, long rootstock	Pioneer species, invades water's edge.
Sedge, Nebraska	Val.-Asp.	Marshes and meadows	Common	Strongly rhizomatous	Excellent soil stabilizer, palatable, widely distributed.
Sedge, rock	Alp.	Dry slopes and meadows	Abundant	Short rhizomes	Vigorous, spreads rapidly, limited distribution.
Sedge, russet	LLP-SF	Water's edge	Abundant	Culms from long, creeping rootstock	Excellent streambank cover, limited distribution.
Sedge, slim	Val.-Asp.	Dry to moist alkali bottomlands	Abundant	Long, creeping rootstock	Large, dense, persistent, moderately palatable.
Sedge, smallwing	Mtn. B.-Asp.	Meadow edges	Abundant	Densely caespitose	Good cover for streambank, palatable, spreads by seeds, widely distributed.
Sedge, soft-leaved	ASP-Alp.	Swamps, meadows	Abundant	Caespitose, long rhizomes	Shady areas, solid mat, moderate vigor.
Sedge, valley	Sage-Asp.	Dry slopes	Abundant	Caespitose	Spreads onto dry grass-sage sites.
Sedge, woolly	Val.-SF	Dry to wet meadows	Abundant	Caespitose	Very robust, good species for streambank stabilization.
Spikerush, common	Val.-SF	Wet meadows and streams, alkali tolerant	Abundant	Rhizomatous	Spreads rapidly, low palatability, wide elevational range.

[a] Areas: Alp. = alpine; SF = spruce-fir; Asp. = aspen; LPP = lodgepole pine; PP = ponderosa pine; Mtn. B. = mountain brush; PJ = pinyon-juniper; Sage = big sagebrush; Val. = valley.

Table 6—Characteristics of broadleaf herbs recommended for planting riparian sites (from Monsen in Platts and others 1987).

Species	Areas of adaptation[a]	Origin	Seeding trait	Transplant capability	Growth rate
Alfalfa	Asp.-Sage	Introduced	Excellent	Good	Rapid
Aster, Pacific	Asp.-V	Native	Poor	Excellent	Moderate
Bassia, fivehook	PJ-SDS	Native	Excellent	Good	Rapid
Checker-mallow, Oregon	Asp.-Mtn. B.	Native	Good	Good	Moderate
Clover, alsike	Asp.-Mtn. B.	Introduced	Good	Fair	Moderate
Clover, strawberry	V	Introduced	Good	Fair	Moderate
Cinquefoil, gland	Asp.-PP	Native	Good	Excellent	Moderate
Cowparsnip	Alp.-Mtn. B.	Native	Poor	Poor	Poor
Crownvetch	PJ-Mtn. B.	Introduced	Good	Excellent	Rapid
Fireweed	Asp.-Mtn. B.	Native	Excellent	Good	Rapid
Flax, Lewis	Asp.-Sage	Native	Excellent	Good	Moderate
Groundsel, butterweed	Asp.-PP	Native	Good	Excellent	Moderate
Medick, black	Asp.-Sage	Introduced	Excellent	Good	Moderate
Sage, Louisiana	Alp.-Sage	Native	Excellent	Excellent	Rapid
Solomon-seal, western	Asp.-Mtn. B.	Native	Poor	Fair	Slow
Sweetclover, yellow	Asp.-Sage	Introduced	Excellent	Poor	Rapid
Valerian, edible	Asp.-Mtn. B.	Native	Poor	Fair	Slow
Yarrow, western	Alp.-V	Native	Excellent	Excellent	Rapid

[a] Areas of adaptation: Alp. = alpine; SF = spruce-fir; Asp. = aspen; PP = ponderosa pine; Mtn. B. = mountain brush; PJ = pinyon-juniper; Sage = big sagebrush; Salp. = subalpine; SDS = salt desert shrub; V = valley bottom.

Table 7—Characteristics of grasses adapted for direct seeding and transplanting riparian sites (from Monsen in Platts and others 1987).

Species	Areas of adaptation[a]	Origin	Seeding trait	Transplant capability	Growth rate
Barley, meadow	Alp.-Asp.	Native	Excellent	Excellent	Moderate
Bentgrass, redtop	Salp.-SF	Introduced	Fair	Good	Moderate
Bluegrass, Sandberg	Mtn. B.-Sage	Native	Fair	Good	Slow
Brome, meadow	Alp.-PJ	Introduced	Excellent	Excellent	Moderate
Brome, mountain	Alp.-PJ	Native	Excellent	Excellent	Rapid
Brome, smooth	Alp.-Mtn. B.	Introduced	Good	Excellent	Moderate
Fescue, tall	Asp.-SDS	Introduced	Excellent	Excellent	Rapid
Foxtail, meadow	Alp.-Mtn. B.	Introduced	Excellent	Good	Rapid
Hairgrass, tufted	Alp.-SF	Native	Poor	Fair	Slow
Orchardgrass	Alp.-Sage	Introduced	Good	Good	Rapid
Reedgrass, bluejoint	SF-Sage	Native	Good	Excellent	Moderate
Reedgrass, chee	Alp.-PJ	Introduced	Poor	Good	Slow
Ryegrass, perennial	SF-PP	Introduced	Excellent	Good	Rapid
Sacaton, alkali	Sage-SDS	Native	Fair	Good	Slow
Saltgrass	V	Native	Poor	Excellent	Slow
Squirreltail, bottlebrush	Mtn. B.-V	Native	Good	Fair	Moderate
Timothy	Asp.-Mtn. B.	Introduced	Good	Good	Rapid
Wheatgrass, slender	SF-PJ	Native	Excellent	Excellent	Rapid
Wheatgrass, tall	Mtn. B.-V	Introduced	Excellent	Good	Rapid
Wheatgrass, western	PP-Sage	Native	Fair	Excellent	Slow
Wildrye, creeping	JP-V	Introduced	Good	Excellent	Moderate
Wildrye, Great Basin	Mtn. B.-V	Native	Good	Good	Moderate
Wildrye, mammoth	Mtn. B.-Sage	Introduced	Fair	Good	Moderate
Wildrye, Russian	Mtn. B.-V	Introduced	Fair	Good	Moderate

[a] Areas of adaptation: Alp. = alpine; SF = spruce-fir; Asp. = aspen; PP = ponderosa pine; Mtn. B. = mountain brush; PJ = pinyon-juniper; Sage = big sagebrush; Salp. = subalpine; SDS = salt desert shrub; V = valley bottom.

Table 8—Characteristics of grasses adapted for direct seeding and transplanting riparian sites (from Monsen in Platts and others 1987).

Species	Growth habit	Salinity tolerance[a]	Flooding tolerance	Palatability	Spreadability
Barley, meadow	Rhizomatous	T	Tolerant	Fair	Good
Bentgrass, redtop	Rhizomatous	MT	Moderate	Good	Rapid
Bluegrass, Sandberg	Bunch	MT	Moderate	Good	Fair
Brome, meadow	Rhizomatous	MT	Moderate	Good	Rapid
Brome, mountain	Rhizomatous	MT	Moderate	Good	Good
Brome, smooth	Rhizomatous	MT	Moderate	Good	Rapid
Fescue, tall	Rhizomatous	T	Tolerant	Good	Rapid
Foxtail, meadow	Rhizomatous	MT	Tolerant	Good	Rapid
Hairgrass, tufted	Bunch	MT	Tolerant	Fair	Poor
Orchardgrass	Bunch	MS	Sensitive	Excellent	Fair
Reedgrass, bluejoint	Rhizomatous	MT	Tolerant	Good	Rapid
Reedgrass, chee	Rhizomatous	MT	Tolerant	Good	Good
Ryegrass, perennial	Small bunch	MT	Sensitive	Good	Good
Sacaton, alkali	Bunch	MT	Moderate	Good	Rapid
Saltgrass	Rhizomatous	T	Tolerant	Fair	Rapid
Squirreltail, bottlebrush	Bunch	MT	Moderate	Good	Good
Timothy	Bunch	MS	Moderate	Good	Good
Wheatgrass, slender	Rhizomatous	MS	Sensitive	Excellent	Good
Wheatgrass, tall	Large clump	MT	Moderate	Fair	Good
Wheatgrass, western	Rhizomatous	MS	Moderate	Good	Good
Wildrye, creeping	Rhizomatous	T	Tolerant	Poor	Good
Wildrye, Great Basin	Large clump	T	Moderate	Good	Fair
Wildrye, mammoth	Rhizomatous	T	Tolerant	Good	Good

[a] Salinity tolerance: MS = moderately sensitive; MT = moderately tolerant; T = tolerant.

Table 9—Characteristics of woody species recommended for riparian disturbances (from Monsen in Platts and others 1987).

Species	Areas of occurrence		Adaptation to disturbed sites	Methods of culture[b]
	Zones[a]	Habitat		
Alder, thinleaf	SF-Mtn. B.	Stream edge and well-drained soils	Excellent	NS, CS, DS
Aspen, quaking	SF-Asp.	Well-drained, moist soils, occasionally occurs at streams edges	Fair	NS, CS, RC
Birch, water	SF-Mtn. B.	Stream edges	Good	NS
Buckthorn, cascara		Frequently wet sites		
Buffaloberry, silver	Mtn. B.-V	Well-drained sites, edges of streams and ponds	Good	NS
Ceanothus, redstem	SF-PP	Moist soils, seeps, well-drained soils	Good	DS, NS, CS
Chokecherry, black	SF-PJ	Well-drained, moist soils, occasionally occurs at stream edges	Fair	NS, CS, RC
Cinquefoil, shrubby	Alp.-PP	Stream edges, wet meadows	Excellent	NS, CS
Cottonwood, Fremont	Mtn. B.-V	Moist soils, seeps, frequently wet sites	Good	NS, CS, RC
Cottonwood, narrowleaf	Asp.-Sage	Well-drained and wet sites, edges of streams, ponds, and bogs	Good	NS, CS, RC
Currant, golden	SF-PP	Moist soils	Fair	NS, CS
Dogwood, redosier	SF-Mtn. B.	Stream edges and well-drained soils	Good	DS, NS, CS, RC
Elderberry, red	Asp.-PP	Moist sites, occasional seeps and streambanks	Good	NS, CS
Greasewood, black	SDS-V	Sites with shallow water tables, occasionally flooded sites	Good	NS, CS
Hawthorn, Douglas	Asp.-Sage	Stream edges and well-drained soils	Good	NS
Honeysuckle, Tatarian	Mtn. B.-Sage	Well-drained and moist soils, occasional wet sites	Excellent	NC, CS, DS
Mountain ash, Greene's	SF-Asp.	Moist soils, occasional seeps and stream bottoms	Fair	NS, CS
Mountain lover	SF-Asp.	Moist soils and seeps, requires some shade	Fair	NS, CS
Ninebark, mallow	SF-Asp.	Moist and well-drained soils	Fair	NS, CS
Rabbitbrush, threadleaf rubber	Sage-V	Well-drained soils	Good	DS, NS, CS
Rockspirea	SF-Mtn. B.	Well-drained and moist soils, occasional seeps	Good	NC, CS
Rose, Woods	Asp.-Mtn. B.	Moist and well-drained soils, seeps, streambanks	Excellent	NS, CS, W, RC
Sagebrush, big basin	Mtn. B.-SDS	Deep, well-drained soils, occasional flooding	Excellent	DS, NS, CS
Sagebrush, big mountain	Asp.-Mtn. B.	Well-drained soils, moist sites	Excellent	DS, NS, CS
Sagebrush, silver	Asp.-Sage	Well-drained and moist soils	Fair	DS, NS, CS
Sagebrush, tall threetip	Asp.-Mtn. B.	Well-drained soils, moist sites	Excellent	DS, NS, CS
Saltbush, fourwing	Mtn. B.-V	Well-drained soils, frequent flooding	Good	DS, NS
Saltbush, Gardner	SDS-V	Semi-arid deserts, withstands seasonal flooding and alternating wet/dry periods	Fair	DS, NS, CS
Serviceberry, Saskatoon	Asp.-Mtn. B.	Well-drained soils, seeps occasionally	Good	NS, CS
Silverberry	PJ-V	Stream edges and well-drained soils	Excellent	NS, SC
Snowberry, common	SF-Asp.	Moist sites and well-drained soils	Good	NS, CS, W, RC
Snowberry, mountain	Asp.-Sage	Well-drained soils, edges of streams	Good	NS, CS, W, RC
Snowberry, western	SF-Mtn. B.	Moist sites, occasionally streambanks and valley bottoms	Good	NS, CS, W, RC
Thimbleberry	Asp.-PP	Well-drained soils, frequently wet sites	Excellent	NS, CS, W, RC
Willows (see table 11)				

[a] Areas of adaptation: Alp. = alpine; SF = spruce-fir; Asp. = aspen; PP = ponderosa pine; Mtn. B. = mountain brush; PJ = pinyon-juniper; Sage = big sagebrush; SDS = salt desert shrub; V = valley bottom.

[b] Methods of culture: DS = direct seeding; RC = rooted cuttings; NS = nursery-grown seedling; CS = container-grown seedling; W = wilding.

Table 10—Characteristics of woody species recommended for riparian disturbances (from Monsen in Platts and others 1987).

	Establishment traits			
Species	**Seedling establishment**	**Growth rates**	**Soil stability value**	**Comments**
Alder, thinleaf	Excellent	Rapid	Excellent	Easily established, adapted to harsh sites, grows rapidly.
Aspen, quaking	Good	Rapid	Good	Considerable ecotypic differences, not well-suited to highly disturbed sites.
Birch, water	Excellent	Rapid	Excellent	Establishes well by transplanting, adapted to streambanks and bogs.
Buckthorn, cascara	Fair	Moderate	Good	Limited plantings, plants perform well on disturbed sites.
Buffaloberry, silver	Good	Moderate	Good	Adapted to valley bottoms and saline soils.
Ceanothus, redstem	Excellent	Rapid	Excellent	Not adapted to saturated soils, but useful in planting disturbed streambanks.
Chokecherry, black	Good	Moderate	Good	Widely adapted, larger transplant stock establishes, and grows rapidly.
Cinquefoil, shrubby	Good	Moderate	Excellent	Valuable species for riparian disturbances, establishes well, and provides excellent site stability.
Cottonwood, Fremont	Good	Rapid	Good	Establishes easily, grows rapidly, furnishes good cover.
Cottonwood, narrowleaf	Good	Rapid	Good	Establishes easily, grows rapidly.
Currant, golden	Excellent	Excellent	Good	Widely adapted, easily established, excellent site stability.
Dogwood, redosier	Excellent	Rapid	Excellent	Easy to grow and establish, useful for disturbed sites, requires fresh aerated water.
Elderberry, red	Fair	Moderate	Good	Adapted to restricted sites, establishes slowly on disturbed sites.
Greasewood, black	Fair	Slow	Good	Difficult to establish, well adapted to valley bottoms and salty soils.
Hawthorn, Douglas	Fair	Slow	Good	Slow growing, but well-suited to disturbed streambanks.
Honeysuckle, Tatarian	Excellent	Rapid	Good	Easily established, provides immediate cover, well-adapted to different soil conditions.
Mountain ash, Greene’s	Fair	Slow	Good	Not well adapted to disturbed soils, establishes slowly.
Mountain lover	Fair	Slow	Good	Common on upland slopes, not well adapted to disturbances.
Ninebark, mallow	Fair	Moderate	Good	Requires good sites.
Rabbitbrush, rubber threadleaf	Excellent	Moderate	Good	Suited to heavy, saturated soils.
Rockspirea	Fair	Moderate	Good	Erratic establishment, but suited to disturbed sites.
Rose, Woods	Excellent	Moderate	Good	Widely adapted, easily established, excellent site stability, commonly used species for riparian disturbances.
Sagebrush, big basin	Good	Rapid	Fair	Useful for planting extremely disturbed and well-drained soils.
Sagebrush, big mountain	Good	Rapid	Fair	Adapted to disturbed sites, suited to moist, but not saturated, soils.
Sagebrush, silver	Good	Rapid	Fair	Well adapted to exposed, moist soils, able to tolerate flooding for a short time.
Sagebrush, tall threetip	Excellent	Rapid	Fair	Well suited to eroded, exposed soils, spreads quickly.
Saltbush, fourwing	Excellent	Rapid	Good	Useful for well-drained and disturbed soils.
Saltbush, Gardner	Fair	Moderate	Fair	Adapted to arid sites and seasonally saturated soils.
Serviceberry, Saskatoon	Fair	Slow	Good	Slow to establish, sensitive to understory competition.
Silverberry	Excellent	Rapid	Good	Easily established, rapid rate of growth, adapted to harsh sites.
Snowberry, common	Fair	Moderate	Excellent	Not well suited to extremely disturbed soils, provides excellent stability and spreads well.
Snowberry, mountain	Fair	Slow	Excellent	Plants not well adapted to disturbed soils, provides excellent stability and spreads well.
Snowberry, western	Fair	Slow	Excellent	Plants not well adapted to disturbed soils, provides excellent stability and spreads well.
Thimbleberry	Excellent	Moderate	Good	Well adapted to eroded sites, limited range of distribution.
Willows (see table 11)				

Table 11—Areas of adaptation and selected characteristics of several willow species (from Monsen in Platts and others 1987).

	Areas of adaptation				Period required for:		
Species	Zones	Habitat	Origin of roots	Prevalence of roots	Root formation	Stem formation	Comments
					- - - - *Days* - - - -		
Willow, arroyo	Aspen-mountain brush	Restricted to stream edges	Callus and lower one-third of stem	Few to many	10	10	Erratic rooting habits.
Willow, barrenground	Subalpine-spruce-fir	Wet sites and well-drained soils	Roots throughout entire length of stem	Abundant	15–20	15–25	Roots freely.
Willow, Bebb	Spruce-fir-aspen	Edges of streams, occasionally well-drained soils	Roots throughout entire length of stem	Moderate	10	10–20	Roots freely.
Willow, Booth	Aspen-sagebrush	Stream edges and standing water	Roots mostly at lower one-third of stem	Abundant	10–15	10–15	Roots freely.
Willow, Drummond	Spruce-fir, upper sagebrush	Edges of streams and ponds	Roots throughout entire length of stem	Abundant	10	10	Roots freely.
Willow, Geyer's	Subalpine-aspen-upper sagebrush	Edges of streams, frequent in wet meadows	Roots throughout entire length of stem	Few to moderate	10	10–15	Fair rooting capabilities
Willow, grayleaf	Subalpine-spruce-fir	Wet and dry sites, widely distributed, occupies seeps	Roots throughout entire length of stem	Few to moderate	10	10	Requires special treatment to root.
Willow, Pacific	Aspen-upper sage-brush	Wet soils, edges of streams and ponds	Roots throughout entire length of stem	Abundant	10	10–15	Easily rooted.
Willow, peachleaf	Aspen-big sagebrush	Stream edges, pond margins, soils saturated seasonally	Callus cut	Moderate	10–20	10	Moderate rooting capabilities.
Willow, plainleaf	Subalpine-aspen	Wet sites, edges of streams, wet meadows	Roots throughout entire length of stem	Few to moderate	10	10–15	Fair rooting.
Willow, sandbar	Spruce-fir-sagebrush	Edges of streams, wet sites, some times well-drained soils	Roots throughout entire length of stem	Moderate	10–15	10	Easily rooted.
Willow, Scouler	Spruce-fir	Well-drained soils, forest understory	Callus cut	Moderate	10–15	10–15	Requires special treatment to root.
Willow, Wolf	Spruce-fir-aspen	Stream edges and ponds	Roots throughout entire length of stem	Few to moderate	10–15	10–15	Erratic rooting.
Willow, yellow	Aspen-sagebrush	Mostly along streams, may occur on sites that remain dry for short periods	Entire stem section, most abundant at lower one-third	Moderate	10	10	Roots easily.

Table 12—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding aspen and coniferous forests and associated openings.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	Ecological status[a]	Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	Mature plant
Grasses						
Barley, foxtail	P,E		X	ME	ME	ME
Barley, meadow	P,E,L	X	X	EX	EX	ME
Bentgrass redtop	P,E,L		X	EX	EX	ME
Bluegrass, Canada	P,E		X	ME	ME	ME
Bluegrass, big	P,E	X	X	ME	ME	ME
Bluegrass, Kentucky	P,E,L	X	X	ME	ME	ME,NC
Brome, meadow	P,E,L		X	EX	EX	ME
Brome, mountain	P,E,L	X	X	EX	EX	EX
Brome, nodding	P,E,L	X	X	EX	EX	ME
Brome, Regar	P,E,L		X	ME	ME	ME
Brome, smooth northern	P,E,L		X	ME	EX	EX,NC
Brome, subalpine	P,E,L		X	ME	EX	EX
Fescue, alta	P,E,L		X	ME	ME	ME
Fescue, hard sheep	P,E,L		X	PO	ME	ME
Fescue, red	P,E,L	X	X	ME	ME	ME
Fescue, thurber	P,E	X		ME	ME	PO
Foxtail, meadow	P,E,L		X	ME	ME	EX
Needlegrass, green	P,E,L	X	X	PO	ME	ME
Needlegrass, Letterman	P,E,L	X	X	ME	ME	EX
Needlegrass, subalpine	P,E,L	X	X	ME	ME	ME
Oatgrass, tall	P,E		X	ME	ME	PO
Orchardgrass	P,E,L		X	EX	EX	ME
Rye, mountain	P,E		X	EX	EX	PO
Timothy	P,E		X	EX	EX	ME
Timothy, alpine	P,E,L	X		ME	ME	ME
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC
Wheatgrass, slender	P,E,L	X		EX	EX	EX
Wildrye, blue	P,E,L	X	X	EX	ME	ME
Forbs						
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	ME
Angelica, small leaf	P,E,L	X		EX	EX	ME
Aster, alpine leafybract	P,E,L	X		EX	EX	ME
Aster, blueleaf	P,E,L	X	X	PO	ME	ME
Aster, Engelmann	P,E,L	X	X	PO	PO	EX
Aster, Pacific	P,E,L	X	X	PO	ME	ME
Aster, smooth	P,E,L	X	X	PO	PO	EX
Bluebell, tall	E,L	X		PO	ME	EX
Columbine, Colorado	E,L	X		PO	ME	ME
Cowparsnip	P,E,L	X		ME	ME	ME
Crownvetch	P,E,L		X	ME	ME	EX
Eriogonum, cushion	P,E,L	X		ME	ME	ME
Geranium, sticky and Richardson	P,E,L	X		PO	PO	ME
Goldeneye, showy	P,E,L	X	X	ME	ME	ME
Goldenrod, Canada	P,E,L	X	X	ME	ME	ME
Goldenrod, low	P,E,L	X	X	ME	ME	ME

(con.)

Table 12 (Con.)

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Forbs (con.)						
Groundsel, butterweed	P,E,L	X		ME	ME	ME
Helianthella, oneflower	P,E	X	X	EX	EX	ME
Ligusticum, Porter	P,E	X		ME	ME	EX
Lomatium, Nuttall	P,E,L	X		ME	ME	ME
Lupine, mountain	E,L	X		ME	ME	EX
Lupine, silky	E,L	X		ME	ME	EX
Medick, black	P,E,L		X	ME	ME	ME
Milkvetch, cicer	P,E,L		X	ME	EX	ME
Peavine, thickleaf	P,E,L	X		PO	ME	ME
Peavine, Utah	P,E,L	X		PO	ME	EX
Penstemon, Rocky Mountain	P,E,L	X	X	ME	ME	ME
Penstemon, Rydberg	P,E	X	X	PO	ME	PO
Penstemon, Wasatch	P,E,L	X		ME	ME	ME
Sainfoin	P,E		X	ME	ME	PO
Sage, Louisiana	P,E	X	X	PO	ME	ME
Sweetanise	P,E,L	X		ME	ME	EX
Sweetroot, spreading	P,E,L	X		ME	ME	ME
Vetch, American	P,E,L	X		PO	ME	EX
Yarrow, western	P,E,L	X	X	ME	ME	ME
Shrubs						
Alder, thinleaf	P,E,L	X		ME	EX	EX
Bitterbrush, antelope	P,L	X		ME	ME	EX
Chokecherry, black	P,L	X		PO	PO	EX
Cinquefoil, shrubby	E,L	X		PO	PO	EX
Elderberry, blue	E,L	X		PO	PO	EX
Elderberry, red	E,L	X		PO	PO	EX
Maple, bigtooth	P,E,L	X		ME	ME	EX
Mountain ash, Greene's	L	X		PO	ME	EX
Oregon grape	L	X		PO	PO	EX
Rabbitbrush, rubber mountain	P,E	X		ME	ME	ME
Rabbitbrush, rubber whitestem mountain and basin	P,E	X	X	ME	EX	EX
Rose, Woods	E,L	X	X	PO	PO	EX
Sagebrush, big mountain	P,E,L	X	X	ME	ME	EX
Serviceberry, Saskatoon	E,L	X		PO	PO	EX
Snowberry, mountain	E,L	X		PO	PO	EX

	Seeding rate
Growth form	**Wet and dry sites**
	Pls lb/acre[c]
Grasses	5 to 6
Forbs	6 to 8
Shrubs	1 to 2

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 13—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding mountain brush and ponderosa pine communities.

Species	Ecological status[a]	Use index for:		Competitiveness[b] as a seedling in the presence of:		Mature plant
		Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	
-Grasses						
Bluegrass, big	P,E,L	X	X	ME	ME	ME
Bluegrass, Canada	P,E,L		X	ME	ME	ME
Brome, mountain	P,E	X	X	EX	EX	ME
Brome, Regar	P,E,L		X	EX	EX	ME
Brome, smooth northern and southern	P,L		X	EX	EX	EX,NC
Fescue, sheep	P,E,L	X	X	ME	ME	ME
Fescue, hard sheep	P,E,L		X	ME	EX	EX,NC
Fescue, sulcata sheep	P,E,L	X	X	ME	EX	EX
Junegrass, prairie	P,E,L	X		ME	ME	ME
Needlegrass, green	P,E,L	X	X	ME	ME	EX
Oatgrass, tall	P,E		X	ME	ME	ME
Orchardgrass	P,E,L		X	ME	ME	EX
Orchardgrass,'Paiute'	P,E,L		X	ME	ME	EX
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME
Timothy	P,E		X	EX	EX	ME
Wheatgrass, bluebunch	P,E,L	X		ME	ME	EX
Wheatgrass, fairway crested	P,E,L		X	EX	EX	EX
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX
Wheatgrass, slender	P,E,L	X	X	EX	EX	ME
Wheatgrass, streambank	P,E,L	X	X	ME	EX	EX
Wheatgrass, tall	P,E		X	EX	EX	ME
Wheatgrass, thickspike	P,E,L	X	X	ME	EX	EX
Wheatgrass, western	P,E,L	X	X	ME	ME	EX
Forbs						
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	EX
Aster, blueleaf	P,E,L	X	X	PO	PO	ME
Aster, Pacific	P,E,L	X	X	PO	ME	ME
Balsamroot, arrowleaf	E,L	X		PO	PO	EX
Balsamroot, cutleaf	E,L	X		PO	PO	EX
Balsamroot, hairy	E,L	X		PO	PO	EX
Burnet, small	P,E,L		X	EX	EX	ME
Crownvetch	P,E,L		X	ME	ME	EX
Eriogonum, cushion	P,E,L	X	X	ME	ME	ME
Flax, Lewis	P,E,L	X	X	EX	EX	ME
Goldeneye, Nevada showy	P,E,L	X	X	ME	ME	ME
Goldeneye, showy	P,E,L	X	X	ME	ME	ME
Goldenrod, Canada	P,E,L	X	X	ME	ME	ME
Groundsel, butterweed	P,E,L	X		ME	ME	EX
Lomatium, Nuttall	P,E,L	X		ME	ME	ME
Lupine, Nevada	E,L	X		ME	ME	ME
Lupine, silky	E,L	X		ME	ME	ME
Milkvetch, cicer	P,E,L		X	ME	ME	ME
Penstemon, Eaton	P,E,L	X		EX	EX	ME
Penstemon, low	P,E,L	X		EX	EX	EX
Penstemon, Palmer	P,E	X	X	EX	EX	PO
Penstemon, Rocky Mountain	P,E,L	X		ME	ME	EX
Penstemon, Wasatch	P,E,L	X		EX	EX	ME
Sage, Louisiana	P,E,L	X	X	PO	ME	EX

(con.)

Table 13 (Con.)

Species	Ecological status[a]	Use index for:		Competitiveness[b] as a seedling in the presence of:		Mature plant
		Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	
Forbs (con.)						
Sainfoin	P,E,L		X	ME	ME	ME
Sweetclover, yellow	P		X	EX	EX	PO
Sweetvetch, Utah	P,E,L	X		ME	ME	EX
Trefoil, birdsfoot	P,E		X	ME	ME	ME
Yarrow, western	P,E,L	X	X	ME	ME	ME
Shrubs						
Alder, thinleaf	P,E,L	X	X	ME	EX	EX
Bitterbrush, antelope	P,E,L	X	X	EX	EX	EX
Ceanothus, Martin	P,E,L	X		PO	ME	EX
Ceanothus, redstem	P,E,L	X	X	ME	EX	EX
Ceanothus, snowbush	P,E,L	X		ME	EX	EX
Cherry, bitter	P,E,L	X		PO	PO	EX
Chokecherry, black	E,L	X		PO	PO	EX
Cliffrose, Stansbury	P,E,L	X		ME	ME	EX
Cotoneaster, Peking	P,E		X	PO	PO	ME
Elderberry, blue	E,L	X		PO	ME	EX
Ephedra, green	P,E,L	X		ME	ME	ME
Eriogonum, sulfur	P,E,L	X	X	ME	ME	ME
Honeysuckle, Tatarian	P,E,L		X	PO	ME	ME
Honeysuckle, Utah	E,L	X		PO	ME	ME
Maple, Rocky Mountain	E,L	X	X	ME	ME	EX
Mountain ash, Greene’s	E,L	X		PO	ME	EX
Mountain mahogany, true	P,L	X	X	PO	ME	EX
Mountain mahogany, curlleaf	P,L	X	X	PO	ME	EX
Penstemon, bush	P,E,L	X	X	ME	ME	ME
Rabbitbrush, mountain rubber	P,E	X	X	ME	ME	ME
Rabbitbrush, Parry	P,E	X	X	ME	ME	ME
Rabbitbrush, mountain and basin whitestem rubber	P,E	X	X	ME	ME	ME
Rose, Woods	P,E,L	X	X	PO	ME	EX
Sagebrush, mountain big	P,E,L	X	X	ME	ME	EX
Sagebrush, silver	P,E,L	X		ME	ME	EX
Sagebrush, foothills big	P,E,L	X	X	ME	ME	EX
Serviceberry, Saskatoon	E,L	X		PO	PO	EX
Serviceberry, Utah	E,L	X		PO	PO	EX
Snowberry, longleaf	E,L	X		PO	PO	EX
Snowberry, mountain	E,L	X		PO	PO	EX
Squawapple	E,L	X		PO	PO	EX
Sumac, Rocky Mountain smooth	P,E,L	X	X	PO	ME	EX
Sumac, skunkbush	P,E,L	X	X	ME	ME	EX

Growth form	Seeding rate	
	Exposure	
	North and East	South and West
	Pls lb/acre[c]	
Grasses	5 to 6	6 to 8
Forbs	5 to 6	3 to 5
Shrubs	2 to 4	2 to 4

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 14—Ecological status, use index, competitiveness, and seeding rates for species adapted for seeding juniper-pinyon sites that receive less than 11 inches (280 mm) of annual precipitation.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Grasses						
Bluegrass, Sandberg	P,E,L	X		ME	ME	ME
Dropseed, sand	P,E,L	X		PO	ME	ME
Fescue, hard sheep	P,E,L		X	ME	ME	EX,NC
Fescue, sheep	P,E,L	X		ME	ME	EX
Muttongrass	P,E,L	X		ME	ME	ME
Needle-and-thread	P,E	X		ME	ME	ME
Orchardgrass, ‘Paiute’	P,E,L		X	EX	EX	EX
Ricegrass, Indian	P,E,L	X	X	ME	ME	EX
Rye, winter	P		X	EX	EX	PO
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME
Wheatgrass, bluebunch	P,E,L	X		ME	EX	ME
Wheatgrass, fairway crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, standard crested	P,E,L		X	EX	EX	ME,NC
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC
Wheatgrass, pubescent	P,E		X	EX	EX	EX,NC
Wheatgrass, Siberian	P,L		X	EX	EX	EX
Wheatgrass, streambank	P,E,L	X	X	ME	EX	EX
Wheatgrass, western	P,E,L	X	X	PO	ME	EX
Wildrye, Russian	P,E,L		X	PO	ME	EX
Forbs						
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	ME
Burnet, small	P,E,L		X	EX	EX	ME
Flax, Lewis	P,E,L	X	X	EX	EX	ME
Goldeneye, Nevada showy	P,E,L	X	X	EX	EX	ME
Globemallow, gooseberryleaf	P,E,L	X	X	PO	PO	EX
Globemallow, scarlet	P,E,L	X	X	PO	PO	EX
Penstemon, Palmer	P,E	X	X	EX	EX	PO
Sweetclover, yellow	P		X	EX	EX	PO
Yarrow, western	P,E,L	X	X	ME	ME	ME
Shrubs						
Apache plume	P,L	X		PO	ME	EX
Bitterbrush, antelope	P,E,L	X	X	EX	EX	EX
Bitterbrush, desert	P,E,L	X	X	EX	EX	EX
Buffaloberry, roundleaf	L	X		PO	PO	EX
Ceanothus, Fendler	P,E,L	X		ME	ME	EX
Cliffrose, Stansbury	P,E,L	X		ME	ME	ME
Ephedra, green	P,E,L	X		ME	ME	EX
Ephedra, Nevada	P,E,L	X		ME	ME	EX
Hopsage, spineless	P,L	X		PO	ME	EX
Kochia, forage ‘Immigrant’	P,E		X	EX	EX	ME

(con.)

Table 14 (Con.)

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	Ecological status[a]	Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	Mature plant
Shrubs (con.)						
Mountain mahogany, littleleaf	P,L	X		PO	ME	EX
Peachbrush, desert	P,L	X		PO	PO	EX
Rabbitbrush, mountain and basin whitestem rubber	P,E,L	X	X	ME	ME	ME
Sagebrush, basin big	P,E,L	X	X	PO	ME	EX
Sagebrush, black	P,E,L	X	X	PO	ME	EX
Sagebrush, fringed	P,L	X		PO	ME	EX
Sagebrush, Wyoming big	P,E,L	X	X	PO	ME	EX
Sagebrush, foothills big	P,E,L	X	X	ME	ME	EX
Saltbush, fourwing	P,E,L	X	X	ME	ME	ME
Serviceberry, Utah	P,E,L	X	X	PO	PO	EX
Winterfat	P,E,L	X	X	ME	ME	EX

Growth form	Seeding rate
	Pls lb/acre[c]
Grasses	4 to 6
Forbs	4 to 6
Shrubs	3 to 4

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 15—Ecological status, use index, competitiveness, and seeding rates for species adapted for seeding juniper-pinyon sites that receive 11 to 15 inches (280 to 380 mm) of annual precipitation.

Species	Ecological status[a]	Use index for:		Competitiveness[b] as a seedling in the presence of:		Mature plant
		Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	
Grasses						
Bluegrass, big	P,E,L	X	X	ME	ME	ME
Bluegrass, Canada	P,E,L		X	ME	ME	ME
Bluegrass, Sandberg	P,E,L	X	X	ME	ME	ME
Brome, Regar	P,E,L		X	ME	ME	ME
Brome, smooth (southern)	P,L		X	EX	EX	EX,NC
Fescue, hard sheep	P,E,L		X	ME	ME	ME,NC
Fescue, sulcata sheep	P,E,L	X	X	ME	ME	EX
Junegrass, prairie	P,E,L	X		ME	ME	ME
Muttongrass	P,E,L	X		ME	ME	ME
Needle-and-thread	P,E	X		ME	ME	ME
Needlegrass, green	P,E,L	X	X	ME	ME	EX
Orchardgrass, ‘Paiute’	P,E,L		X	EX	EX	EX
Ricegrass, Indian	P,E,L	X		ME	ME	EX
Rye, mountain	P,E		X	EX	EX	PO
Rye, winter	P		X	EX	EX	PO
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME
Wheatgrass, bluebunch	P,E,L	X	X	ME	ME	EX
Wheatgrass, fairway crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC
Wheatgrass, Siberian	P,E,L		X	EX	EX	EX
Wheatgrass, streambank	P,E,L	X	X	EX	EX	EX
Wheatgrass, thickspike	P,E,L	X	X	ME	EX	EX
Wheatgrass, western	P,E,L	X	X	ME	ME	EX
Wildrye, Great Basin	P,E,L	X		PO	ME	EX
Wildrye, Russian	P,E,L		X	PO	ME	EX
Forbs						
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	EX
Aster, Pacific	P,E,L	X	X	PO	ME	ME
Balsamroot, arrowleaf	E,L	X		PO	PO	EX
Burnet, small	P,E,L		X	EX	EX	ME
Flax, Lewis	P,E,L	X	X	EX	EX	ME
Globemallow, gooseberryleaf	P,E,L	X	X	ME	ME	EX
Goldeneye, Nevada showy	P,E,L	X	X	ME	ME	ME
Goldeneye, showy	P,E,L	X	X	ME	ME	ME
Penstemon, Palmer	P,E	X	X	EX	EX	PO
Sainfoin	P,E,L		X	ME	ME	ME
Sweetclover, yellow	P,E		X	EX	EX	PO
Sweetvetch, Utah	P,E,L	X		ME	ME	ME
Yarrow, western	P,E,L	X	X	ME	ME	ME

(con.)

Table 15 (Con.)

Species	Ecological status[a]	Use index for: Restoration plantings	Use index for: Revegetation plantings	Competitiveness[b] as a seedling in the presence of: Maximum competition	Competitiveness[b] as a seedling in the presence of: Minimum competition	Mature plant
Shrubs						
Apache plume	P,L	X		PO	ME	EX
Ash, singleleaf	P,E,L	X		PO	PO	EX
Bitterbrush, antelope	P,E,L	X	X	EX	EX	EX
Bitterbrush, desert	P,E,L	X	X	EX	EX	EX
Ceanothus, Fendler	P,E,L	X		ME	ME	EX
Cliffrose, Stansbury	P,E,L	X		ME	ME	EX
Cypress, Arizona	P,L		X	PO	PO	ME
Elderberry, blue	E,L	X		PO	ME	EX
Ephedra, green	P,E,L	X		ME	ME	EX
Ephedra, Nevada	P,E,L	X		ME	ME	EX
Eriogonum, Wyeth	P,E,L	X	X	ME	EX	ME
Kochia, forage	P,E		X	EX	EX	ME
Mountain mahogany, curlleaf	P,L	X		ME	ME	EX
Mountain mahogany, littleleaf	P,L	X		ME	ME	EX
Mountain mahogany, true	P,L	X		ME	ME	EX
Peachbrush, desert	P,L	X		PO	PO	EX
Rabbitbrush, mountain rubber	P,E,L	X	X	ME	ME	ME
Rabbitbrush, mountain and basin whitestem rubber	P,E,L	X	X	ME	ME	ME
Sagebrush, basin big	P,E,L	X	X	ME	ME	EX
Sagebrush, black	P,E,L	X	X	ME	ME	EX
Sagebrush, mountain big	P,E,L	X	X	ME	ME	EX
Sagebrush, foothill big	P,E,L	X	X	ME	ME	EX
Saltbush, fourwing	P,E,L	X	X	ME	ME	ME
Serviceberry, Saskatoon	P,E,L	X	X	PO	PO	EX
Serviceberry, Utah	P,E,L	X	X	PO	PO	EX
Snowberry, mountain	P,E,L	X	X	PO	PO	EX
Squawapple	E,L	X		PO	PO	EX
Sumac, Rocky Mountain smooth	P,E,L	X	X	PO	ME	EX
Sumac, skunkbush	P,E,L	X	X	PO	ME	EX
Winterfat	P,E,L	X	X	ME	ME	EX

Growth form	Seading rate
	Pls lb/acre[c]
Grasses	4 to 6
Forbs	4 to 6
Shrubs	3 to 4

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 16—Ecological status, use index, competitiveness, and seeding rates for species adapted for seeding juniper-pinyon sites that receive more than 15 inches (380 mm) of annual precipitation.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Grasses						
Bluegrass, big	P,E,L	X	X	ME	ME	ME
Bluegrass, Canada	P,E,L		X	ME	ME	ME
Bluegrass, Sandberg	P,E,L	X	X	ME	ME	ME
Brome, Regar	P,E,L		X	EX	EX	ME
Brome, smooth (northern and southern)	P,E,L		X	EX	EX	EX,NC
Fescue, hard sheep	P,E,L		X	ME	EX	EX,NC
Fescue, sulcata sheep	P,E,L	X		ME	EX	EX
Junegrass, prairie	P,E,L	X		ME	ME	ME
Needle-and-thread	P,E	X	X	ME	ME	ME
Needlegrass, green	P,E,L	X	X	ME	ME	EX
Orchardgrass, 'Paiute'	P,E,L		X	EX	EX	EX
Ricegrass, Indian	P,E,L	X		ME	ME	EX
Rye, mountain	P,E		X	EX	EX	PO
Rye, winter	P,E		X	EX	EX	PO
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME
Wheatgrass, bluebunch	P,E,L	X		EX	EX	EX
Wheatgrass, fairway crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC
Wheatgrass, slender	P,E,L	X	X	ME	ME	ME
Wheatgrass, streambank	P,E,L	X	X	ME	ME	EX
Wheatgrass, thickspike	P,E,L	X	X	ME	ME	EX
Wheatgrass, western	P,E,L	X	X	ME	ME	EX
Wildrye, Great Basin	P,E,L	X		ME	ME	EX
Forbs						
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	ME
Aster, blueleaf	P,E,L	X	X	EX	EX	EX
Aster, Pacific	P,E,L	X	X	EX	EX	EX
Balsamroot, arrowleaf	E,L	X		PO	PO	EX
Balsamroot, cutleaf	E,L	X		PO	PO	EX
Balsamroot, hairy	E,L	X		PO	PO	EX
Burnet, small	P,E,L		X	EX	EX	ME
Crownvetch	P,E,L		X	ME	ME	ME
Eriogonum, cushion	P,E,L	X	X	ME	ME	ME
Flax, Lewis	P,E,L	X	X	ME	ME	ME
Goldeneye, showy	P,E,L	X	X	ME	ME	ME
Goldenrod, Parry	P,E,L	X		ME	ME	ME
Helianthella, oneflower	P,E	X		ME	ME	ME
Lupine, Nevada	E,L	X		PO	PO	EX
Lupine, silky	E,L	X		PO	PO	ME
Lomatium, Nuttall	P,E,L	X		ME	ME	ME
Milkvetch, cicer	P,E,L		X	ME	ME	ME
Penstemon, Eaton	P,E,L	X		EX	EX	ME
Penstemon, Palmer	P,E	X	X	EX	EX	PO
Penstemon, Rocky Mountain	P,E,L	X	X	ME	ME	PO
Penstemon, thickleaf	P,E,L	X		ME	ME	ME
Penstemon, toadflax	P,E,L	X		PO	ME	ME
Penstemon, Wasatch	P,E,L	X		EX	EX	ME

(con.)

Table 16 (Con.)

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Forbs (con.)						
Sainfoin	P,E,L		X	ME	ME	ME
Sage, Louisiana	P,E,L	X	X	PO	PO	ME
Sage, tarragon	P,E,L	X		PO	PO	ME
Sweetclover, yellow	P,E		X	EX	EX	PO
Sweetvetch, Utah	P,E	X		PO	ME	ME
Shrubs						
Ash, singleleaf	P,E,L	X		PO	PO	ME
Bitterbrush, antelope	P,E,L	X	X	ME	EX	EX
Ceanothus, Martin	P,E,L	X		ME	ME	EX
Chokecherry, black	P,L	X		PO	ME	EX
Cliffrose, Stansbury	P,E,L	X		ME	ME	EX
Cotoneaster, Peking	P,E		X	PO	ME	ME
Cypress, Arizona	P,E		X	PO	PO	ME
Elderberry, blue	P,E,L	X		PO	ME	EX
Ephedra, green	P,E,L	X		ME	ME	EX
Ephedra, Nevada	P,E,L	X		ME	ME	EX
Eriogonum, Wyeth	P,E,L	X		EX	EX	ME
Kochia, forage	P,E		X	EX	EX	ME
Mountain mahogany, curlleaf	P,E,L	X	X	PO	ME	EX
Mountain mahogany, true	P,E,L	X	X	PO	ME	EX
Maple, Rocky Mountain	E,L	X		ME	ME	EX
Rabbitbrush, mountain rubber	P,E,L	X	X	EX	EX	ME
Rabbitbrush, mountain and basin whitestem rubber	P,E,L	X	X	ME	ME	ME
Rose, Woods	P,E,L	X	X	PO	ME	EX
Sagebrush, mountain big	P,E,L	X	X	ME	EX	EX
Sagebrush, foothill big	P,E,L	X	X	ME	ME	EX
Saltbush, fourwing	P,E,L	X	X	ME	ME	ME
Serviceberry, Saskatoon	P,E,L	X	X	PO	PO	EX
Snowberry, longflower	E,L	X		PO	PO	EX
Snowberry, mountain	P,E,L	X		PO	ME	EX
Squawapple	P,E,L	X		PO	ME	EX
Sumac, Rocky Mountain smooth	P,E,L	X	X	PO	ME	EX
Sumac, skunkbush	P,E,L	X	X	PO	ME	EX
Winterfat	P,E,L	X	X	ME	ME	EX

	Seeding rate	
	Soils	
Growth form	**Neutral pH**	**Basic pH**
	Pls lb/acre[c]	
Grasses	3 to 5	4 to 7
Forbs	4 to 5	5 to 6
Shrubs	3 to 4	3 to 4

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 17—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding fourwing saltbush sites occurring in association with juniper-pinyon, basin big sagebrush, and Wyoming big sagebrush.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	Ecological status[a]	Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	Mature plant
Grasses						
Bluegrass, Sandberg	P,E,L	X	X	ME	EX	ME
Dropseed, sand	P,E,L	X	X	ME	ME	EX
Galleta	E,L	X		ME	ME	EX
Needle-and-thread	E,L	X		ME	ME	ME
Ricegrass, Indian	P,E,L	X	X	ME	ME	EX
Sacaton, alkali	P,E,L	X		ME	ME	ME
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	EX
Wheatgrass, fairway crested	P,E,L		X	EX	EX	ME,NC
Wheatgrass, standard crested	P,E,L		X	EX	EX	ME,NC
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC
Wheatgrass, Siberian	P,E,L		X	EX	EX	EX
Wheatgrass, streambank	P,E,L	X	X	ME	ME	EX
Wheatgrass, thickspike	P,E,L	X	X	ME	ME	EX
Wildrye, Great Basin	P,E,L	X	X	PO	PO	EX
Wildrye, Russian	P,E,L		X	PO	PO	EX
Forbs						
Burnet, small	P,E		X	ME	ME	ME
Flax, Lewis	P,E	X	X	ME	ME	ME
Globemallow, gooseberryleaf	P,E,L	X	X	PO	PO	EX
Globemallow, scarlet	P,E,L	X	X	PO	PO	EX
Penstemon, Palmer	P,E	X	X	ME	ME	PO
Sweetclover, yellow	P		X	ME	ME	ME
Yarrow, western	P,E,L	X	X	ME	ME	ME
Shrubs						
Ephedra, green	P,E,L	X	X	PO	ME	EX
Ephedra, Nevada	P,E,L	X	X	PO	ME	EX
Hopsage, spiny	P,E,L	X		PO	PO	EX
Kochia, forage	P,E		X	EX	EX	ME
Rabbitbrush, low	P,E	X	X	EX	EX	ME
Sagebrush, basin big	E,L	X	X	ME	ME	ME
Sagebrush, foothills	E,L	X	X	ME	ME	ME
Sagebrush, low	E,L	X	X	ME	EX	ME
Sagebrush, Wyoming big	E,L	X	X	ME	ME	ME
Saltbush, fourwing	P,E,L	X	X	ME	ME	EX
Saltbush, Gardner	P,E,L	X	X	ME	ME	EX
Shadscale	P,E,L	X		PO	PO	ME
Winterfat	P,E,L	X	X	ME	ME	ME

Growth form	Seeding rate
	Pls lb/acre[c]
Grasses	4 to 6
Forbs	4 to 6
Shrubs	3 to 4

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 18—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding basin big sagebrush sites.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Grasses						
Bluegrass, Sandberg	P,E,L	X		ME	ME	ME
Dropseed, sand	P,E,L	X		PO	ME	ME
Fescue, hard sheep	P,E,L		X	ME	ME	EX,NC
Fescue, Idaho	E,L	X		PO	ME	ME
Fescue, sulcata sheep	P,E,L	X	X	ME	ME	ME,NC
Fescue, sheep	P,E,L	X		ME	ME	ME
Needle-and-thread	P,E	X		ME	ME	ME
Needlegrass, Thurber	P,E,L	X		ME	ME	EX
Orchardgrass,‘Paiute’	P,E,L		X	ME	ME	ME
Ricegrass, Indian	P,E,L	X		ME	EX	EX
Rye, mountain	P,E		X	EX	EX	ME
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME
Wheatgrass, bluebunch	E,L	X		ME	ME	EX
Wheatgrass, fairway crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC
Wheatgrass, Siberian	P,E,L		X	EX	EX	EX,NC
Wheatgrass, streambank	P,E,L	X	X	ME	ME	ME
Wheatgrass, tall	P,E		X	ME	ME	ME
Wheatgrass, thickspike	P,E,L	X	X	ME	ME	EX
Wheatgrass, western	P,E,L	X	X	PO	ME	EX
Wildrye, Great Basin	P,E,L	X		PO	ME	EX
Wildrye, Russian	P,E,L		X	PO	ME	EX
Forbs						
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	ME
Aster, Pacific	P,E	X	X	ME	ME	ME
Burnet, small	P,E,L		X	EX	EX	ME
Flax, Lewis	P,E,L	X	X	ME	EX	ME
Goldeneye, Nevada showy	P,E,L	X	X	ME	ME	PO
Globemallow, gooseberryleaf and scarlet	P,E,L	X	X	ME	ME	EX
Lupine, Nevada	E,L	X		ME	ME	EX
Penstemon, Eaton	P,E,L	X		EX	EX	ME
Penstemon, low	P,E,L	X		EX	EX	EX
Penstemon, Palmer	P,E	X	X	EX	EX	PO
Sweetclover, yellow	P,E		X	EX	EX	PO
Sweetvetch, Utah	E,L	X		ME	ME	ME
Yarrow, western	P,E,L	X	X	EX	EX	ME
Shrubs						
Bitterbrush, antelope	P,E,L	X		ME	EX	EX
Cliffrose, Stansbury	P,E,L	X		ME	ME	EX
Ephedra, green	P,E,L	X		PO	ME	EX

(con.)

Table 18 (Con.)

Species	Ecological status[a]	Use index for: Restoration plantings	Use index for: Revegetation plantings	Competitiveness[b] as a seedling in the presence of: Maximum competition	Competitiveness[b] as a seedling in the presence of: Minimum competition	Mature plant
Shrubs (con.)						
Ephedra, Nevada	P,E,L	X		PO	ME	EX
Hopsage, spiny	P,E,L	X		ME	ME	EX
Rabbitbrush, mountain low	P,E,L	X	X	EX	EX	ME
Rabbitbrush, mountain and basin whitestem rubber	P,E,L	X	X	EX	EX	ME
Sagebrush, basin big	P,E,L	X	X	ME	EX	EX
Sagebrush, Wyoming big	P,E,L	X		ME	EX	EX
Sagebrush, foothills big	P,E,L	X		ME	ME	EX
Sagebrush, low	P,E,L	X		ME	EX	EX
Saltbush, fourwing	P,E,L	X	X	ME	ME	ME
Winterfat	P,E,L	X	X	ME	ME	ME

Growth form	Seeding rate: Precipitation: 9 to 13 inches	13+ inches
	Pls lb/acre[c]	
Grasses	4 to 5	4 to 5
Forbs	4 to 5	5 to 6
Shrubs	3 to 4	4 to 5

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 19—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding mountain big sagebrush sites.

Species	Ecological status[a]	Use index for:		Competitiveness[b] as a seedling in the presence of:		Mature plant
		Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	
Grasses						
Bluegrass, big	P,E,L	X	X	ME	ME	ME
Bluegrass, Canada	E,L		X	ME	ME	ME
Bluegrass, Sandberg	P,E,L	X		ME	ME	ME
Brome, Regar	P,E,L		X	EX	EX	ME
Brome, smooth (southern)	P,E,L		X	EX	EX	EX,NC
Fescue, hard sheep	P,E,L		X	ME	ME	EX,NC
Fescue, Idaho	E,L	X		PO	ME	ME
Fescue, sulcata sheep	P,E,L	X	X	ME	ME	EX
Fescue, sheep	P,E,L	X	X	ME	ME	ME
Junegrass, prairie	P,E,L	X		ME	ME	ME
Muttongrass	P,E,L	X		ME	ME	ME
Needle-and-thread	P,E	X		ME	ME	ME
Needlegrass, green	P,E,L	X	X	ME	ME	ME
Needlegrass, Letterman	P,E,L	X		ME	ME	ME
Oatgrass, tall	P,E		X	ME	ME	ME
Orchardgrass, ‘Paiute’	P,E,L		X	EX	EX	EX
Ricegrass, Indian	P,E,L	X		ME	EX	ME
Rye, mountain	P,E		X	EX	EX	ME
Squirreltail, bottlebrush	P,E	X	X	EX	EX	ME
Wheatgrass, bluebunch	P,E,L	X		EX	EX	ME
Wheatgrass, fairway crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC
Wheatgrass, slender	P,E,L	X		EX	EX	ME
Wheatgrass, streambank	P,E,L	X	X	ME	ME	ME
Wheatgrass, thickspike	P,E,L	X	X	ME	ME	EX
Wheatgrass, western	P,E,L	X	X	PO	ME	EX
Wildrye, Great Basin	P,E	X		PO	ME	ME
Forbs						
Alfalfa (drought tolerant)	P,E,L		X	EX	EX	ME
Aster, Pacific	P,E	X	X	ME	ME	ME
Balsamroot, arrowleaf	E,L	X		PO	PO	EX
Burnet, small	P,E,L		X	EX	EX	ME
Crownvetch	P,E,L		X	ME	ME	ME
Flax, Lewis	P,E,L	X	X	EX	EX	ME
Goldeneye, showy	P,E,L	X	X	ME	ME	PO
Lupine, mountain	E,L	X		PO	ME	ME
Lupine, silky	E,L	X		ME	ME	ME
Milkvetch, cicer	P,E,L		X	ME	ME	ME
Penstemon, Eaton	P,E,L	X		EX	EX	ME
Penstemon, low	P,E,L		X	EX	EX	EX
Penstemon, Palmer	P,E	X		EX	EX	PO

(con.)

Table 19 (Con.)

Species	Ecological status[a]	Use index for: Restoration plantings	Use index for: Revegetation plantings	Competitiveness[b] as a seedling in the presence of: Maximum competition	Competitiveness[b] as a seedling in the presence of: Minimum competition	Mature plant
Forbs (con.)						
Penstemon, Rocky Mountain	P,E,L	X	X	ME	ME	ME
Penstemon, Wasatch	P,E,L	X		EX	EX	ME
Sainfoin	P,E		X	ME	ME	ME
Sweetclover, yellow	P,E		X	EX	EX	PO
Sweetvetch, Utah	P,E,L	X		ME	ME	ME
Trefoil, birdsfoot	P,E		X	ME	ME	ME
Yarrow, western	P,E,L	X	X	EX	EX	ME
Shrubs						
Bitterbrush, antelope	P,E,L	X	X	ME	EX	EX
Ceanothus, Martin	P,E,L	X		PO	ME	EX
Ceanothus, snowbush	P,E,L	X		ME	ME	EX
Chokecherry, black	E,L	X		PO	PO	EX
Cliffrose, Stansbury	P,E,L	X		ME	ME	EX
Elderberry, blue	P,E,L	X		PO	ME	EX
Ephedra, green	E,L	X		ME	ME	ME
Eriogonum, sulfur	P,E,L	X	X	ME	ME	ME
Eriogonum, Wyeth	P,E,L	X	X	ME	ME	ME
Kochia, forage	P,E		X	ME	EX	ME
Mountain mahogany, curlleaf	P,E,L	X	X	PO	ME	EX
Mountain mahogany, true	P,E,L	X	X	PO	ME	EX
Rabbitbrush, mountain low	P,E,L	X	X	EX	EX	EX
Rabbitbrush, mountain rubber	P,E,L	X	X	EX	EX	EX
Rabbitbrush, mountain and basin whitestem rubber	P,E,L	X	X	EX	EX	EX
Rose, Woods	P,E,L	X	X	PO	PO	EX
Sagebrush, low	P,E,L	X		EX	EX	ME
Sagebrush, mountain big	P,E,L	X	X	EX	EX	EX
Sagebrush, silver	P,E,L	X		EX	EX	ME
Sagebrush, foothills big	P,E,L	X	X	EX	EX	EX
Saltbush, fourwing	P,E	X	X	ME	ME	ME
Serviceberry, Saskatoon	P,E,L	X		PO	PO	EX
Snowberry, mountain	P,E,L	X		PO	PO	EX
Squawapple	P,E,L	X		PO	PO	EX
Sumac, skunkbush	P,E,L	X		PO	ME	EX
Sumac, Rocky Mountain smooth	P,E,L	X		PO	ME	EX

	Seeding rate	
	Precipitation	
Growth form	12 to 17 inches	17+ inches
	Pls lb/acre[c]	
Grasses	4 to 6	4 to 5
Forbs	4 to 6	3 to 5
Shrubs	3 to 4	3 to 4

---

[a] Species status: P = pioneer; E = early seral; L = late seral.

[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.

[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 20—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding Wyoming big sagebrush sites.

Species	Ecological status[a]	Use index for: Restoration plantings	Use index for: Revegetation plantings	Competitiveness[b] as a seedling in the presence of: Maximum competition	Competitiveness[b] as a seedling in the presence of: Minimum competition	Mature plant
Grasses						
Bluegrass, Sandberg	P,E,L	X		ME	ME	EX
Dropseed, sand	P,E,L	X	X	PO	ME	EX
Fescue, hard sheep	P,E,L		X	ME	ME	EX
Fescue, Idaho	P,E,L	X		PO	ME	ME
Needle-and-thread	P,E	X		ME	ME	ME
Needlegrass, Thurber	P,E,L	X		ME	ME	EX
Ricegrass, Indian	P,E,L	X		ME	ME	EX
Rye, mountain	P,E		X	EX	EX	ME
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	EX
Wheatgrass, bluebunch	P,E,L		X	EX	EX	EX
Wheatgrass, fairway crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC
Wheatgrass, Siberian	P,E,L		X	EX	EX	EX,NC
Wheatgrass, streambank	P,E,L	X		ME	ME	ME
Wheatgrass, thickspike	P,E,L	X		ME	ME	EX
Wheatgrass, western	P,E,L	X		PO	ME	EX
Wildrye, Great Basin	P,E,L	X		PO	ME	EX
Wildrye, Russian	P,E,L		X	PO	ME	EX
Forbs						
Alfalfa	P,E,L		X	ME	ME	PO
Burnet, small	P,E,L		X	ME	ME	PO
Flax, Lewis	P,E,L	X	X	ME	ME	PO
Goldeneye, Nevada showy	P,E,L	X	X	ME	ME	PO
Globemallow, gooseberryleaf	P,E,L	X	X	PO	ME	EX
Globemallow, scarlet	P,E,L	X	X	PO	ME	EX
Lupine, Nevada	E,L	X		ME	ME	ME
Penstemon, Palmer	P,E,L	X	X	ME	ME	PO
Sweetclover, yellow	P,E		X	EX	EX	PO
Shrubs						
Ephedra, green	P,E,L	X		PO	PO	PO
Ephedra, Nevada	P,E,L	X		PO	PO	ME
Hopsage, spiny	P,E,L	X		PO	ME	EX
Kochia, forage	P,E,L		X	EX	EX	ME
Peachbrush, desert	P,E,L	X		PO	PO	EX
Rabbitbrush, mountain low	P,E,L	X	X	EX	EX	ME
Rabbitbrush, mountain and basin whitestem rubber	P,E,L	X	X	EX	EX	EX
Sagebrush, foothills big	P,E,L	X	X	EX	EX	EX
Sagebrush, Wyoming big	P,E,L	X	X	ME	EX	EX
Saltbush, fourwing	P,E	X	X	ME	ME	ME
Winterfat	P,E,L	X	X	ME	ME	ME

Growth form	Seeding rate
	Pls lb/acre[c]
Grasses	5 to 6
Forbs	4 to 5
Shrubs	2 to 3

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 21—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding black sagebrush sites.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Grasses						
Bluegrass, Sandberg	P,E,L	X		ME	ME	ME
Needle-and-thread	P,E	X		ME	ME	ME
Ricegrass, Indian	P,E,L	X		ME	ME	ME
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	EX
Wheatgrass, fairway crested	P,E,L		X	EX	EX	ME,NC
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, streambank	P,E,L	X	X	ME	ME	ME
Wheatgrass, western	P,E,L	X	X	PO	ME	EX
Wildrye, Russian	P,E,L		X	PO	ME	EX
Forbs						
Globemallow, gooseberryleaf	P,E,L	X	X	PO	PO	ME
Globemallow, scarlet	P,E,L	X	X	PO	PO	ME
Penstemon, Palmer	P,E	X	X	EX	EX	PO
Shrubs						
Ephedra, green	P,E,L	X		PO	ME	PO
Ephedra, Nevada	P,E,L	X		PO	ME	PO
Rabbitbrush, low	P,E,L	X	X	EX	EX	ME
Sagebrush, black	P,E,L	X	X	ME	ME	EX
Sagebrush, low	P,E,L	X		ME	ME	EX
Winterfat	P,E,L	X	X	ME	ME	ME

Growth form	**Seeding rate**
	Pls lb/acre[c]
Grasses	6 to 8
Forbs	2 to 3
Shrubs	2 to 4

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 22—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding low sagebrush sites.

		Use index for:		**Competitiveness[b] as a seedling in the presence of:**		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Grasses						
Bluegrass, Sandberg	P,E,L	X	X	ME	EX	ME
Fescue, hard sheep	P,E,L	X	X	EX	EX	EX,NC
Fescue, Idaho	E,L	X	X	ME	ME	ME
Muttongrass	P,E,L	X	X	ME	ME	ME
Needle-and-thread	P,E	X		ME	EX	PO
Ricegrass, Indian	P,E,L	X	X	ME	ME	EX
Rye, mountain	P,E		X	EX	EX	PO
Squirreltail, bottlebrush	P,E	X	X	ME	EX	PO
Sacatoon, alkali	P,E,L	X		ME	ME	ME
Wheatgrass, bluebunch	P,E,L	X	X	ME	EX	ME
Wheatgrass, fairway crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC
Wheatgrass, Siberian	P,E,L		X	ME	EX	ME,NC
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, streambank	P,E,L	X	X	ME	ME	ME
Wheatgrass, thickspike	P,E,L	X	X	ME	EX	ME
Wildrye, Russian	P,E,L		X	ME	EX	EX
Forbs						
Burnet, small	P,E		X	ME	ME	ME
Flax, Lewis	P,E	X	X	ME	ME	ME
Globemallow, scarlet	P,E,L	X	X	PO	PO	EX
Penstemon, Palmer	P,E	X	X	ME	ME	PO
Sweetclover, yellow	P		X	ME	ME	ME
Shrubs						
Rabbitbrush, low	P,E	X	X	ME	ME	ME
Rabbitbrush, mountain whitestem rubber	P,E	X	X	ME	ME	ME
Sagebrush, Wyoming big	P,E,L	X	X	ME	ME	EX
Sagebrush, black	P,E,L	X	X	ME	ME	EX
Saltbush, fourwing	P,E,L	X	X	PO	ME	EX

Growth form	**Seeding rate**
	Pls lb/acre[c]
Grasses	4 to 6
Forbs	2 to 3
Shrubs	2 to 3

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 23—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding threetip sagebrush sites.

Species	Ecological status[a]	Use index for: Restoration plantings	Use index for: Revegetation plantings	Competitiveness[b] as a seedling in the presence of: Maximum competition	Competitiveness[b] as a seedling in the presence of: Minimum competition	Mature plant
Grasses						
Bluegrass, Sandberg	P,E,L	X	X	EX	EX	EX
Brome, Regar	P,E,L		X	ME	ME	ME
Brome, smooth (southern and northern)	P,E,L		X	EX	EX	EX,NC
Fescue, hard sheep	P,E,L		X	ME	EX	EX,NC
Fescue, Idaho	P,E,L	X	X	PO	ME	ME
Fescue, sheep	P,E,L	X	X	EX	EX	EX
Junegrass, prairie	P,E	X		PO	ME	ME
Muttongrass	P,E,L	X	X	ME	ME	ME
Needlegrass, green	E,L	X	X	ME	ME	ME
Needlegrass, Thurber	P,E,L	X		PO	EX	ME
Oatgrass, tall	P,E		X	EX	EX	ME
Orchardgrass	P,E,L		X	EX	EX	EX
Ricegrass, Indian	P,E	X	X	ME	EX	EX
Rye, mountain	P,E		X	EX	EX	PO
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME
Wheatgrass, bluebunch	E,L	X	X	ME	ME	EX
Wheatgrass, fairway crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, intermediate	P,E,L		X	EX	EX	EX,NC
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX,NC
Wheatgrass, Siberian	P,E,L		X	ME	EX	EX,NC
Wheatgrass, slender	E,L	X	X	ME	EX	ME
Wheatgrass, streambank	P,E,L	X	X	ME	ME	EX
Wheatgrass, thickspike	P,E,L	X	X	ME	ME	EX
Wheatgrass, western	P,E,L	X	X	ME	ME	EX
Wildrye, Great Basin	P,E,L	X	X	ME	ME	EX
Wildrye, Russian	P,E,L		X	PO	ME	EX
Forbs						
Alfalfa (drought tolerant)	P,E,L		X	ME	ME	EX
Balsamroot, arrowleaf	P,E	X	X	PO	ME	EX
Balsamroot, cutleaf	P,E	X	X	PO	ME	EX
Burnet, small	P,E		X	ME	ME	ME
Flax, Lewis	P,E	X	X	ME	ME	ME
Goldeneye, showy	P,E,L	X	X	ME	ME	EX
Globemallow, gooseberry	P,E		X	PO	ME	EX
Lupine, silky	E,L		X	PO	PO	EX
Penstemon, Eaton	P,E	X	X	ME	ME	ME
Penstemon, Palmer	P,E	X	X	ME	ME	ME
Sweetvetch, Utah	P,E,L	X	X	ME	ME	ME
Sunflower	P,E	X	X	ME	EX	ME
Yarrow, western	P,E,L	X	X	ME	EX	EX

(con.)

Table 23 (Con.)

Species	Ecological status[a]	Use index for: Restoration plantings	Use index for: Revegetation plantings	Competitiveness[b] as a seedling in the presence of: Maximum competition	Competitiveness[b] as a seedling in the presence of: Minimum competition	Mature plant
Shrubs						
Bitterbrush, antelope	P,E,L	X	X	ME	EX	EX
Ceanothus, snowbush	P,E	X	X	ME	EX	EX
Chokecherry, black	P,E,L	X	X	PO	PO	EX
Elderberry, blue	P,E	X	X	PO	PO	EX
Rabbitbrush, mountain low	P,E	X	X	ME	ME	ME
Rabbitbrush, mountain rubber	P,E	X	X	ME	ME	ME
Rabbitbrush, mountain and basin whitestem rubber	P,E	X	X	ME	ME	ME
Rose, Woods	P,E,L	X	X	PO	ME	EX
Spirea, rock	P,E	X		PO	PO	EX
Sagebrush, basin big	P,E,L	X	X	ME	ME	ME
Sagebrush, mountain big	P,E,L	X	X	ME	ME	ME
Sagebrush, threetip	P,E,L	X	X	ME	ME	EX
Sagebrush, Wyoming big	P,E,L	X	X	ME	ME	ME
Serviceberry, Saskatoon	P,E,L	X	X	PO	PO	EX
Snowberry, mountain	P,E,L	X		PO	PO	EX
Sumac, skunkbush	P,E,L	X	X	ME	ME	EX

Growth form	Seeding rate
	Pls lb/acre[c]
Grasses	4 to 5
Forbs	3 to 5
Shrubs	3 to 4

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 24—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding silver sagebrush, timberline sagebrush, and subalpine big sagebrush sites.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	Ecological status[a]	Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	Mature plant
Grasses and sedges						
Barley, meadow	P,E,L	X	X	EX	EX	ME
Bluegrass, big	E,L	X	X	ME	ME	ME
Bluegrass, Canada	E,L		X	ME	ME	ME
Brome, meadow	P,E,L		X	ME	ME	ME
Brome, mountain	P,E,L	X	X	EX	EX	EX
Brome, smooth (northern and southern)	P,E,L		X	EX	EX	EX,NC
Brome, subalpine	E,L		X	ME	EX	EX,NC
Fescue, hard sheep	P,E,L		X	ME	ME	EX,NC
Fescue, sheep	P,E,L	X	X	ME	ME	EX,NC
Foxtail, creeping	P,E,L		X	ME	EX	EX
Foxtail, meadow	P,E,L		X	ME	ME	EX
Needlegrass, green	P,E,L	X		ME	ME	ME
Needlegrass, Letterman	P,E,L	X	X	ME	ME	ME
Oatgrass, tall	P,E		X	ME	EX	ME
Orchardgrass	P,E,L		X	EX	EX	ME
Hairgrass, tufted	P,E	X	X	PO	ME	ME
Sedge, ovalhead	P,E,L	X		PO	ME	EX
Timothy	P,E		X	EX	EX	PO
Timothy, alpine	P,E,L	X		EX	EX	ME
Wheatgrass, slender	P,E,L	X	X	EX	EX	ME
Forbs						
Alfalfa (nonirrigated type)	P,E		X	EX	EX	ME
Aster, blueleaf	P,E,L	X		ME	ME	EX
Aster, Engelmann	P,E,L	X		PO	ME	EX
Crownvetch	P,E,L		X	ME	ME	EX
Geranium, sticky and Richardson	P,E,L	X	X	ME	ME	EX
Goldeneye, showy	P,E	X		ME	EX	EX
Goldenrod, Canada	P,E,L	X		ME	ME	EX
Groundsel, butterweed	P,E	X		PO	ME	EX
Lupine, mountain	P,E	X		ME	ME	EX
Lupine, silky	P,E	X		ME	ME	EX
Milkvetch, cicer	P,E,L		X	ME	EX	ME
Penstemon, Eaton	P,E	X	X	ME	ME	ME
Penstemon, low	P,E	X	X	ME	ME	ME
Penstemon, Rocky Mountain	P,E	X	X	ME	ME	ME
Penstemon, Wasatch	P,E	X	X	ME	ME	EX
Sage, Lousiana	P,E	X	X	ME	ME	PO
Sainfoin	P,E		X	ME	EX	ME
Sweetanise	P,E,L	X	X	ME	ME	ME
Yarrow, western	P,E,L	X	X	ME	ME	ME

(con.)

Table 24 (Con.)

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	Ecological status[a]	Restoration plantings	Revegetation plantings	Maximum competition	Minimum competition	Mature plant
Shrubs						
Ceanothus, Martin	P,E,L	X	X	PO	ME	EX
Ceanothus, snowbush	P,E,L	X	X	ME	ME	EX
Chokecherry, black	P,E,L	X	X	PO	PO	EX
Cinquefoil, shrubby	P,E,L	X	X	ME	ME	EX
Elderberry, blue	P,E	X	X	PO	ME	EX
Elderberry, red	P,E	X	X	PO	ME	EX
Rabbitbrush, mountain low	P,E	X	X	ME	ME	ME
Sagebrush, silver	P,E,L	X	X	ME	ME	EX
Sagebrush, subalpine big	P,E,L	X	X	ME	ME	EX
Sagebrush, timberline big	P,E,L	X	X	ME	ME	EX
Snowberry, mountain big	P,E,L	X	X	PO	PO	EX

Growth form	Seeding rate
	Pls lb/acre[c]
Grasses	4 to 5
Forbs	3 to 4
Shrubs	3 to 4

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 25—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding shadscale saltbush sites.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Grasses						
Bluegrass, Sandberg	P,E,L	X	X	ME	ME	ME
Dropseed, sand	P,E,L	X	X	ME	ME	EX
Ricegrass, Indian	P,E,L	X	X	ME	ME	EX
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX,NC
Wheatgrass, Siberian	P,E,L		X	EX	EX	EX,NC
Wheatgrass, streambank	P,E,L	X	X	ME	ME	ME
Wheatgrass, western	P,E,L	X	X	PO	ME	ME
Wildrye, Russian	P,E,L		X	PO	PO	EX
Wildrye, Salina	P,E,L	X		PO	PO	EX
Forbs						
Globemallow, gooseberryleaf	P,E,L	X	X	PO	ME	EX
Globemallow, scarlet	P,E,L	X	X	PO	ME	EX
Yarrow, western	P,E,L	X	X	ME	ME	EX
Shrubs						
Budsage	P,E,L	X		PO	PO	EX
Hopsage, spineless	P,E,L	X		PO	ME	EX
Hopsage, spiny	P,E,L	X		PO	ME	EX
Peachbrush, desert	P,E,L	X		PO	PO	EX
Rabbitbrush, spreading	P,E	X	X	ME	ME	ME
Rabbitbrush, low	P,E	X	X	ME	ME	ME
Sagebrush, black	P,E,L	X	X	ME	ME	ME
Sagebrush, Wyoming big	P,E,L	X	X	ME	ME	ME
Saltbush, fourwing	P,E	X	X	ME	ME	ME
Saltbush, Gardner	P,E,L	X	X	ME	ME	EX
Saltbush, mat	P,E	X	X	ME	ME	EX
Shadscale	P,E,L	X	X	PO	PO	EX
Winterfat	P,E,L	X	X	ME	EX	EX

Growth form	**Seeding rate**
	Pls lb/acre[c]
Grasses	5 to 7
Forbs	1 to 2
Shrubs	3 to 4

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 26—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding black greasewood sites.

		Use index for:		Competitiveness[b] as a seedling in the presence of:		
Species	**Ecological status[a]**	**Restoration plantings**	**Revegetation plantings**	**Maximum competition**	**Minimum competition**	**Mature plant**
Grasses						
Bluegrass, Sandberg	P,E,L	X	X	ME	ME	ME
Squirreltail, bottlebrush	P,E,L	X	X	EX	EX	ME
Wheatgrass, standard crested	P,E,L		X	EX	EX	EX
Wheatgrass, Siberian	P,E,L		X	ME	EX	EX
Wheatgrass, streambank	P,E,L	X	X	PO	ME	EX
Wheatgrass, tall	P,E,L		X	EX	EX	EX
Wheatgrass, western	P,E,L	X	X	ME	ME	EX
Wildrye, Great Basin	P,E,L	X	X	ME	ME	EX
Wildrye, Russian	P,E,L		X	PO	PO	EX
Forbs						
Globemallow, gooseberryleaf	P,E,L	X	X	ME	ME	ME
Shrubs						
Greasewood, black	P,E,L	X		PO	PO	EX
Kochia, forage	P,E,L		X	EX	EX	EX
Sagebrush, basin big	P,E	X	X	ME	ME	ME
Saltbush, Castle Valley clover	P,E,L	X	X	ME	ME	EX
Saltbush, fourwing	P,E	X	X	ME	ME	ME
Saltbush, Gardner	P,E	X	X	ME	ME	ME
Shadscale	P,E,L	X	X	PO	PO	ME
Winterfat	P,E,L	X	X	ME	ME	EX

Growth form	**Seeding rate**
	Pls lb/acre[c]
Grasses	6 to 8
Forbs	1
Shrubs	3 to 4

---

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 27—Ecological status, use index, competitiveness, and seeding rate for species adapted for seeding in the blackbrush type.

Species	Ecological status[a]	Use index for: Restoration plantings	Use index for: Revegetation plantings	Competitiveness[b] as a seedling in the presence of: Maximum competition	Competitiveness[b] as a seedling in the presence of: Minimum competition	Mature plant
Grasses						
Dropseed, sand	P,E,L	X	X	ME	ME	EX
Galleta	P,E	X	X	ME	ME	ME
Needle-and-thread	P,E	X	X	ME	ME	PO
Ricegrass, Indian	P,E,L	X	X	ME	ME	EX
Squirreltail, bottlebrush	P,E	X	X	ME	EX	ME
Wheatgrass, fairway crested	P,E		X	ME	EX	ME
Wheatgrass, pubescent	P,E,L		X	EX	EX	EX
Wheatgrass, Siberian	P,E,L		X	ME	ME	EX
Wheatgrass, standard crested	P,E		X	ME	EX	ME
Wheatgrass, western	P,E,L	X	X	ME	ME	EX
Wildrye, Russian	P,E,L		X	PO	PO	EX
Forbs						
Globemallow, gooseberryleaf	P,E,L	X	X	ME	ME	ME
Globemallow, scarlet	P,E,L	X	X	ME	ME	ME
Penstemon, Palmer	P,E	X	X	PO	ME	ME
Shrubs						
Apache plume	P,E,L	X		PO	ME	EX
Bitterbrush, desert	P,E,L	X	X	ME	EX	EX
Blackbrush	P,E,L	X		ME	ME	EX
Buffaloberry, roundleaf	P,E,L	X		PO	PO	EX
Ephedra, Nevada	P,E,L	X		ME	ME	EX
Hopsage, spineless	P,E,L	X		ME	ME	EX
Hopsage, spiny	P,E,L	X		ME	ME	EX
Kochia, forage	P,E		X	EX	EX	EX
Peachbrush, desert	P,E,L	X	X	PO	PO	EX
Rabbitbrush, low	P,E	X	X	ME	ME	ME
Sagebrush, black	P,E,L	X	X	ME	ME	ME
Sagebrush, sand	P,E,L	X		ME	ME	ME
Saltbush, fourwing	P,E,L	X	X	ME	EX	ME
Winterfat	P,E,L	X	X	ME	EX	EX

Growth form	Seeding rate
	Pls lb/acre[c]
Grasses	4 to 6
Forbs	3 to 4
Shrubs	2 to 3

[a] Species status: P = pioneer; E = early seral; L = late seral.
[b] Competitiveness rating: PO = poor competitor; ME = medium competitor; EX = excellent competitor; NC = noncompatable with other species.
[c] Drill rate—broadcast seeding requires ¼ to ⅓ more seed.

Table 28—Species with the ability to establish and spread within stands of cheatgrass brome, red brome, or medusahead[a].

			Adapted to:			Competitiveness[b] as a:	
Species	Native	Introduced	Mid-elevation	Foothills and valleys	Spread-ability[b]	Seedling	Mature plant
Grasses							
Bluegrass, Sandberg	X		X		ME	ME	ME
Fescue, hard sheep		X	X		EX	ME	EX
Fescue, Idaho	X		X		ME	ME	ME
Needle-and-thread	X			X	ME	EX	ME
Needlegrass, Thurber	X			X	EX	ME	EX
Ricegrass, Indian	X			X	PO	PO	EX
Rye, mountain		X		X	EX	EX	EX
Squirreltail, bottlebrush	X			X	EX	EX	ME
Wheatgrass, bluebunch	X		X	X	ME	EX	
Wheatgrass, fairway crested		X	X	X	ME	EX	EX
Wheatgrass, standard crested		X	X	X	ME	EX	EX
Wheatgrass, ‘Hycrest’		X	X		ME	EX	EX
Wheatgrass, intermediate		X	X		ME	EX	EX
Wheatgrass, pubescent		X	X		ME	ME	EX
Wheatgrass, streambank	X		X	X	ME	ME	EX
Wheatgrass, thickspike	X		X	X	EX	ME	EX
Wheatgrass, western	X		X	X	ME	ME	EX
Forbs							
Aster, Pacific	X		X		EX	ME	EX
Burnet, small		X	X	X	EX	EX	ME
Flax, Lewis	X	X		X	EX	EX	EX
Penstemon, Palmer	X		X	X	EX	EX	EX
Yarrow, western	X		X	X	EX	EX	EX
Shrubs							
Kochia, forage		X	X	X	EX	EX	EX
Rabbitbrush, low	X		X	X	ME	ME	EX
Sagebrush, big	X			X	ME	ME	EX

[a] Individual species and mixtures recommended for use in cheatgrass, red brome, and medusahead areas are essentially the same as are recommended for seeding the vegetative type that existed prior to when the annuals gained control. These include: mountain brush-ponderosa pine (table 13), juniper-pinyon (tables 14,15,16), fourwing saltbush (table 17), basin big sagebrush (table 18), mountain big sagebrush (table 19), Wyoming big sagebrush (table 20), black sagebrush (table 21), low sagebrush (table 22), threetip sagebrush (table 23),shadscale saltbush (table 25), black greasewood (table 26), and blackbrush (table 27).

[b] Key to ability to spread and compete with annual grasses: PO = poor spreader, poor competitor; ME = medium spreadability, medium competitor; EX = excellent spreadability, excellent competitor.

Index

RMRS
ROCKY MOUNTAIN RESEARCH STATION

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals.

Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

Research Locations

Flagstaff, Arizona
Fort Collins, Colorado*
Boise, Idaho
Moscow, Idaho
Bozeman, Montana
Missoula, Montana
Lincoln, Nebraska
Reno, Nevada
Albuquerque, New Mexico
Rapid City, South Dakota
Logan, Utah
Ogden, Utah
Provo, Utah
Laramie, Wyoming

*Station Headquarters, Natural Resources Research Center,
2150 Centre Avenue, Building A, Fort Collins, CO 80526

Federal Recycling Program Printed on Recycled Paper

Shadscale—bottlebrush squirreltail plant community *Photo by Bob Moseley*