Sagebrush Establishment on Mined Lands: Ecology and Research

Gerald E. Schuman, Timothy C. Richmond, and Dennis R. Neuman

Editors

Proceedings of Symposium, "Sagebrush Establishment on Mined Lands," 2000 Billings Land Reclamation Symposium, March 20-24, 2000, Billings, MT

Table of Contents

Preface

The Wyoming Abandoned Coal Mine Land Research Program (WACMLRP) funded by the Wyoming Department of Environmental Quality, Abandoned Mine Land Division and administered by the Office of Research, University of Wyoming supports applied research to address key issues confronting the mining industry and State agencies that are responsible for reclamation and associated environmental aspects of mining. This program was initiated in 1991 and during the ensuing years one of the key issues that confronted the mining industry and the Land Quality Division, Department of Environmental Quality was the need to better understand native shrub ecology and develop technology that would enable establishment of native shrubs on rangelands disturbed by mining. In the period from 1991 through 1998 the WACMLRP funded five research projects that dealt with the study of sagebrush ecology, seed ecology, and the development of cultural practices to enhance sagebrush re-establishment from seed on reclaimed mined lands. These research projects have greatly expanded our knowledge of sagebrush community dynamics, seed ecology, the effects of cultural practices such as mulching, topsoil management, and competition on sagebrush seedling establishment, and have allowed for assessing the effectiveness of historic revegetation practices on sagebrush establishment on pre-1985 reclamation sites. To further assess the state-of-the-art knowledge base of sagebrush establishment on mined lands the Steering Committee of the WACMLRP concluded that a symposium be organized and the research investigators of the these five projects be invited to report on their findings and conclusions. To develop a more thorough and comprehensive symposium program other sagebrush researchers and industry representatives were invited. The symposium was held as part of the 2000 Billings Land Reclamation Symposium (March 20-24, 2000 Billings, MT) on March 20. Attendance was excellent, exceeding 100 during most of the symposium and discussion periods were effective and fully utilized. The attendance and discussion at the symposium are indicators of the interest in this topic and the need to ensure that these research results are readily available to the industry and regulatory agencies.

The symposium was composed of nine presentations and opened with a presentation on the general topic of sagebrush ecology and sagebrush restoration potential. This presentation gave an excellent background on the ecology of big sagebrush communities and reviewed the historic literature relating to its restoration potential on rangelands in the western U.S. Wyoming's post-mine shrub density regulation and its interpretation was also presented. During the discussion period questions arose as to how the shrub density evaluations should be monitored and how these measurements would be interpreted to meet the regulations. Seed factors (viability, germination, processing, and dormancy), cultural practices (mulches, topsoil management, arbuscular mycorrhiza, and competition) to aid establishment, and the effects of grass competition and sagebrush seeding rates on sagebrush establishment were discussed in three separate presentations. Using nursery grown sagebrush transplants to develop seed production plots and facilitation beds to enhance natural recruitment of sagebrush was proposed and discussed as a method of re-establishing big sagebrush on reclaimed mined lands. Studies on the demographic characteristics of big sagebrush communities has shown that Wyoming and mountain big sagebrush stand ages are older than those for basin big sagebrush. Research also showed that mean recruitment intervals (years) were shorter for basin than for Wyoming and mountain big sagebrush. A review of historic sagebrush establishment practices by mines in the Powder River Basin covering the past 20 years was presented. This chronology showed that the mining industry has been quick to implement new research findings into their reclamation practices to aid them in establishing big sagebrush. Significant advances in establishing big sagebrush has occurred and is reflected in sagebrush seedling densities in the early phases of reclamation but concern exists as to the longevity of these seedlings and severe wildlife browse. The symposium was concluded with a presentation that reviewed the chronology of sagebrush research conducted under the WACMLRP and summarized the significant findings from this research. This last presentation also identified additional research needs and highlighted the fact that the research and technology developed must keep in mind the economics of shrub re-establishment because of the very competitive coal market.

This collection of presentations/papers identified the importance of big sagebrush in reclaimed rangeland ecosystems and discussed a significant pool of recent research that greatly aids our understanding of the many factors affecting its re-establishment. These research findings ranged from understanding the demographic characteristics of native sagebrush stands and the influence of climate on that demographics; to research on seed quality and on the many cultural practices that have aided re-establishment as noted in the constantly improving re-establishment success demonstrated by the mining industry in the Powder River Basin. The symposium also pointed out that economics of new technology developed for re-establishment of big sagebrush must be a major consideration. The question was also raised as to whether additional cultural practices should be evaluated such as using livestock to aid establishment and whether soil physical and nutrient characteristics influence big sagebrush establishment.

The consensus of those in attendance at the symposium was that it was an excellent technology transfer mechanism and that much new knowledge exists. However, it was also clearly stated that additional advances could and must be made to make shrub establishment success a more consistent occurrence realizing that climatic conditions cannot be controlled, but our knowledge of precipitation patterns and other climatic variable be used in developing future technology and recommendations for big sagebrush establishment. A primary example of this is the fact that several researchers and the mining companies themselves have noted that seed viability in the field is longer than previously thought and this fact can be used to develop seeding recommendations that will greatly enhance the probabilities of successful re-establishment of big sagebrush considering the benefits received from other cultural practices.

The Editors

Big Sagebrush (*Artemisia Tridentata*) Communities – Ecology, Importance and Restoration Potential

Stephen B. Monsen[1] and Nancy L. Shaw[2]

Abstract

Big sagebrush (*Artemisia tridentata* Nutt.) is the most common and widespread sagebrush species in the Intermountain region. Climatic patterns, elevation gradients, soil characteristics and fire are among the factors regulating the distribution of its three major subspecies. Each of these subspecies is considered a topographic climax dominant. Reproductive strategies of big sagebrush subspecies have evolved that favor the development of both regional and localized populations.

Sagebrush communities are extremely valuable natural resources. They provide ground cover and soil stability as well as habitat for various ungulates, birds, reptiles and invertebrates. Species composition of these communities is quite complex and includes plants that interface with more arid and more mesic environments.

Large areas of big sagebrush rangelands have been altered by destructive grazing, conversion to introduced perennial grasses through artificial seeding and invasion of annual weeds, principally cheatgrass (*Bromus tectorum* L.). Dried cheatgrass forms continuous mats of fine fuels that ignite and burn more frequently than native herbs. As a result, extensive tracts of sagebrush between the Sierra Nevada and Rocky Mountains are rapidly being converted to annual grasslands. In some areas recent invasions of perennial weeds are now displacing the annuals. The current weed invasions and their impacts on native ecosystems are recent ecological events of unprecedented magnitude.

Restoration of degraded big sagebrush communities and reduction of further losses pose major challenges to land managers. Loss of wildlife habitat and recent invasion of perennial weeds into seedings of introduced species highlight the need to stem losses and restore native vegetation where possible. Initial efforts to stabilize degraded sagebrush communities relied upon the use of introduced grasses. It is now generally recognized that restoration of the structure, functions and values of sagebrush ecosystems requires the use of site adapted species, subspecies and ecotypes. Our ability to accomplish this goal is improving with the use of an increasing numbers of native species and development of seed production and seeding practices for these species.

---

[1]Rocky Mountain Research Station, USDA-Forest Service, Provo, UT 84606
[2]Rocky Mountain Research Station, USDA-Forest Service, Boise, ID 83702

Introduction

Big sagebrush (*Artemisia tridentata* Nutt.), the most widely distributed of the 11 sagebrush species in the Intermountain region, also occurs on the western Great Plains in western Montana, Wyoming and Colorado. Seasonal precipitation patterns, elevation gradients and soil conditions regulate the distribution of the three major subspecies of this landscape-dominating shrub.

Basin big sagebrush (*A. t.* Nutt. ssp. *tridentata*), once the most widespread of the three subspecies, is a tall, erect, heavily branched shrub growing 1 to 3 m in height with trunk-like main stems (Cronquist 1994). Plant crowns and heights of the broad panicles are uneven, giving the shrub a ragged appearance. Persistent leaves are narrowly lanceolate and apically 3-toothed. When crushed they emit a pungent, spicy odor (Blaisdell et al. 1982). Basin big sagebrush flowers from late August to October and seeds mature from October to November (McArthur et al. 1979).

This subspecies is common to dominant on plains, in valleys and canyon bottoms and along ditch banks and fence rows in areas below 2,500 m elevation that receive 32 to 36 cm of annual precipitation (Cronquist 1994, Goodrich and Neese 1986, Goodrich et al. 1999, Monsen and McArthur 1984). It normally occurs in sagebrush, rabbitbrush (*Chrysothamnus* Nutt. spp.), juniper (*Juniperus* L.) and pinyon (*Pinus* L.)-juniper communities on deep, productive, well-drained, gravelly to fine sandy loams and deep alluvial soils (Welsh et al. 1987). Many of these areas have been converted to agricultural uses. Some basin big sagebrush populations occur on alkaline soils and form mosaics with salt desert shrubs (McArthur et al. 1979).

Wyoming big sagebrush (*A. t*. Nutt. ssp. *wyomingensis* Beetle & Young) is the most xeric subspecies of big sagebrush, generally growing on shallow, gravelly soil on sites receiving 20 to 30 cm of annual precipitation (Cronquist 1994, Goodrich et al. 1999, Monsen and McArthur 1984). It exhibits a ragged growth habit, similar to that of basin big sagebrush, but most plants are less than 1 m in height. The main stems branch at or near ground level. Persistent leaves are narrowly cuneate to cuneate and emit a pungent odor when crushed (McArthur et al. 1979). Panicles are narrower than those of basin big sagebrush. Flowering occurs from late July to September and seeds mature in October and November.

Common throughout much of the Intermountain area, Wyoming big sagebrush also occurs east of the Continental Divide in Montana, Wyoming, and Colorado. It is most abundant at low to moderate elevations, but may be found at elevations up to 2,700 m in sagebrush, rabbitbrush, salt desert shrub, juniper and bitterbrush (*Purshia tridentata* [Pursh] D.C.) communities (Cronquist 1994, Welsh et al. 1987).

Mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle), like Wyoming big sagebrush, is normally less than 1 m in height, but some low elevation plants may be 2 m tall. Main branches divide near the ground and sometimes layer. Unlike the other two subspecies, the crown and inflorescence branches of Wyoming big sagebrush are of uniform height, giving the plant a spreading to rounded outline. Persistent leaves are broadly cuneate and spatulate and emit a sweet, camphor or mint-like odor (McArthur et al. 1979). Panicles are narrow and dense. Plants bloom in July and seeds mature from September through October (McArthur et al. 1979). Mountain big sagebrush occurs at elevations from 800 to 3,200 m on sites receiving more than 30 cm of annual precipitation (Cronquist 1994, Goodrich et al. 1999, Monsen and McArthur 1984). It grows on well-drained, slightly alkaline to slightly acid soils in plant communities ranging from sagebrush-grass to aspen (*Populus tremuloides* Michx.) to spruce (*Picea* Link.)-fir (*Abies* Hill.) (Sampson and Jesperson 1963, Welsh et al. 1987).

All subspecies of big sagebrush are considered topographic and edaphic climax dominants. Their ability to differentiate and adapt to the widely varying and continuously changing habitats of the Intermountain region is attributed, at least partially, to development of polyploid populations capable of surviving in drier habitats (McArthur 2000). In addition, hybridization between overlapping taxa and populations of this wind pollinated species produces new genetic combinations, thus expediting the occupation of available niches.

Several adaptive features influence the distribution and persistence of big sagebrush subspecies. These include variation in growth habit, root system development, response to fire, the ability to conduct photosynthesis at low temperatures and the production of allelopathic substances in roots and leaves that decrease the respiration of associated species and provide a chemical defense against herbivory (Blaisdell et al. 1982, Kelsey 1986a, Kelsey 1986b, Petersen 1995). Additional adaptive features include seed germination capabilities over a wide range of temperatures, unusual seed dispersal strategies, seed size and structure and timing of seed maturation (Blaisdell et al. 1982, Kelsey 1986a, Kelsey 1986b, Meyer and Monsen 1992, Petersen 1995).

Prior Use and Status of Big Sagebrush Communities in the West

Extensive disturbances have occurred throughout big sagebrush communities of the western United States. Degradation began soon after domestic livestock were introduced into the region beginning in the 1840's (Young et al. 1979). Grazing occurred throughout a wide range of plant associations at various elevations and in areas characterized by differing climatic regimes. Grazing was particularly disruptive in big sagebrush communities as use was imposed during spring and fall periods when forage quality and accessibility of these communities are generally greater than for upland communities, but when plants are most susceptible to damage. Consequently, herbaceous understory species associated with big sagebrush vegetation received concentrated and repeated heavy use, which reduced their vigor and ability to recover (Houston 1961). The duration of favorable temperature and soil water conditions for growth in spring is highly variable in sagebrush communities (Hanson et al. 1986). Thus in dry years, grazed plants were often further stressed, hastening the decline of the more palatable species.

Grazing also disrupted ecological processes associated with natural succession (Blaisdell et al. 1982), facilitating the invasion of annual weeds (Billings 1994, Mack 1981). Weed infestations, in turn, dramatically increased the frequency of wildfires and further reduced the vitality and integrity of the remaining native communities (Whisenant 1990). Increased fire frequency and aggressive annual weeds combined to displace big sagebrush with the ultimate result that extensive areas of shrub and perennial grass communities were converted to annual grasses (Bunting 1985, Piemeisel 1951). Pellant and Hall (1994) and Sparks et al. (1990) reported that more than 1.3 million hectares in Nevada, Oregon, Utah, Washington, and Idaho were occupied by cheatgrass (*Bromus tectorum* L.) and medusahead wildrye (*Taeniatherm caput-medusae* L.), while another 30.8 million hectares were classified as infested and susceptible to invasion by these two annual grasses.

Serious disturbances were created by livestock grazing in numerous other western plant communities at the same time big sagebrush sites were being impacted. Numerous high elevation watersheds were severely degraded by grazing as early as 1880 (Ellison 1960). This created such serious downstream problems that attention became focused on the restoration of aspen and mountain herbland communities. The importance of stabilizing high elevation watersheds prompted the selection of species that could provide immediate and permanent protective ground cover (Sampson 1921). As might be expected, the native species tested exhibited erratic establishment, due, in part, to inexperience and inappropriate planting techniques. Scientists and land managers discovered that various introduced perennial species, principally grasses, established quickly and provided uniform ground cover on exposed soils as well as palatable forage for livestock (Forsling and Dayton 1931).

Based on successes in high elevation watersheds, land managers accepted and began to use a number of introduced perennial grasses to stabilize disturbances in other plant communities (Meeuwig 1965). The introduction of exotic forage species to replace understory bunchgrasses on low elevation shrublands quickly became a common practice (Hull and Holmgren 1964, Plummer et al. 1955). In addition, a number of early surveys and inventories of western lands recommended conversion of shrub communities to introduced forage species (Williams 1898).

Many native plant communities, principally big sagebrush types, were converted to introduced perennial grasses and managed specifically for seasonal grazing by livestock (Hull 1971, Pechanec et al. 1944, Plummer et al. 1955). Land managers and private landowners accepted the concept that conversion of big sagebrush communities to introduced grasses would not only provide persistent cover, acceptable forage yields, and improved seasonal forage quality and availability, but would also control weeds and enhance wildlife habitat and watershed quality. Breeding and plant selection programs were instigated to develop introduced species as forage plants for big sagebrush communities (Johnson 1980, Johnson et al. 1981).

Later observations and studies of seeded watersheds and rangelands, including big sagebrush sites, began to indicate that introduced grasses were not compatible with native communities (Walker 1999). Their presence reduced the survival of remnant native species, restricted natural recruitment and changed the composition of entire communities. Seeding crested wheatgrass *(Agroypron cristatum* [L.] Gaertner), intermediate wheatgrass (*Elymus hispidus* [Opis] Meld) and smooth brome (*Bromus inermis* Leysser) directly with big sagebrush has prevented shrub seedlings from establishing (Richardson et al. 1986). Mature stands of these grasses also prevented natural recruitment of antelope bitterbrush (Monsen and Shaw 1982) and big sagebrush (Meyer 1994). Frischknecht and Bleak (1957) reported that seeded bluebunch wheatgrass (*Elymus spicatas* [Pursh] Gould) stands were more likely to permit sagebrush seedling recruitment than were crested wheatgrass stands. Seeding introduced grasses on big sagebrush sites occupied with some native perennial herbs and shrubs have resulted in the conversion of mixed assemblages of species to a predominance of introduced species. This conversion process has continued over a nearly 30-year period in some areas (Walker 1999). Its progress is influenced by climatic conditions as well as by livestock and wildlife use.

Livestock grazing, weed invasion, wildfires, and plant conversion projects have all negatively impacted wildlife habitats in big sagebrush communities (Dobler 1994; Workman and Low 1976). The high nutritional quality and variety of forbs and shrubs present in native communities is vital for maintaining wildlife diversity (Dietz and Negy 1976, Memmott 1995, Yoakum 1978). Many important shrubs, suffrutescent species, and broadleaf herbs that were critical to wildlife, particularly during winter periods were reduced (Updike et al. 1990) or lost. Declines or losses of species that furnish habitat for numerous wildlife species occurred throughout the sagebrush zone (Monsen and Shaw 1984, Peterson 1987, Shaw et al. 1999, Workman and Low 1976). A rapid and continued decline in populations of small mammals, raptors, sage grouse (*Centrocercus urophasianus*) (Connelly and Braun 1997), songbirds (Saab and Rich 1997), and other vertebrates and invertebrates has also occurred throughout big sagebrush communities of the West, particularly in the past 20 to 40 years.

The use of woody and herbaceous plants to restore wildlife habitat began prior to 1930 in several western states (Brown and Martinsen 1959, Holmgren 1954, Hubbard et al. 1959). By 1950 native species were being used to revegetate mined sites, roadway disturbances, parks and natural areas. The demand for site-adapted material prompted the collection and planting of some native species, but demands were small compared to those for seeds of introduced species used for rangeland and watershed seedings. During the 1950s the demand for native species for a wide range of sites grew rapidly.

A major increase in mining activities occurred in the western United States beginning in the mid 1960's. Open pit mining for coal provided a major source of income from areas previously used primarily for grazing. At the same time, public demand for revegetation of human-caused disturbances began increasing (Monsen and Plummer 1978, Wieland et al. 1971). Regulations were adapted to insure that disturbances were regraded, topsoiled and planted to a mixture of species that existed on the site prior to mining. Concern for proper revegetation of mined sites soon expanded to include roadways, pipelines and related disturbances (Megahan 1974). Native species were now considered valuable for providing ecologically stable communities.

In 1958 the Utah Fish and Game Department began funding a cooperative study with the USDA Forest Service to develop the ecological database and technology required to improve big game habitats in Utah. The initial emphasis was on pinyon-juniper woodlands and big sagebrush communities (Plummer and Jensen 1957). Major objectives were to reestablish shrub and forb communities, thus emphasis was shifted to a new suite of species (Monsen 1989). Reliance upon introduced grasses was reduced, and research was directed toward the development of technology required to harvest, process and plant native shrubs and forbs. This project ultimately provided the scientific basis and methodology for revegetating shrub-dominated communities in Utah and surrounding states (McArthur 1988). Large acreage of private, state and federal lands were planted with site-adapted species, and the work is ongoing. Based on demands for seeds of native species generated by this and other public and private revegetation efforts, the native seed industry underwent rapid growth (McArthur and Young 1999).

Perhaps the single most important issue that has emerged to promote the re-establishment of native communities, particularly big sagebrush sites, has been the spread of weeds throughout the West. One of the most troublesome species is cheatgrass *(Bromus tectorum* L.), a cool season winter-annual grass. Cheatgrass and several other annual weeds were first reported in about 1900, but spread rapidly and occupied large areas within 10 to 30 years (Platt and Jackman 1946). Other equally troublesome weeds, including numerous perennials, were introduced later, but now present serious problems (Roche and Roche 1988). Many disturbances were initially planted to introduced perennial grasses as they developed rapidly and were able to compete with the annual weeds (Monsen 1994). Seeding exotic perennials to contain exotic annuals proved successful initially, but the resulting stands did not provide the structure, functions, resilience or values of the native communities.

A new generation of weeds is now emerging; some are capable of invading existing stands of exotic perennial grasses as well as some native communities (Sheley and Petroff 1999). This new group includes such aggressive weeds as the knapweeds *(Centaurea* L. spp.) and rush skeletonweed (*Chondrilla juncea* L.) (Liao 1996), some of which are capable of invading and displacing annual weeds, including cheatgrass. Re-establishing communities of native species appears to be the most ecologically sound means of containing these weeds.

Advancement of Native Plants

Acceptance

The evolution of the native seed and plant industry has been totally dependent upon the demand for these species. Some native species have been planted for over 50 years, but only a fraction of all native species are currently in use. Sufficient amounts of big sagebrush seeds are collected annually from wildland stands to plant many large disturbances, including portions of the 0.6 million hectares that burned in Nevada and other western states in 1999. However, only small quantities of many other species are collected each year. Nonetheless, a number of additional species native to big sagebrush communities are becoming more available (McArthur and Young 1999).

Land managers have recognized the need for locally adapted species and ecotypes and appropriate planting technology for each. Studies of ecotypic variation have provided site requirement data and facilitated the development of seed transfer guidelines for some commonly collected shrub and herb ecotypes (Shaw and Roundy 1997). Research has also provided a better understanding of the seedbed conditions required to establish big sagebrush and other species, thus increasing the opportunity to create seedbed microenvironments and devise seeding schedules that maximize the opportunity for establishment of uniform stands (Boltz 1994, Meyer 1994, Roundy 1994). Although an increasing number of native species are being used, many species needed for the restoration of entire communities have only rarely, or more often, never been planted. In addition, our understanding of species relationships and planting practices required to restore communities to a complete assemblage of adapted species at ecologically compatible densities and patterns is poorly developed.

Seed prices are generally quite high as species first come into use. Suppliers realize that extremely expensive seed lots will likely not be purchased. Consequently they tend to provide species that can be sold, yet provide a satisfactory profit. Obviously, costs to collect or produce and clean many species may remain quite high, due to unusual seed characteristics. However, as demand grows, increased emphasis is generally given to the development of improved collection, production, and cleaning techniques, often resulting in increased availability, higher quality, and lower prices (Stevens et al. 1996). Many native species that are urgently needed to restore shrublands are not available in sufficient amounts from wildland collections; consequently field production protocols are being developed to grow the required quantities of seed.

Research and Development

Various federal and state agencies have organized projects to study the ecology and seed and seedling biology of selected native species in order to develop guidelines for their use in revegetation projects (Shaw and Roundy 1997). Research conducted to facilitate the initial use of many native species on mine sites, roadways, recreation sites, and similar disturbances have ultimately benefited many other users.

The USDA Forest Service, Shrub Sciences Laboratory and the Utah Division of Wildlife Resources have conducted cooperative research for more than 40 years. Efforts have centered the on studying the ecology and use of native shrubs and herbs for revegetating range and wildlife habitats. The long-term commitment to this effort has resulted in the release of over a dozen native cultivars and the development of data required to make over 100 species available for use by the commercial seed industry (McArthur and Young 1999).

State and federally funded research has been instrumental in encouraging the collection and study of native species. Research has been directed toward defining the areas of adaptation of populations or ecotypes within individual species. Plant materials have been assembled to better define the adaptive characteristics that may limit species or ecotypes to specific sites, climatic regions, or soil conditions (Monaco 1996). Sufficient differences have been noted among populations or ecotypes of individual species that users should be cautioned against moving plant materials outside their area of adaptation.

A limited number of studies have been conducted to determine the genetic relationships among species, subspecies, and populations and the nature of genetically controlled characteristics. Collections of selected species have been assembled to permit comparisons of specific characteristics such as herbage production, drought tolerance, seedling vigor and related attributes that may enhance their use. A principal concern is the maintenance of genetic diversity within a population when seeds are grown under cultivation. Guidelines for retaining genetic integrity must be developed for native species grown in seed fields to avoid shifts in genetic characteristics if some plants may be favored or eliminated during field production.

Research has also been conducted to determine the agronomic characteristics of potential revegetation species and ecotypes. Of greatest concern are the germination and seedling establishment characteristics of each plant. Considerable variation has been found to occur in seed dormancy, germination patterns, and growth characteristics among different collections and populations (Meyer and Monsen 1990, Shaw 1994). Germination patterns are genetically regulated and have evolved to enhance survival under different climatic regimes (Meyer and Monsen 1992). Seeds of different species and populations require specific micro-environmental seedbed conditions for germination and establishment. Determining specific requirements for individual species and populations is essential for developing appropriate seedbed preparation and planting techniques and equipment (Monsen and Meyer 1990, Shaw 1994).

A site-identified certification program to verify and certify the origin of wildland-collected seeds was recently developed and accepted by the Association of Official Seed Certifying Agencies (Young 1994). This program provides a system for inspection, labeling, and certification of specific collections. Seed collections are inspected in the field by qualified state seed certification agency personnel who tag individual seed lots and maintain records to assure that seeds are sold with proper data on the site of origin.

Development of Wildland Harvesting, Cleaning, and Storage Practices

Although the development of technology to harvest, clean, and plant the seeds of species native to sagebrush communities is often not recognized as a major issue, development of this information is extremely critical. Most conventional seed harvesting equipment is not capable of harvesting many native species. In addition, existing seed cleaning equipment used for agronomic species has not been completely satisfactory for cleaning some native seeds. Consequently, funding by federal and state agencies has been required to develop new equipment or modify existing equipment for harvesting and cleaning wildland seeds. Competition for seed sales has compelled native seed collectors and growers to assume a role in these endeavors. Although the costs required developing new harvesting and cleaning equipment often exceed the capabilities of individual companies, modifications and improvements of existing equipment have considerably streamlined harvesting and improved the quality of the seed lots marketed.

Research has been conducted to develop safe and effective techniques for cleaning and planting seeds of species that present unusual difficulties. Some seed lots are difficult and costly to clean; others are easily damaged during the cleaning process. Removal of seed coats or other appendages from seeds of some species may decrease seed germinability and seedling survival. The condition of individual seed lots directly affects the metering of seeds through conventional drills and seeders. Consequently, safe and efficient techniques must be developed for cleaning each species.

Development of Seed Germination and Quality Standards

Development of seed germination and quality standards is essential for the marketing of native seeds. Standard testing procedures are essential to aid buyers in determining the quality and value of individual lots. Federal and state agencies have conducted studies to develop germination procedures for individual species for use by state seed testing laboratories. Purity and other tests of seed quality are also being standardized.

Seed Warehousing

A high percentage of native seed sales are made to either state or federal agencies. Sales of some species are dependent on annual collections from wildland stands; consequently their availability varies considerably. To reduce this uncertainty in seed supply, the Utah State Division of Wildlife Resources (Utah DWR) and the USDI Bureau of Land Management in Idaho (Idaho BLM) have each constructed and manage seed warehouses. The BLM warehouse handles seeds for plantings in much of the western United States. At each location, seeds are acquired in advance to ensure their availability when planting begins. The DWR distributes a list of seeds and seed sources required on an annual basis.

Advanced seed purchasing and warehousing has added stability to the native seed industry as collectors are aware of the species and amounts of seeds required at the beginning of the field season and can plan their harvest accordingly. Many other agencies, private companies, and contractors who enter into cooperative plantings with the Utah DWR and Idaho BLM also benefit from the seed warehousing program. In addition, these programs have improved the availability of numerous species, making them available to other buyers. The result has been a much more rapid advancement of the native species program than would otherwise have been expected. The use of adapted ecotypes has increased, and in some cases seed prices have been reduced.

Both the Utah DWR and Idaho BLM have hired and trained individuals to manage these seed warehouse facilities. These individuals are involved in the development and execution of revegetation projects and monitoring programs to assess planting success. This combined responsibility has greatly increased the tracking of seed quality, improved seed storage techniques, and increased the use of adapted species and ecotypes. More thorough monitoring of seeding success permits feedback to improve the success of future plantings.

The DWR has developed seed quality standards and they set maximum acceptable seed prices for individual species each year. Seeds are often stockpiled during good harvest years. Seed companies quickly recognized that seeds of some species harvested from wildland stands were costly and supplies often unreliable, consequently some progressive companies began raising seeds under cultivation, thus improving seed availability and reducing prices.

Development of Site Preparation and Planting Practices

A primary challenge to the use of native seeds was the development and use of successful planting practices. This required the development of equipment to seed trashy seeds and seeds with unusual morphological characteristics. Private contractors and companies normally do not have the resources to research and develop suitable equipment. A concentrated effort has been required to address these problems. The development of seeding and related equipment for range and wildlands use is often not attractive to large equipment companies as equipment sales are normally quite low compared with sales of conventional agricultural equipment. However, small machinery companies have often been instrumental in developing and modifying equipment to solve specific problems. A small Utah company, for example, developed the “Hansen Seed Dribbler” which permitted planting seeds of different shapes and sizes. This machine completely revolutionized shrub seeding.

The Range Technology and Equipment Committee

An independent committee was organized in 1944 to help advance the development of equipment needed to revegetate rangelands. This organization, now known as the Range Technology and Equipment Committee (RTEC) has been successful in soliciting funds from state and federal agencies to develop and construct harvesting, cleaning and seeding equipment. In addition, the group has published and distributed proceedings, manuals and reports to advance revegetation technology.

References

Billings, W.D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin, pp. 22-30. S.B. Monsen and S.G. Kitchen (comps.). In: Proc., Ecology and Management of Annual Rangelands.. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Blaisdell, J.P., R.B. Murray and E.D. McArthur. 1982. Managing Intermountain rangelands-sagebrush-grass ranges. USDA, Forest Service, Intermountain Forest and Range Research Station. Gen. Tech. Rep. INT-134. Ogden, UT. 41 p.

Boltz, M. 1994. Factors influencing post fire sagebrush regeneration in south-central Idaho, pp. 281-290. In: S.B. Monsen and S.G. Kitchen (comps.). Proc., Ecology and Management of Annual Rangelands. USDA Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Brown, E.R. and C.F. Martinsen. 1959. Browse planting for big game in the state of Washington. Washington State Game Department Biol. Bull. 12. Olympia, Washington. 63 p.

Bunting, S.C. 1985. Fire in sagebrush-grass ecosystems: successional changes, pp. 7-11. K. Sanders and J. Durham (eds.). In: Rangeland Fire Effects. Symposium sponsored by USDI Bureau of Land Management and University of Idaho. USDI, Bureau of Land Management, Boise, ID.

Connelly, J.S. and C.E. Braun. 1997. Long-term changes in sage grouse (*Centrocercus urophasianus* populations in western North America. Wildlife Biology 3:123-128.

Cronquist, A. 1994.. Asterales. In: A. Cronquist, A.H. Holmgren, N.H. Holmgren, J.L. Reveal and P.K. Holmgren (eds.). Intermountain Flora. Vol. 5. The New York Botanical Garden, Bronx, NY.

Deitz, D.R and J.G. Negy. 1976. Mule deer nutrition and plant utilization, pp. 71-78. In: G.W. Workman and J.B. Low (eds.). Mule Deer Decline in the West--A Symposium. Utah State University, College of Natural Resources, Utah Agricultural Experiment Station, Logan, UT.

Dobler, F.C. 1994. Washington state shrub-steppe ecosystem studies with emphasis on the relationship between nongame birds and shrub and grass cover densities, pp. 149-161. In: S.B. Monsen and S.G. Kitchen (comps). Proc., Ecology and Management of Annual Rangelands. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Ellison, L. 1960. Influence of grazing on plant succession of rangelands. Bot. Rev. 26:1-78.

Forsling, C.L. and W.A. Dayton. 1931. Artificial reseeding on western mountain range lands. USDA Circ. 178. Washington, DC. 48 p.

Frischknecht, N.C. and A.T. Bleak. 1957. Encroachment of big sagebrush on seeded range in north-eastern Nevada. J. Range Manage. 10:165-170.

Goodrich, S. and E. Neese. 1986. Uinta Basin Flora. USDA Forest Service, Intermountain Region and Ashley National Forest and USDI Bureau of Land Management, Vernal District, Ogden, UT. 319 p.

Goodrich, S., E.D. McArthur and A.H. Winward. 1999. Sagebrush ecotones and average annual precipitation. In: E.D. McArthur, W.K. Ostler and C.L. Wambolt (comps.). Proc., Shrubland Ecotones. USDA Forest Service, Rocky Mountain Research Station. RMRS-P-11. Ogden, UT.

Hanson, C.L., H.G. Fisser and J.R. Wight. 1986. Biology and ecology of sagebrush in Wyoming: V. Herbage yield dynamics and seasonal precipitation patterns, pp. 326-330.

In: E.D. McArthur and B.L. Welch (comps.). Proc., Symposium on the Biology of *Artemisia* and *Chrysothamnus*. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-200. Ogden, UT.

Holmgren, R.C. 1954. A comparison of browse species for revegetation of big game winter ranges in southwestern Idaho. USDA, Forest Service, Intermountain Forest and Range Experiment Station. Res. Pap. 33. Ogden, UT. 12 p.

Houston, W.R. 1961. Some interrelations of sagebrush, soils, and grazing intensity in the Northern Great Plains. Ecol. 42:31-38.

Hubbard, R.L, E.C. Nord and L.L. Brown. 1959. Bitterbrush reseeding--a tool for the game manager. Misc. Paper 39. USDA, Forest Service, Pacific Southwest Forest and Range Experiment Station. Misc. Paper 39. Berkeley, CA. 14 p.

Hull, A.C., Jr. 1971. Grass mixtures for seeding sagebrush lands. J. Range Manage. 24:150-152.

Hull, A.C., Jr. and R.C. Holmgren. 1964. Seeding southern Idaho rangelands. USDA Forest Service, Intermountain Forest and Range Experiment Station. Res. Pap. INT-10. Ogden, UT. 31 p.

Johnson, D.A. 1980. Improvement of herbaceous plants for drought-stressed western rangelands, pp. 419-433. In: N.C. Turner and P.J. Kramer (eds.). Adaptation of Perennial Herbaceous Plants for Drought-stressed Western Rangelands. John Wiley and Sons, New York.

Johnson, D.A., M.D. Rumbaugh and K.H. Asay. 1981. Plant improvement for semiarid rangelands: possibilities for drought resistance and nitrogen fixation. Plant and Soil 58: 279-303.

Kelsey, RG. 1986a. Emergence, seedling growth, and crude terpenoid concentrations in a sagebrush garden, pp. 358-365. In: McArthur, E.D. and B.L. Welch (comps.).Proc., Symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. U.S. Department of Agriculture, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-200. Ogden, UT.

Kelsey, R.G. 1986b. Foliage biomass and crude terpenoid productivity of big sagebrush (*Artemisia tridentata*), pp. 375-388. In: McArthur, E.D. and B.L. Welch (comps.). Proc., Symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. U.S. Department of Agriculture, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-200. Ogden, UT.

Liao, J. 1996. Phenological development and seed germination characteristics of rush skeletonweed in southwestern Idaho. M.S. Thesis. Brigham Young University, Provo, UT. 57 p.

Mack, R.N. 1981. Invasion of *Bromus tectorum* L. into western North America: an ecological chronicle. Agro-Ecosystems. 7:145-165.

McArthur, E.D. 1988. New plant development for range management, pp. 81-112. In: P.T. Tueller (ed.). Vegetation Science Application for Rangeland Analysis and Management. Kluwer Academic Publishers, Dordrecht, Netherlands.

McArthur, E.D. 2000. Sagebrush systematics and distribution, pp. 9-14. In: Entwistle, P.G., A.M. DeBolt, J.H. Kaltenecker and K. Steenhof (comps.). Proc., Sagebrush Steppe Ecosystem Symposium. USDI, Bureau of Land Management. BLM Pub. BLM/ID/PT-001001 + 1/50. Boise, ID.

McArthur, E.D. and S.A. Young. 1999. Development of native seed supplies to support restoration of pinyon-juniper sites, pp. 327-330. In: S.B. Monsen and R. Stevens (comps.). Proc., Ecology and Management of Pinyon-Juniper Communities within the Interior West. USDA Forest Service, Rocky Mountain Research Station. Proc. RMRS-P-9. Ogden, UT.

McArthur, E.D., A.C. Blauer, A.P. Plummer, and R. Stevens. 1979. Characteristics and hybridization of important intermountain shrubs. III. Sunflower family. USDA Forest Service, Intermountain Forest and Range Experiment Station. Res. Pap. INT-220. Ogden, UT.

Meeuwig, R.O. 1965. Effects of seeding and grazing on infiltration capacity and soil stabilization of a subalpine range in central Utah. J. Range Manage. 18:173-180.

Megahan, W.F. 1974. Deep-rooted plants for erosion control on granitic road fills in the Idaho Batholith. USDA, Forest Service, Intermountain Forest and Range Experiment Station. Res. Pap. INT-161. Ogden, UT.

Memmott, K.L. 1995. Seasonal dynamics of forage shrub nutrients and seasonal grazing impacts on cryptogamic crusts. M.S. Thesis. Brigham Young University, Provo, UT. 42 p.

Meyer, S.E. 1994. Germination and establishment ecology of big sagebrush: Implications for community restoration, pp. 244-251. In: S.B. Monsen and S.G. Kitchen (comps.). Proc., Ecology and Management of Annual Rangelands. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Meyer, S.E. and S.B.Monsen. 1990. Seed-source differences in initial establishment for big sagebrush and rubber rabbitbrush, pp. 200-208. In: McArthur et al. (comps.) Proc., Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. E.D.. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-276. Ogden, UT.

Meyer, S.E. and S.B. Monsen. 1992. Big sagebrush germination patterns: subspecies and population differences. J. Range Manage. 45:87-93.

Monaco, T.A. 1996. Use of dark respiration to determine optimal adaptation in native Great Basin plant species. M.S. Thesis. Brigham Young University, Provo, UT. 74 p.

Monsen, S.B. 1989. Shrub selection for pinyon-juniper plantings, pp. 326-329. In: R.L. Everett (comp.). Proc., Pinyon-juniper Conference. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-215. Ogden, UT.

Monsen, S.B. 1994. The competitive influence of cheatgrass (*Bromus tectorum*) on site restoration, pp. 43-50. In: S.B. Monsen and S.G. Kitchen (comps.). Proc., Ecology and Management of Annual Rangelands. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Monsen, S.B. and E.D. McArthur, 1984. Factors influencing establishment of seeded broadleaf herbs and shrubs following fire, p. 112-124. In: K. Sanders and J. Durham (eds.). Rangeland Fire Effects, a Symposium. USDI, Bureau of land Management, Idaho State Office, Boise, ID.

Monsen, S.B. and S.E. Meyer. 1990. Seeding equipment effects on establishment of big sagebrush on mine disturbances, pp. 192-199. In: F.F. Munshower and S.E. Fisher (eds.), Fifth Billings Symposium on Disturbed Land Rehabilitation. Vol. I. Hardrock Waste, Analytical, and Revegetation. Reclamation Research Unit Publ. 9003, Montana State University, Bozeman.

Monsen, S.B. and A.P. Plummer. 1978. Plants and treatment for revegetation of disturbed sites in the Intermountain area, pp 155-173. In: R.A. Wright (ed.). The Reclamation of Disturbed Arid Lands. University of New Mexico Press, Albuquerque, NM.

Monsen, S.B. and N.L. Shaw. 1982. Seeding antelope bitterbrush with grass on south-central Idaho rangelands–a 39-year response, pp. 126-136. In: A.R. Tiedemann and K.L. Johnson (comps.). Proc., Research and Management of Bitterbrush and Cliffrose in Western North America. USDA, Forest Service, Intermountain Forest and Range Experiment Station. Gen. Tech. Rep. INT-152. Ogden, UT.

Monsen, S.B. and N.L. Shaw. 1984. Response of an alkali sagebrush/fescue site to restoration treatments, pp. 126-133. In: E.D. McArthur and B.L. Welch (comps.). Proc., Symposium on the Biology of *Artemisia* and *Chrysothamnus*. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-200. Ogden, UT.

Pechanec, J.F., A.P. Plummer, J.H. Robertson and A.C. Hull, Jr. 1944. Eradication of big sagebrush (*Artemisia tridentata*). USDA, Forest Service, Intermountain Forest and Range Experiment Station. Res. Pap.10. Ogden, UT. 23 p.

Pellant, M. and C. Hall. 1994. Distribution of two exotic grasses on Intermountain rangelands: status in 1992, pp 109-112. In: S.B. Monsen and S.G. Kitchen (comps.). Proc., Ecology and Management of Annual Rangelands. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Petersen, K.L. 1987. Effects of prescribed burning on nongame birds in a sagebrush community. Wildlife Soc. Bull. 15:317-329.

Peterson, J.G. 1995. Ecological implications of sagebrush manipulation. Montana Fish, Wildlife and Parks, Wildlife Management Division. Federal Aid in Wildlife Restoration Project W-101-R-2. Helena, MT. 49 p.

Piemeisel, R.L. 1951. Causes affecting changes and rate of change in vegetation of annuals in Idaho. Ecol. 32:53-72.

Platt, K. and D.R. Jackman. 1946. The cheatgrass problem in Oregon. Oregon Agriculture Experiment Station. Bull. 668. Corvallis, OR. 48 p.

Plummer, A.P. and R.L. Jensen. 1957. Job completion report for artificial revegetation studies on big game ranges in Utah. Information Bull. 1955-56. Utah State Department of Fish and Game, Salt Lake City, UT. 26 p.

Plummer, A.P, A.C. Hull, Jr, G. Stewart and J.H. Robertson. 1955. Seeding rangelands in Utah, Nevada, southern Idaho, and western Wyoming. USDA Handbook 71. Washington, DC. 73 p.

Richardson, B.Z., S.B. Monsen and D.M.Bowers. 1986. Interseeding selected shrubs and herbs on mine disturbances in southeastern Idaho, pp 134- 139. In: E.D. McArthur and B.L. Welch (eds.). Proc., Symposium on the Biology of *Artemisia* and *Chrysothamnus*. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-200. Ogden, UT.

Roche, C.T. and B.F. Roche, Jr. 1988. Distribution and amount of four knapweed (*Centaurea* L.) species in eastern Washington. Northwest Sci. 62:242-251.

Roundy, B.A. 1994. Relating seedbed environmental conditions to seedling establishment, pp 295-299. In: S.B. Monsen and S.G. Kitchen (comps.). Proc., Ecology and Management of Annual Rangelands.. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Saab, V.A. and T. C. Rich. 1997. Large-scale conservation assessment for Neotropical migratory land birds in the interior Columbia River Basin. PNW-GTR-399. USDA-FS, Portland, Oregon.

Sampson, A.W. 1921. Reseeding the range. National Wool Grower 11:11-13.

Sampson, A.W. and B.S. Jespersen. 1963. California range brushlands and browse plants. Calif. Agric. Exp. Stn. Ext. Serv. Man. 33. Berkeley, CA. 162 p.

Shaw, N.L. 1994. Germination and seedling establishment of spiny hopsage in response to planting date and seedbed environment. J. Range Manage. 47:165-174.

Shaw, N.L. and B.A. Roundy. 1997. Proceedings: Using Seeds of Native Species on Rangelands. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station Gen. Tech. Rep. INT-GTR-372. Ogden, UT. 30 p.

Shaw, N.L., V.A. Saab, S.B. Monsen and T.D. Rich. 1999. *Bromus tectorum* expansion and biodiversity loss on the Snake River Plain, southern Idaho, USA. pp. 586-588. In: D. Eldridge and D. Freudenberger (eds.). People and Rangelands Building the Future. VI International Rangeland Congress, July 19-23, 1999,Townsville, Queensland, Australia. VI International Rangeland Congress, Inc., Aitkenvale, Queensland, Australia.

Sheley, R.L. and J.K. Petroff. 1999. Biology and management of noxious rangeland weeds. Oregon State University Press. Corvallis, OR. 438 p.

Sparks, S.R., N.E. West and E.D. Allen. 1990. Changes in vegetation and land use at two townships in Skull Valley, western Utah, pp 26-36. In: E.D. McArthur et al. (comps.).

Proc., Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-276. Ogden, UT.

Stevens, R., K.R. Jorgensen, S.A. Young and S.B. Monsen. 1996. Forb and shrub seed production guide for Utah. Utah State University Extension Service, Logan, UT. 51 p.

Updike, D.R, E.R. Loft and F.A. Hall. 1990. Wildfires on big sagebrush/antelope bitterbrush range in northeastern California: Implications for deer populations, pp 41-46. In: E.D. McArthur et al. (comps.). Proc., Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-276. Ogden, UT.

Walker, S.C. 1999. Species compatibility and successional processes affecting seeding of pinyon-juniper types, pp. 331-337. In: S.B. Monsen and S.G. Kitchen (comps.). Proc., Ecology and Management of Pinyon-Juniper Communities within the Interior West. USDA, Forest Service, Rocky Mountain Research Station. RMRS-P-9. Ogden, UT.

Welsh, S.L., N.D. Atwood, S. Goodrich, and L.C. Higgins (eds.). 1987. A Utah Flora. Great Basin Naturalist Memoirs 9. Brigham Young University, Provo, UT. 894 p.

Wieland, P.A. T., E.R. Frolich and A. Wallace. 1971. Vegetation propagation of woody shrub species from the Northern Mojave and southern Great Basin deserts. Madrono 21:149-152.

Workman, G.W. and J.B. Low. 1976. Mule deer decline in the West - a symposium. Utah State University, College of Natural Resources, Utah Agricultural Experiment Station, Logan, UT. 134 p.

Whisenant, S.G. 1990. Changing fire frequencies on Idaho's Snake River Plain: ecology and management implications, pp. 4- 10. In: E.D. McArthur et al. (comps.). Proc., Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-276. Ogden, UT.

Williams, T.A. 1898. A report upon the grasses and forage plants and forage conditions of the Rocky Mountain Region. USDA, Division of Agrostology. Bull. 12. Washington, DC.

Yoakum, J.D. 1978. Pronghorn, pp 103-121. In: Big Game of North America. J.L. Schmidt and D.L. Gilbert (eds.). Stackpole Books, Harrisburg, PA.

Young, J.A., R.E. Eckert, Jr. and R.A. Evans. 1979. Historical perspectives regarding the sagebrush ecosystem, pp. 1-13. In: The Sagebrush Ecosystem; A Symposium. Utah State University, College of Natural Resources, Logan, UT.

Young, S.A. 1994. The (certified) seeds of revegetation, pp 271-272. In: S.B. Monsen and S.G. Kitchen (comps.). Proc., Ecology and Management of Annual Rangelands.USDA, Forest Service, Intermountain Research Station. Gen. Tech. Rep. INT-GTR-313. Ogden, UT.

Derivation and Interpretation of Wyoming's Post-Mining Shrub Density and Composition of Standards for Coal Mine Lands

B. Giurgevich[1,] P. Smith[2], and S. Page[1]

Abstract

Since its approval in 1980, the Wyoming Coal Program has had a variety of post-mining shrub density and shrub composition standards. This paper briefly outlines the history of those standards and how they have changed. The current standards make distinctions between density and composition for coal mine lands affected prior to August 6, 1996 and lands affected after that date.

This paper was originally presented at the 2000 Billings Land Reclamation Symposium; however, this version of the paper makes significantly different interpretation of the historical standards based upon the Land Quality Division's reassessment of a 1986 Federal Register which approved 1986 Rules and Regulations for the Wyoming Coal Program.

This paper presents and discusses select vegetation data which bear on the question of whether coal permittees are achieving the historical and current shrub density and shrub composition standards for reclaimed lands.

Introduction

The history of shrub restoration requirements for Wyoming coal mine lands is checkered and complex. The general topic of shrub restoration has all too often devolved to haggling over the contribution of one or more of the three subspecies of big sagebrush (*Artemisia tridentata*). The emotionally charged opinions about big sagebrush confound and do not help elucidate the more general topic of the restoration of shrub habitat and shrub composition. The use of the term shrub in this paper includes a variety of shrub species, including all shrubs and sub-shrubs which were identified in baseline vegetation surveys.

Historical Perspectives

The 1973 Wyoming Legislature promulgated the Wyoming Environmental Quality Act (Wyoming EQA) which held that lands affected by mining operations shall be reclaimed to the highest previous use of the affected lands. The Wyoming EQA uses words such as "surrounding terrain and natural vegetation", "wildlife and aquatic habitat and resources" and the "utility and

---

[1] Wyoming Department of Environmental Quality, Land Quality Division, Sheridan, WY 82801.
[2] Wyoming Department of Environmental Quality, Land Quality Division, Cheyenne, WY 82001.

capacity of the reclaimed lands to support such (highest previous) uses". The Wyoming EQA has never detailed shrub restoration requirements, but it does establish a requirement to consider habitat when reclaiming mined lands.

The 1973 Wyoming EQA directed the establishment of rules and regulations for reclamation standards. By November 1975, the Wyoming Department of Environmental Quality, Land Quality Division (LQD) had published a set of Rules and Regulations which required permittees to restore the land to a condition equal to or greater than its highest previous use and required permittees to restore wildlife habitat commensurate with or superior to pre-mining habitat. The 1975 Rules and Regulations did not specifically require shrub replacement and did not establish a quantitative or qualitative replacement standard.

The United States Congress promulgated the Surface Mining Control and Reclamation Act (SMCRA) and thereby established the Office of Surface Mining Reclamation and Enforcement (OSM) in 1977. SMCRA included a quantitative post-mining shrub density standard for coal mine lands. Perhaps more importantly SMCRA provided a mechanism by which states could assume primacy for implementation of SMCRA.

After lengthy negotiations, the OSM approved the Wyoming State Coal Program (Wyoming Coal Program) in November 1980. When the Wyoming Coal Program was approved, the LQD Rules and Regulations required that operators restore post-mining shrub density ***equal to*** pre-mining shrub density.

Subsequent changes to the LQD Rules and Regulations in 1981 through 1985 retained the performance standard that "when wildlife is part of the post-mining land use, shrubs and trees shall be returned to a density at least equal to that existing on the area before mining".

In 1986, revised LQD Rules and Regulations introduced the terms "... the goal for shrub restoration...". Historically, the LQD has interpreted these words to introduce a fundamental shift from a quantitative performance standard (restore equal shrub density) to a more qualitative, non-absolute standard. The historical interpretation implied that it was (or would be) adequate for coal permittees **to attempt to attain** the shrub restoration goal, even if vegetation data did not unambiguously demonstrate attainment of the goal. The components of the shrub restoration goal/standard are outlined later in this paper.

Later in 1986, the Wyoming Game and Fish Department (Wyo. G&FD) petitioned the LQD to modify the revised shrub restoration goal of the 1986 LQD Rules and Regulation. Negotiations on this petition continued into the third quarter of 1994. The LQD eventually took revised Rules and Regulation through the complex rule making process. On August 6, 1996, the OSM approved the new LQD Rules and Regulations which created a dual shrub restoration standard:

1. restoration of one shrub per square meter in patches totaling 10% of all lands affected prior to August 6, 1996.

2. restoration of no more than a total density of one shrub per square meter in patches totaling 20% of all lands affected after August 6, 1996. These shrub patches also have defined species composition requirements.

These shrub restoration revisions were not the only revisions to the Wyoming EQA and LQD Rules and Regulations over these years. The cumulative effect of all revisions created a great deal of uncertainty concerning what goal or standard applied to specific affected land units. On October 31, 1998, the LQD Administrator published a document entitled "How To Handle Bond Release On Coal Mined Lands Affected During Various Regulatory Time Frames". This document was also the product of extensive interaction between LQD staff and members of the Wyoming coal industry.

Application of Current LQD Rules and Regulations

The LQD Administrator's October 1998 statement of policy outlined five time periods which help frame application and interpretation of the many historical laws and policies. This paper compresses and rearranges the five temporal categories outlined in the original document and addresses only the shrub restoration topic. This compression is not appropriate for other post-mining topics.

Lands Affected After June 30, 1973 And Prior To March 26, 1981

The Wyo. EQA (effective July 1, 1973) and OSM approval of the 1981 LQD Rules and Regulations (effective March 26, 1981) frame this period. If these affected lands were not used after March 26, 1981 in support of continuing mining operations, these lands have no shrub restoration goal or standard. The date the land was affected, not the date of permanent reclamation, establishes the applicable trigger date.

For various reasons, the LQD Administrator has stated that no quantitative or qualitative evaluation of shrub density or composition will be required on lands disturbed during this time frame.

Lands Affected After March 26, 1981 And Prior To August 6, 1996

The OSM's August 6, 1996 approval of revised LQD Rules and Regulations established a separate ***shrub restoration goal/standard*** for lands affected in this category and where those affected lands have not been used after August 6, 1996 in support of continuing mining operations.

When wildlife use is part of the post-mining land use, this 1981-96 shrub restoration goal/standard required that:

1. a set percent of the reclaimed surface shall have an average density of one shrub per square meter in a mosaic of shrub patches.

2. the percentage and distribution of shrub patches shall be determined through site specific evaluation of the pre-mining shrub cover, density, distribution and wildlife use. Except where a lesser density may be justified from pre-mining conditions, 10% of the reclaimed lands shall be restored to shrub patches.

3. best technology available shall be applied to achieve the shrub density goal/standard.

4. approved shrub species and seeding techniques shall be applied to all residual reclaimed lands used jointly by livestock and wildlife .

The interpretation of this goal/standard has been widely debated since the 1986 LQD Rules and Regulations revision. All parties in these debates apparently overlooked the November 24, 1986 Federal Register (51FR12217) under which the OSM approved the 1986 LQD Rules and Regulations. The Federal Register stated that “the Director interprets Wyoming’s use of the term “goal” as equivalent in meaning to that of a required standard and he is approving the proposed rule on that basis”. The LQD will evaluate the attainment of this goal/standard at final incremental bond release (Phase 3 bond release) using qualitative and quantitative data.

Lands Affected After August 6, 1996

The OSM’s August 6, 1996 approval established a ***shrub restoration standard*** for lands in this category and for all lands which were affected before this date but which have been used after August 6, 1996 in support of continuing mining operations. The shrub restoration standard applies to all reclaimed lands which have the designated land uses of grazing land and fish and wildlife habitat.

Appendix A of the LQD Coal Rules and Regulations holds that coal permittees shall:

1. except where a lesser density is justified by pre-mining conditions, restore at least 20% of eligible lands to shrub patches supporting an average density of one shrub per square meter.

2. ensure that shrub patches are no smaller than 0.5 acres each and are arranged in a mosaic that will optimize habitat interspersion and edge-effect.

3. use plant community-specific, pre-mining shrub density and shrub composition data to determine the post-mining areal extent of shrub patches and their specific post-mining density and composition.

4. choose one of four calculation options for all eligible land within each permit area or amendment area.

5. ensure that the average post-mining total and species-specific shrub densities are at least 90% of the calculated densities at the time of final incremental bond release (Phase 3 bond release).

The shrub restoration standard is an absolute, statutory requirement which must be unambiguously achieved on all eligible lands at the time of final incremental bond (Phase 3) release. Simply trying to attain the performance standard is not adequate.

Appendix A of the LQD Rules and Regulations details the four options and calculation procedures for the shrub restoration standard. The calculation procedures are complex and use pre-mining baseline data. The fact that some of the pre-mining data sets are now as old as 25 years, that they were gathered by many different consultants and that the data sets were seldom developed with the detail required in Appendix A, calculation creates some distinct challenges. Table 1 is a brief summary of the four possible options. To date, most coal permittees in the Wyoming Powder River Basin have chosen Option II or III.

Table 1. Characteristics of Options I through IV for a post-mining shrub restoration standard

Option	Distinguishing Characteristics
I	Post-mining standard is not community-specific, but is based upon the pre-mining density of only full shrubs; reductions in pre-mining shrub density are possible if any pre-mining community has a shrub density greater than one per square meter and is less than 20% of the eligible lands.
II	Post-mining standard is not community-specific, but is based upon the pre-mining density of only full shrubs; the post-mining shrub density is set at one per square meter.
III	Post-mining standard is community-specific and is based upon the pre-mining density of only full shrubs; each eligible pre-mining community contributes to the calculation of post-mining density and areal extent of community-specific shrub patches.
IV	Post-mining standard is community specific, but is based upon the pre-mining density of full and subshrubs; each eligible pre-mining community contributes to the calculation of post-mining density and areal extent of community- specific shrub patches.

Achievement of Shrub Restoration Goal and Standard

The LQD has at least four information sources to evaluate a permittee's progress toward and final achievement of the applicable goal and standard. The first source contains the only data which will be used to make a final determination that the goal and standard were achieved. The other three sources will provide some insight that the permittee is moving toward achievement. The four data sources are:

1. formal data submitted in support of final incremental bond (Phase 3) release. These data derive from detailed quantitative field sampling regimes and rigorous statistical tests of sample adequacy.

2. formal data submitted in fulfillment of Interim Vegetation Monitoring (IVM) programs. These data derive from moderately detailed quantitative field sampling regimes, but are without rigorous tests of sample adequacy.

3. limited data from qualitative and semi-quantitative field surveys conducted by LQD staff. These field surveys are moderately detailed, but are without any tests of sample adequacy.

4. other observations or data submitted by coal permittees or their consultants.

In relation to achievement of the shrub restoration goal, the LQD has received only one request for final incremental bond (Phase 3) release. This single request is not representative of the process and will not be discussed.

However, all coal permittees in the Wyoming Powder River Basin are required to sample reclamation under IVM programs. Table 2 presents a select summary of a partial survey of data from IVM program data from LQD Annual Reports.

Table 2 is not a complete survey of the approximately 24 coal mine permits in the Wyoming portion of the Powder River Basin. Table 2 presents select data which illustrate the conclusions presented below. It is possible to draw only general conclusions from these IVM program data because:

1. permittees have not always seeded specific shrub patches and/or shrub mixes on the shrub restoration goal lands, and

2. the submitted IVM program data do not consistently and clearly specify sampling methods; methods sometimes differ from one sampling period to the next, and

3. the sampling methods do not consistently and clearly state whether sampling occurred within defined shrub patches or within general reclaimed plant communities, and

4. sampling is seldom subjected to a sample adequacy test and may not be representative of all reclaimed lands at a specific mine.

Table 2 data suggest that coal permittees may attain the shrub restoration goal when they selectively seed and specifically map and sample defined shrub patches. Second, these data suggest that coal permittees will not attain the shrub restoration goal if they do not selectively seed shrub patches. The general, background plant communities are not showing adequately dense patches even when reclamation is as old as 20 years. Third, data are not available to clearly assess whether shrub patches cover 10% of the reclaimed goal lands.

The first two conclusions are generally supported by semi-quantitative surveys conducted by Richard Vincent of the LQD on five mines in the Powder River Basin in 1999. Coal permittees or their consultants have not submitted other observations or field data which would alter these conclusions concerning attainment of the shrub restoration goal.

There are very few hard data (but many opinions) available to determine whether coal permittees are achieving the shrub restoration standard, primarily because lands affected after August 6, 1996

Table 2. Total (full plus sub-shrubs) shrub density data from permanently reclaimed lands covered by the ***shrub restoration*** *goal for select coal mines in Campbell County, WY.*

		Reclamation Sampled*			
Mine	**Field Sample Year**	**Seeded Shrub Patch**	**General Plant Community**	**Age of Reclamation at SampleYear**	**Range of Full and Sub-shrubDensity(no./m²)**
Belle Ayr	1995		X	10-16	0 - 0.5
Rawhide	1994	X		3-8	0.1 - 12.1
	1995		X	7-16	0 - 0.5
	1995	X		6-8	0.2 - 4.2
	1996		X	4	0.02 - 0.1
	1996	X		4-10	0.03 - 3.5
	1997		X	3	0.1 - 0.4
	1997	X		3-10	0.01 - 5.4
	1998		X	4-20	0.01 - 0.6
	1999	X		6-12	0.03 - 2.1
Caballo Rojo	1995		X	1-6	0.2 - 2.8
	1998		X	5-9	0.01 - 2.9
Black Thunder	1993		X	1-3	0.2 - 5.8
	1995		X	2-4	0.4 - 1.3
	1997		X	2-6	0 - 1.6
	1998		X	1-7	0 - 2.7
	1999		X	1-3	0 - 4.5

* Unless the methods clearly stated that sampling occurred within a specific shrub patch, this table assumes sampling occurred in the general reclaimed community. Terri Hatch, a Sheridan College student, compiled most of these data during a Practicum with the LQD District III office.

are only now being permanently reclaimed. The permanent reclamation has not yet been sampled under IVM programs. This acreage is progressively increasing, but the authors found only one IVM program data set which addresses lands reclaimed under the standard. A portion of the Black Thunder Mine's 1998 IVM program sampled one-year old shrub patches and recorded total shrub densities ranging from 0.5 - 2.3 shrubs per square meter. The data were not presented in a format suitable to assess the shrub composition element of the shrub restoration standard.

No other specific data have been presented to the LQD in support of attainment of the shrub restoration standard.

The authors conclude that to clearly achieve the shrub restoration goal and standard, coal permittees must:

1. choose and apply the best available technology for establishing diverse (as approved) mixtures in distinct shrub patches.

2. regularly observe and quantitatively sample the established shrub patches to evaluate the areal extent component, the compositional element, and the density elements of the shrub standard.

3. conduct best available husbandry practices to protect and encourage shrub establishment and survival in the shrub patches.

Seeds and Seedling Establishment of Wyoming Big Sagebrush

D.T. Booth[1] and Y. Bai[2]

Abstract

Success with Wyoming sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) depends on good seed vigor, and rapid seedling development. These characteristics are influenced by harvesting, processing, storing, and sowing. In this paper we discuss research findings related to those activities: (1) It appears that Wyoming big sagebrush growing on the western edge of the Great Plains might hold viable seed longer into the winter, and might have greater seed dormancy than do other habitat types. (2) Tests of debearder-processed seeds indicate the procedure does not degrade seed quality. (3) Sagebrush seeds in storage often show unexpected, and seemingly random viability losses. We need research to define the interactions of seed physiology and storage conditions and to predict seed shelf-life. (4) Temperature has a measurable influence on water absorption by sagebrush seeds, but the rate and extent of water absorption does not appear to influence germination or seedling vigor. (5) Moisture stress will affect germination and an increase in moisture stress from 0.00 to -0.50 MPa will result in approximately half of germinable seeds remaining ungerminated. (6) Heavy seeds germinate better. We recommend seed buyers select seed lots with less than 3500 seeds/g to obtain high-vigor seeds; also, that seed lots be monitored using inexpensive in-the-office tests of germination. (7) We recommend sagebrush seeding rates of 1000 seeds/m^2. Lower seeding rates reduce stand density but heavier rates do not give a corresponding density increase. High seeding rates are consistent with sagebrush ecology.

Introduction

The re-establishment of diverse, self-sustaining plant communities that include native shrubs is a prerequisite for bond release to mining companies extracting mineral resources in Wyoming (Federal Register 1996) and other western states. Shrub re-establishment in general, and sagebrush restoration in particular, have presented continuing challenges that only recently have met with some consistency and predictability. Where the 1986 Wyoming coal mining rules stated a **goal** of one shrub /m^2 on 10% of the affected area, the 1996 rule **requires** one shrub /m^2 on 20% of the affected area (Federal Register 1996, Booth et al. 1999). Success with sagebrush, perhaps more than with other native shrubs, depends on a properly prepared seedbed, good seed vigor, and rapid seedling development. Sagebrush seeds are influenced by harvesting, processing, storing, and sowing. In this paper we review some fundamentals for successfully seeding Wyoming big sagebrush.

---

[1]USDA-ARS, High Plains Grasslands Research Station, 8048 Hildreth Road, Cheyenne, WY 82009
[2]Agriculture and Agri-Food Canada, Kamloops Range Research Unit, 3015 Ord Road, Kamloops, BC V2B 8A9 Canada

Big Sagebrush Seeds

Big sagebrush seeds are shiny achenes, about 2 mm long and enclosed in a papery pericarp that is often removed during seed cleaning (Booth et al. 1997). The pericarp can influence seed water uptake; although, differences in water uptake among naked and pericarp-covered achenes are small and probably not biologically significant (Bai et al. 1999). The achenes contain mucilaginous materials that may aid adhesion to the soil surface during radicle penetration (Walton et al. 1986). Achene endosperm is a membrane fused to the inner wall of the seed coat (Atwater 1980, Meyer, in press). The cotyledons are large, thickened and dominate the axis. Young and Young (1992) reported Wyoming big sagebrush has 3500-3800 seeds/g and Bai et al. (1997) reported 3100-4500 seeds/g for five Wyoming collections harvested in February. Most sagebrush seeds used in reclamation are collected from native stands where seed production and quality vary from site to site, reflecting ecotypical influences, and from year to year as a result of weather and parental condition. Seed quantity and quality varies, but reclamation continues. This, and the late seed-ripening dates mean that reclamation depends on seeds stored from previous year's harvests. Thus seed quality changes during storage, and the frustratingly short shelf-lives of some seed lots, are important revegetation issues.

Harvesting, Processing, and Storing Seeds

Sagebrush blooms in late summer and early fall and seeds mature October through December. Young and Young (1992) cautioned that seeds need to be harvested quickly after maturity to avoid losses and storm damage associated with the late season and Walton et al. (1986) report that viable seeds are dispersed during the first seven days after seed-ripening. Most sagebrush seed harvesting occurs in late fall or early winter, but significant amounts of Wyoming big sagebrush in Wyoming can be harvested in February (Bai et al. 1997), indicating ripe seeds are held longer than seven days and that dispersion is spread over a greater time period. Whether this is a characteristic of the subspecies, or a characteristic correlated to the more eastern part of sagebrush distribution is not known (see Meyer and Monsen 1992 for a discussion of habitat-correlated characteristics of sagebrush seeds).

Seed harvesting produces a mixture of seed stalks, flower parts, and seeds which is usually processed with debearders (a machine originally designed to remove the beard or awn from barley). Booth et al. (1997) found that debearder processing resulted in significant increases in the temperature and relative humidity of the material being processed (Fig. 1), but the transient (<10 min.) conditions had no effect on seed quality as measured by percent germination, germination rate, and seedling vigor. Even running a large load for 20 minutes did not damage seeds nor decrease quality factors. Debearders do remove the pericarp from a fraction of the seeds and the longer seeds are in the machine, the greater the percentage with pericarp removal (Fig. 2). However, pericarp removal had no effect on seed germination percentage or rate, nor was there any evidence that it affected seed shelf life (Booth et al. 1997).

Some Wyoming big sagebrush seed lots undergo costly, untimely decreases in germination percentage during storage. Bai et al. (1997) made five collections from Wyoming, stored them for 24 months at room temperature, and found that germination increased for one collection, decreased for two collections, and did not change for two collections. Shaw and Booth (1999) stored two lots of Idaho-collected Wyoming big sagebrush seeds for 15 months at -22°C and at room temperature, experienced significant reductions in germination percentage after six months regardless of storage

Fig. 1. Changes in temperature and relative humidity inside a debearder while processing Wyoming big sagebrush seeds (Booth et al. 1997).

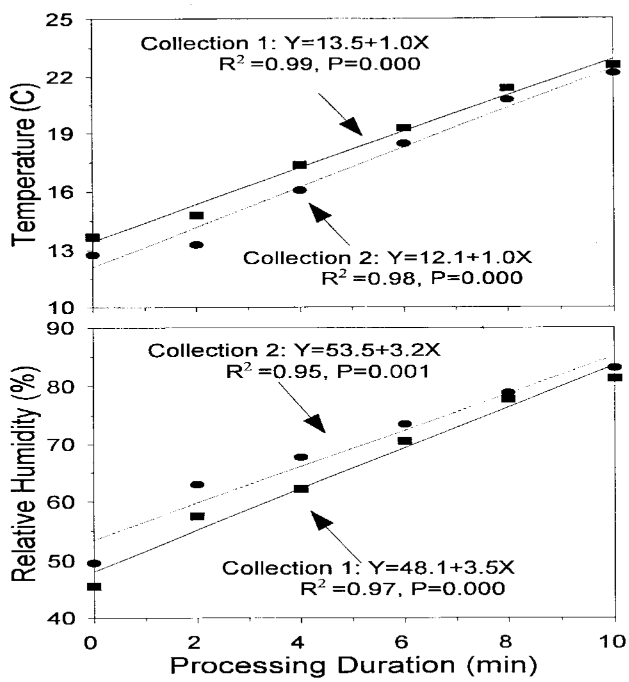
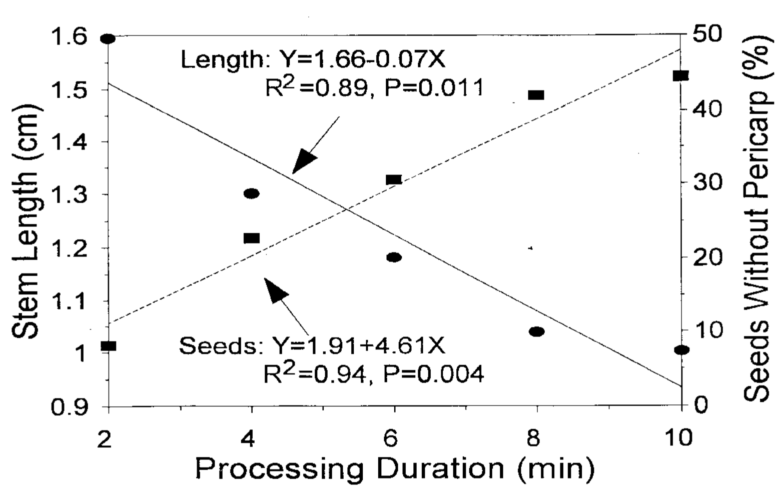


Fig. 2. Stem length and percent of Wyoming big sagebrush seed without pericarp after processing with a debearder (Booth et al. 1997). Stem-length change is a measure of the abrasive action of the debearder on stems contained in material collected at seed harvest.



conditions. After 15 months one protocol indicated cold storage preserved viability but the other protocol indicated decreased viability with no difference among storage conditions. Such results emphasize our need to understand environmental interactions with seed aging – particularly as it relates to accurate seed testing.

Dormancy and Germination Characteristics

Atwater (1980) has noted that seed dormancy in nonendospermic seeds is due to impermeable seed coats or to germination inhibitors contained within the seed. Sagebrush does not have impermeable seed coats and no germination inhibitors have been identified. However, Wyoming big sagebrush seed lots are known to contain some viable seeds that are not readily germinable after harvest (McDonough and Harniss 1974, Meyer and Monsen 1992, Bai et al. 1997, Booth et al. 1997). Meyer and Monsen (1992) reported that Wyoming big sagebrush seeds from 21 collections were largely nondormant when germinated at 15ºC in light. The maximum percentage of dormant seeds in these collections was 11%. All of their collections were from west of the 110th meridian and whether or how the geographic range influenced their results is unknown. Booth et al. (1997) studied two commercial seed lots and found that germination percentage increased by 15 to 20% after 4.5 months of storage, indicating an afterripening effect. Afterripening is post-harvest embryo maturation measured as the time required for seeds to become germinable. True dormancy may also affect a fraction of Wyoming sagebrush seeds. Seeds collected from and sown in the Powder River Basin produced seedlings during four post-sowing growing seasons where annual photographs of plots were used to map and document the establishment and survival of sagebrush seedlings (Booth, D.T. unpublished data).The photographic data extrapolated to large areas imply two to seven thousand seedlings/ha may appear the fourth growing season after seeds are sown, thus distributing Wyoming big sagebrush emergence from a single seed lot through at least three years.

Water Relations and Germination

Seed germination and germination rate of Wyoming big sagebrush are limited by water stress,- similar to basin big sagebrush (Sabo et al. 1979, Walton et al. 1986) and fringed sagebrush (Bai et al. 1995). An increase in moisture stress from 0.00 to -0.50 MPa will result in approximately half of germinable seeds remaining ungerminated and those that do germinate will take twice as long as for seeds with no stress (Fig. 3).

Orthodox seeds like sagebrush are dispersed as desiccated micro-plants. How rehydration occurs, the rate, temperature, and extent, often has a lasting influence on germination and seedling performance (see Booth 1993). Managed rehydration, known as "seed priming," has enhanced field performance of a variety of agricultural seeds (Taylor and Harmon 1990). Bai et al. (1997) tested the interactions of temperature and time on seed water uptake of Wyoming big sagebrush under humid conditions. Significant moisture increases occurred after; 16 hours at 2ºC, 4 hours at 5ºC, and 2 hours at 10 and 15ºC (Figure 4). Seed moisture content equilibrated with humidity and was highest under the 10ºC regime. Surprisingly, no differences were detected in germination percentage, germination rate, or seedling vigor that could be related to moisture uptake. Neither did imbibition under wet (as contrasted to humid) conditions appear to have any significant influence on these processes. Thus, priming appears unlikely to enhance field performance of Wyoming big sagebrush.

Fig. 3. Predicted germination percentage (solid line at left) and rate (D50, solid line at right) with 95% confidence bands (dotted line) of Wyoming big sagebrush seeds with (filled circles) or without (open triangles) pericarp as a function of water potential (Bai et al. 1999). Symbols indicate actual values.

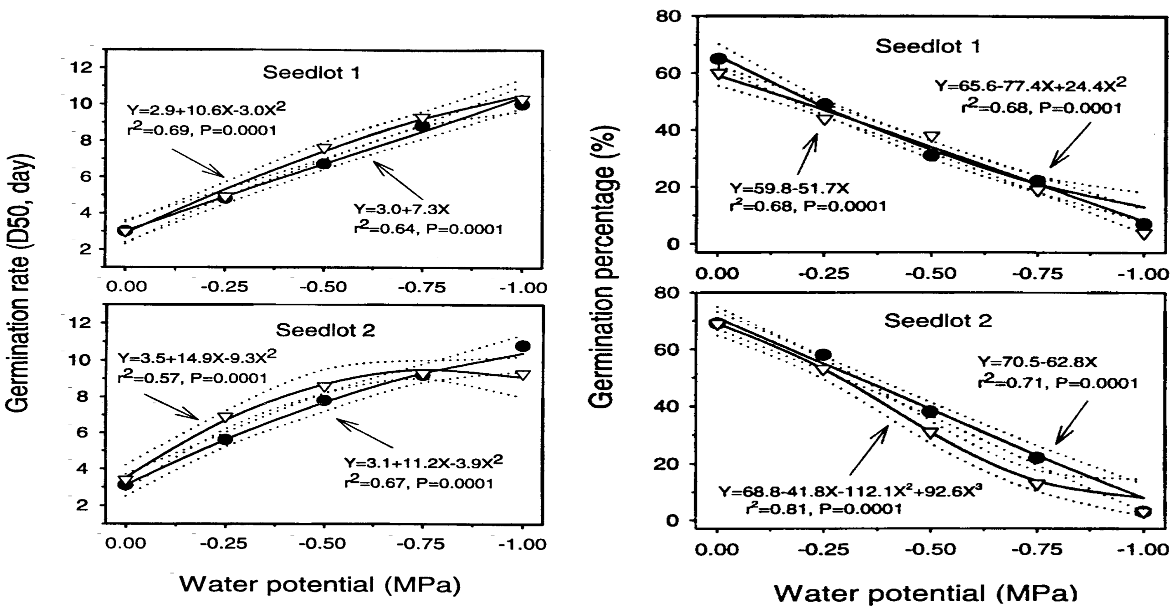
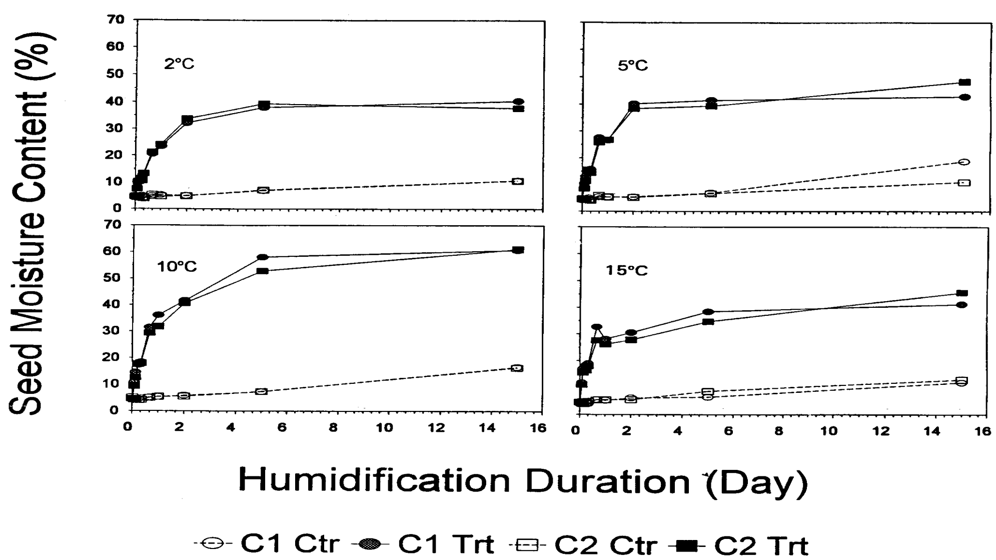


Fig. 4. Seed moisture content of humidified (Trt) and non-humidified (Ctr) Wyoming big sagebrush seeds at different temperatures and treatment durations (Bai et al. 1997).



Seed Size / Testing/ Seeding Rates

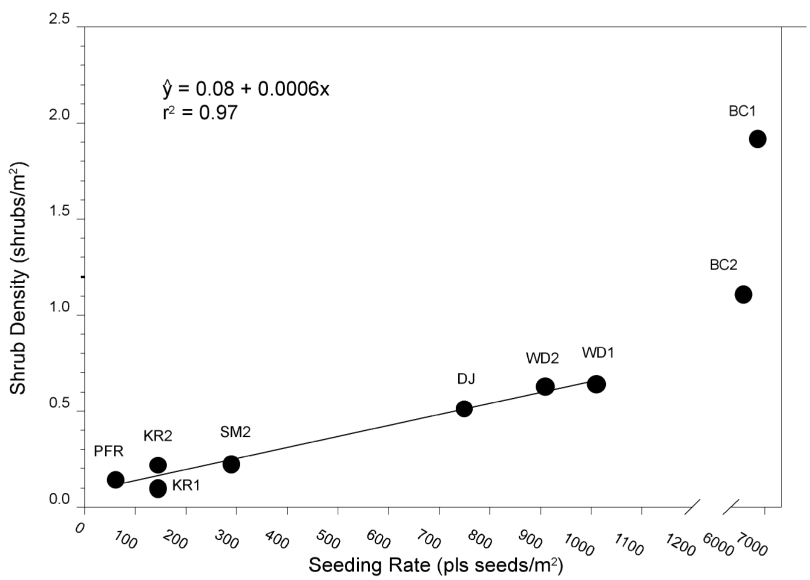
Heavy Wyoming big sagebrush seeds are likely to germinate more quickly and to a greater extent than lighter seeds (Bai et al. 1997). We advise sagebrush seed buyers to pay attention to seed weight and look for lots with less than 3500 seeds/g (remembering that heavier seeds mean fewer seeds per gram). Our selection of 3500 seeds/g is arbitrary and based only on the range in seed weight reported in this paper and our findings that the heavier seed lots performed better than light seed lots.

Seed testing must be an ongoing exercise for sagebrush and can be conducted in the office at low-cost. In addition, seed lots older than six months from harvest should always be evaluated within a month of sowing. [See Bai et al. 1997 for our method of testing Wyoming big sagebrush seeds.]

Germination and seedling establishment are rapid under optimum temperature and moisture conditions when seeds are physiologically ready. However, the co-incidence of germinable seeds and optimum conditions in the field is unpredictable and random and the source of episodic "pulses" in seedling recruitment (Lommasson 1948, Walton et al. 1986, Schuman et al. 1998, Booth et al. 1999). Numerous agronomic practices have been developed to enhance establishment and these are discussed elsewhere in these proceedings. Regardless of these practices, the variability of weather and biological systems make optimum field conditions hard to predict and unlikely to be arranged. Older reclaimed sites with sagebrush have been found to have a shrub density directly correlated to seeding rates up to 1000 seeds/m^2 (Figure 5)(Booth et al. (1999).

The sagebrush diaspore is simple in construction and functions. The reproductive strategy is small seed size, high seed numbers, and distribution near the mother plant (Walton et al. 1986). High seeding rates are therefore consistent with sagebrush ecology. As with other species "good management requires an understanding of ...specific seedbed ecologies and innovation in adapting methods of seed distribution and fixation that will complement ... diaspore functions most critical to seed success" (Booth 1987).

Fig. 5. Shrub density as influenced by the number of pure live seeds sown. The regression equation does not include data from the BC1 & 2 sites. Note the break in the x axis between 1200 and 6000 seeds/m^2. Letter symbols indicate different mines. Figure is from Booth et al. (1999)



References

Atwater, B.R. 1980. Germination, dormancy and morphology of the seeds of herbaceous ornamental plants. Seed Sci. Technol. 8:523-573.

Bai, Y., J.T. Romo, and J.A. Young. 1995. Influences of temperature, light and water stress on germination of fringed sagebrush (*Artemisia frigida*). J. Range Manage. 48:219-225.

Bai, Y., D.T. Booth, and E.E. Roos. 1997. Effect of seed moisture on Wyoming big sagebrush seed quality. J. Range Manage.50:419-422.

Bai, Y., S.P. Hardegree, D.T. Booth, and E.E. Roos. 1999. Technical note: Pericarp removal has little effect on sagebrush seeds. J. Range Manage. 52:384-386.

Booth, D.T. 1987. Diaspores of rangeland plants: ecology and management. pp. 202-211. In: G.W. Frasier and R.A. Evans (eds) Proc. Symp. Seed and Seedbed Ecology of Rangeland Plants. Nat'l. Tech. Info. Serv., 5285 Port Royal Rd., Springfield, VA.

Booth, D.T. 1993. Can we improve shrub seedling vigor by managing seed imbibition? p. 47-58. In: Planning, Rehabilitation and Treatment of Disturbed Lands, Proc., Sixth Billings Symposium, March 21-27, 1993, Billings, MT. Reclamation Research Unit Publ. No. 9301, Montana State Univ., Bozeman.

Booth, D.T., Y. Bai, and E.E. Roos. 1997. Preparing sagebrush seed for the market: Effects of debearder processing. J. Range Manage. 50:51-54.

Booth, D.T., J.K. Gores, G.E. Schuman, and R.A. Olson. 1999. Shrub densities on pre-1985 reclaimed mine lands in Wyoming. Restoration Ecology 7:1-9.

Federal Register. 1996. Office of Surface Mining and Enforcement. 30 CFR Part 950. Wyoming Regulator Program, final rule; approval of amendment. 61 (152):40735.

Lommasson, 1948. Succession in sagebrush. J. Range Manage. 1:19-21 (reprinted in 1993, Rangelands 15:109-110).

McDonough, W.T. and R.O. Harniss.1974. Effect of temperature on germination in three subspecies of big sagebrush. J. Range manage. 27:204-205.

Meyer, S.E. (In press). *Artemisia.* In: Woody Plant Seed Manual, USDA Forest Service, U.S. Government Printing Office, Washington, D.C.

Meyer, S.E. and S.B. Monsen 1992. Big sagebrush germination patterns: Subspecies and population differences. J Range Manage. 45:87-93.

Sabo, D.G., D.V. Johnson, W.E. Martin, and E.F. Aldon. 1979. Germination requirement of 19 species of arid plants. Res. Paper PM-210, USDA Forest Service, Rocky Mountain Forest and Range Exp. Sta., Fort Collins, CO.

Schuman, G.E., D.T. Booth, J.R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. J Range Manage. 51:223-230.

Shaw, N.L. and D.T. Booth. 1999. The germination of Wyoming big sagebrush seed as measured by different protocols. p. 72, Abstracts, 52nd Annual Meeting Society for Range Management, Boise, ID.

Taylor, A.G. and G.E. Harmon. 1990. Concepts and technologies of selected seed treatments. Annu. Rev. Phytopathol. 28:321-339.

Walton, T.P., R.S. White, and C.L. Wambolt. 1986. *Artemisia* reproductive strategies: a review with emphasis on plains silver sagebrush. pp. 67-74. In: D.E. McArthur and B.L. Welch (comps.), Proc., Symposium on the biology of *Artemisia* and *Chrysothamnus*. Intermountain Res. Sta. Gen. Tech. Report INT-200, USDA Forest Service, Ogden, UT.

Young, J.A. and C.G. Young. 1992. Seeds of woody plants in North America. Dioscorides Press, Portland, OR.

Enhancing Wyoming Big Sagebrush Establishment with Cultural Practices

G. E. Schuman[1], D.T. Booth[1], R.A. Olson[2]

Abstract

Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) has proven difficult to re-establish by direct seeding on mined lands in the western U.S. This paper reviews research accomplishments over the last decade that address ecological and cultural practices to enhance big sagebrush establishment. Direct-placed topsoil, mulching and arbuscular mycorrhizae have been shown to positively influence seedling establishment of this species on mined land. Direct-placed topsoil possesses better biological, physical, and chemical characteristics that are conducive to plant establishment. Direct-placed topsoil has greater water storage capacity, better soil physical properties, and higher levels of mycorrhizal inoculum. However, direct-placed topsoil has not shown benefits as a source of sagebrush propagules. Mycorrhizae has in turn been shown to give the seedlings greater drought stress tolerance. Forty-five day old sagebrush seedlings that were mycorrhizal were able to survive in soils at -3.2 MPa of moisture stress compared to -2.8 MPa for those non-infected seedlings. Regardless of sagebrush seedling age, no non-mycorrhizal seedlings survived in soils with water potentials less than -3.3 MPa compared with mycorrhizal seedlings that survived in soils as dry as -3.7 MPa. Mulch is believed to produce micro-climate changes in the seedbed area that provide "safe-sites" that result in more optimum conditions for sagebrush germination and establishment. Grass seeded concurrently with sagebrush creates significant competition and has reduced sagebrush seedling establishment. The use of a more easily established shrub species (*Atriplex cansescens*) as a "pioneer" plant has not shown any beneficial or "exclusionary" effects on Wyoming big sagebrush establishment. Ten-year old reclaimed lands seeded with multiple shrub species had higher canopy cover, density, and diversity than sites where the seed mixture included only a single shrub species. These recent findings are being incorporated into direct seeding technology by the mining industry; however, some questions remain unanswered. These technology advances will not ensure seedling establishment but will greatly enhance the probability of success in arid and semiarid environments.

Introduction

Xerophytic shrubs are a significant component of rangelands throughout much of the arid/semiarid West and provide many benefits to the function and utility of rangeland ecosystems (McKell and Goodin 1973). Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) is one of the most widely distributed and adapted shrub species in Wyoming and the region (Beetle and Johnson 1982). However, its re-establishment on mined lands has generally proven difficult because

[1]USDA, ARS, High Plains Grasslands Res. Stn., 8408 Hildreth Rd., Cheyenne, WY 82009
[2]Dept. Renewable Resources, University of Wyoming, P.O. Box 3354, Laramie, WY 82072

of low seedling vigor, an inability to compete with herbaceous species and altered edaphic conditions (Harniss and McDonough 1976, Young and Evans 1989, Schuman et al. 1998).

Reduced levels of arbuscular mycorrhizae (AM) in disturbed soils have also been postulated as a factor limiting the success of re-establishment of big sagebrush on disturbed lands (Call and McKell 1982, Stahl et al. 1988). Arbuscular mycorrhizae can improve the host plant's ability to extract nutrients and water from soil (Stahl et al. 1988). Indirect evidence has indicated that water availability is one of the key factors involved in big sagebrush seedling establishment success (Jones 1991). Allen (1984) reported that sagebrush is particularly dependent upon AM symbiosis to reach full growth potential. Use of "pioneer" plants to improve soil conditions, including AM levels, of disturbed lands for later seral species has also been postulated as a means to enhance re-establishment of big sagebrush (Booth 1985, Meyer 1990). It is evident from this brief review of the literature that much additional information was needed to enhance our understanding of big sagebrush seedbed ecology and to develop a seeding technology that would result in successful re-establishment of this species.

Recent Findings

Schuman and Booth (1998), Stahl et al. (1998), Schuman et al. (1998), and Booth et al. (1999) reported on recent research evaluating the effects of historic reclamation practices, soil management, mulching, competition, and AM on big sagebrush establishment. Schuman and Booth (1998) and Schuman et al. (1998) in a study to evaluate the effect of topsoil management (5 yr old stockpiled vs direct placement), mulching (stubble, surface, stubble + surface, and no mulch), and competition (three grass seeding rates) found that all three variables affected big sagebrush seedling establishment in an interactive manner. Sagebrush seedling densities responded differently to the treatments during the first year (1992) after seeding and the following spring than they did in the fall of 1993 and 1994 (Table 1-3). The largest increase in sagebrush seedlings were observed between the spring 1993 and fall 1993 due to the wet and cool conditions during that period. Big sagebrush seedling densities observed in 1992 on the direct placed topsoil-no competition-mulched treatments (Table 1) exceeded the shrub density standard (1 shrub/m^2) adopted in Wyoming (Federal Register 1996). If we use Kriger et al. (1987) findings that 32% of the big sagebrush established the first year will survive after 11 years we still have adequate seedling densities for the stubble and surface mulch treatments to achieve this standard. This emphasizes the importance of good cultural practices in establishing big sagebrush since 1992 was a below average (87%) precipitation year. Direct-placed topsoil resulted in 40% more sagebrush seedlings than the stockpiled topsoil treatment after 3 years; however in 1992 and the spring of 1993, differences were 1-2 orders of magnitude greater for direct-placed topsoil. Soil moisture content of the surface 7.5 cm of direct-placed topsoil was always higher than that observed in the stockpiled topsoil treatment in 1992. This observed greater soil moisture undoubtedly improved sagebrush germination and establishment on direct-placed topsoil in 1992. The benefits of direct-placed topsoil were only observed in treatments where no grass was seeded. No differences in sagebrush seedling densities were evident between the 16 and 32 kg PLS/ha grass seeding rates. However, even the lowest grass seeding rate is slightly above the maximum used by the industry in their reclamation programs (further discussion of grass seeding rate will be covered later in the paper).

Table 1. Sagebrush seedling density as affected by topsoil management, mulch type, and grass seeding rate, 1992. (Schuman et al. 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS/ha)	0	16	32	0	16	32
Mulch Type	plants/m^2					
Spring 1992						
stubble	5.78	1.11	0.04	0.11	0	0
surface	7.37	0.07	0	0.04	0	0
stubble + surface	1.59	1.56	0.63	0.11	0	0.04
control	0	0	0.04	0	0	0

$LSD_{0.10}$=2.48, within a mulch type with a topsoil management;
$LSD_{0.10}$=2.51 within a topsoil management with a seeding rate;
$LSD_{0.10}$=2.71 within a mulch type within a seeding rate.

	Fresh			Stockpiled		
Fall 1992	0	16	32	0	16	32
stubble	5.15	0.52	0.07	0	0	0.04
surface	6.07	0	0.15	0	0	0
stubble + surface	1.41	1.11	0.37	0.30	0.04	0
control	0	0	0	0	0	0

$LSD_{0.10}$=2.13 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.16 within a topsoil management within a seeding rate;
$LSD_{0.10}$=2.30 within a mulch type within a seeding rate.

Table 2. Sagebrush seedling density as affected by topsoil management, mulch type, and grass seeding rate, 1993. (Schuman et al. 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS/ha)	0	16	32	0	16	32
Mulch Type	plants/m^2					
Spring 1993						
stubble	6.30	2.04	1.81	1.63	0.04	0.15
surface	8.74	0.30	0.89	0.44	0.04	0.93
stubble + surface	4.07	2.48	1.52	1.56	0.33	0.11
control	1.26	0.56	0.22	0.37	0.14	0.04

$LSD_{0.10}$=2.01 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.07 within a topsoil management within a seeding rate;
$LSD_{0.10}$=2.73 within a mulch type within a seeding rate.

	Fresh			Stockpiled		
Fall 1993						
stubble	9.67	3.93	2.93	5.41	2.11	1.93
surface	13.48	1.00	1.22	2.74	1.81	2.18
stubble + surface	8.04	2.89	1.63	4.59	2.15	1.70
control	7.52	1.37	0.52	1.81	0.52	0.19

$LSD_{0.10}$=2.59 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.89 within a topsoil management within a seeding rate;
$LSD_{0.10}$=3.91 within a mulch type within a seeding rate.

Table 3. Sagebrush seedling density as affected by topsoil management, mulch type, and grass competition, Fall 1994. (Schuman et al. 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS/ha)	0	16	32	0	16	32
Mulch Type			plants/m^2			
stubble	8.15	9.82	7.11	3.44	2.78	3.26
surface	12.11	4.63	5.33	2.40	3.52	5.07
stubble + surface	9.11	3.78	4.26	3.30	3.85	2.52
control	7.22	5.88	4.56	4.48	2.52	1.70

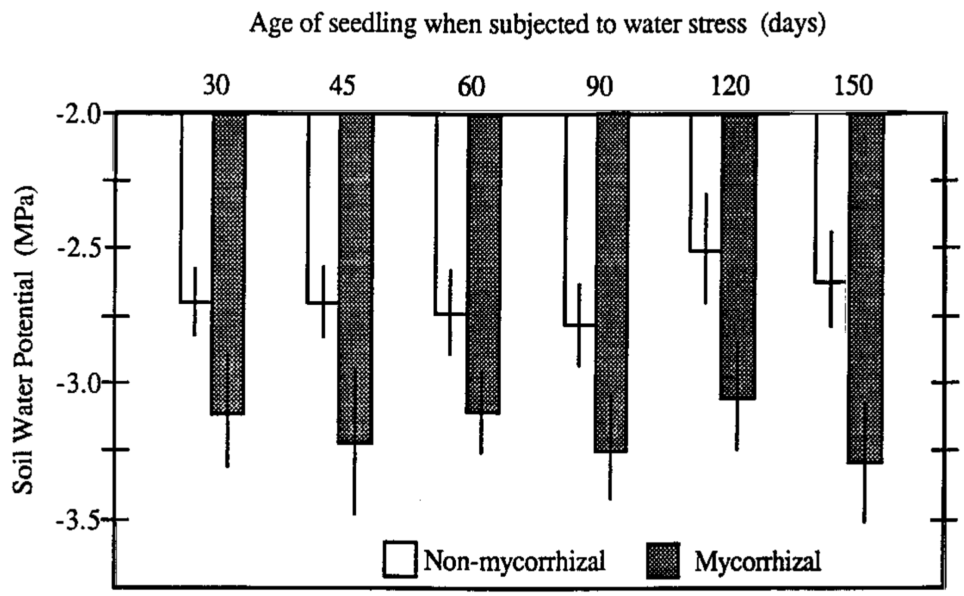
$LSD_{0.10}$=3.00 within a mulch type within a topsoil management;
$LSD_{0.10}$=3.79 within a topsoil management within a seeding rate;
$LSD_{0.10}$=3.99 within a mulch type within a seeding rate.

Benefits of topsoil management were evident in the initial year of establishment; however, this study did not clearly delineate some of the benefits expected. Unseeded control plots in an adjacent study did not have any sagebrush seedlings present after 4 yrs; therefore, direct-placed topsoil did not act as a seedbank for sagebrush nor was natural recruitment occurring (Schuman and Booth 1998),

Even though the AM fungal spore counts were significantly different between the two topsoil management treatments (3088/g stockpiled vs 4500/g direct-placed) no differences in sagebrush seedling infection was observed in the seedlings excavated in June 1993 (Schuman et al. 1998). Root segments examined from the study showed an infection rate of 66-76%. They believe that the time between topsoil placement (late summer 1990) and June 1993 was more than adequate for reinoculation of the stockpiled topsoil. Loree and Williams (1984) found that native grasses became infected with AM within a year of establishment on long-term stockpiled topsoil indicating inoculum is spread quite readily under natural conditions. However, this finding should not diminish the importance of topsoil management for AM concerns. Stahl et al. (1998), in a greenhouse study, found that the sagebrush seedling age groups of 30 to 150-days old that were mycorrhizal were able to tolerate greater drought stress (moisture tension) before dying than non-mycorrhizal seedlings. Non-mycorrhizal, 45-day-old sagebrush seedlings died when the moisture stress level was -2.8 MPa compared to the mycorrhizal seedlings which tolerated soil moisture tensions of -3.2 MPa before dying (Figure 1). Sagebrush seedling age and mycorrhizae treatment interacted, such that as sagebrush seedlings aged the beneficial influence of AM on soil moisture stress tolerance increased

(Figure 1). Those seedlings ≥120 days of age that were non-mycorrhizal were much less tolerant of soil moisture stress than younger non-mycorrhizal seedlings (Figure 1) indicating that sagebrush seedlings become more dependent upon the benefits of mycorrhizae as they age. They also showed

Figure 1. Average soil water potentials resulting in death of mycorrhizal and non-mycorrhizal sagebrush seedlings. Vertical bars on each column represent 1 standard deviation. Differences between mycorrhizal and non-mycorrhizal treatments were statistically significant at P≤0.01 for each age group. (Stahl et al. 1998)

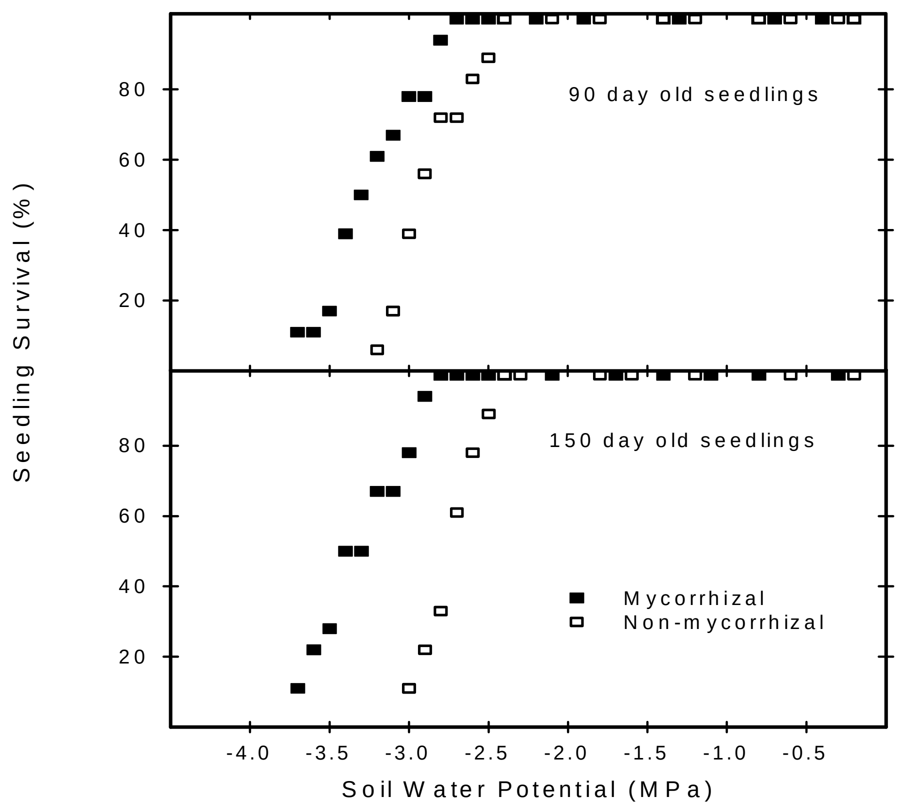


that sagebrush seedling survival across a range of soil water potentials was greater for mycorrhizal than non-mycorrhizal seedlings (Figure 2). These findings could partially explain the lack of infection differences observed by Schuman et al. (1998) in seedlings grown on direct-placed vs stockpiled topsoil. Those seedlings growing in stockpiled topsoil failing to form AM early in their development may have not tolerated repeated drying cycles experienced in a typical spring-summer period in a semiarid climate. Hence, seedlings sampled a year later may not have been representative of the seedling population that originally germinated and emerged because non-mycorrhizal seedlings may have died early in their development.

The presence of mulch also greatly affected sagebrush seedling establishment in 1992 (Schuman and Booth 1998, Schuman et al. 1998). No seedlings were evident in the first year where mulch was not applied (Table 1). Both stubble and surface mulch treatments had similar or greater seedling establishment than the stubble + surface mulch treatment. Soil moisture content of the surface 7.5 cm was greater under all mulch treatments compared to the no-mulch treatment. Schuman et al. (1980) found that stubble mulch enhanced grass seedling establishment through reduced diurnal temperature fluctuations and increased soil moisture.

Grass competition reduced sagebrush seedling densities throughout the duration of the study on direct-placed topsoil treatment where stubble or straw mulch was used (Schuman and Booth 1998, Schuman et al. 1998). They reported grass seedling densities of 0, 196, and 250 grass seedlings/m^2 for the 0, 16, and 32 kg PLS/ha grass seeding rates, respectively. No differences in grass seedling density among topsoil management treatments were observed. They concluded that successful establishment of big sagebrush on mined lands might require seeding in the absence of any grass or

Figure 2. Survival rates for 90 and 150 day old mycorrhizal and non-mycorrhizal sagebrush seedlings at different levels of soil dryness. (Stahl et al. 1998)



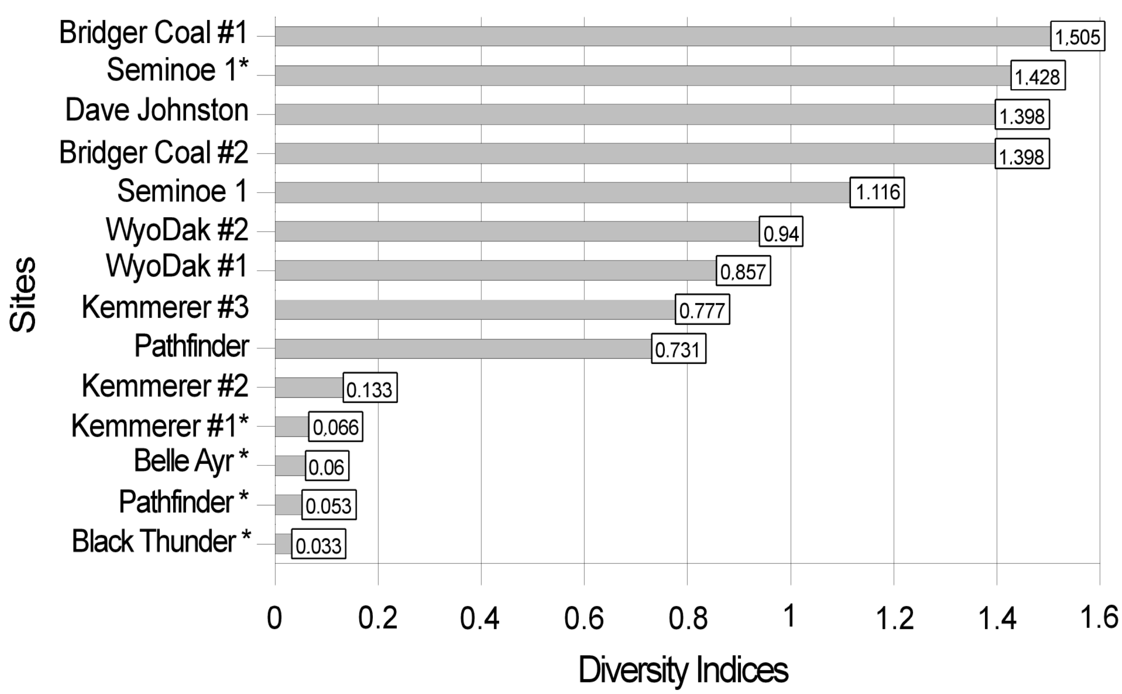
perhaps at very low grass seeding rates. These findings have led to further research by Fortier et al. (2000) evaluating effects of grass competition and big sagebrush seeding rates on sagebrush seedling establishment reported at this conference.

A research study aimed at assessing the role of fourwing saltbush (*Atriplex canescens* ssp. *aptera*) as a "pioneer" plant to enhance the later establishment of big sagebrush and to evaluate the role of this plant in excluding big sagebrush when seeded at rates in excess of 2.2 kg PLS/ha was reported by Schuman and Booth (1998). Grass competition was not evaluated in this study; hence, the only herbaceous plant competition that existed was from plants that became established naturally through the topsoil seedbank or other means of recruitment. The entire study area was stubble mulched. They found that fourwing saltbush neither improved nor restricted sagebrush establishment; however, they did report greater total shrub densities where fourwing saltbush was over-seeded a year later with big sagebrush. Big sagebrush represented 42% of the shrub density and the seeding strategy produced about 10,000 more total shrub seedlings per hectare than other seeding strategies. Gores (1995), Booth et al. (1999), and Olson et al. (2000) also reported that shrub densities were greater when more than one shrub species is included in the reclamation seed mixture.

Schuman et al. (1998) and Schuman and Booth (1998) showed that big sagebrush seed maintains its viability for much longer than thought (Young and Evans 1989) because new seedlings were noted 3-5 years after the initial seeding of big sagebrush. Wyoming big sagebrush has been shown to have some seed dormancy (McDonough and Harniss 1974, Booth et al. 1997); therefore, Schuman et al. (1998) and Schuman and Booth (1998) believe that continued germination and establishment of big sagebrush for several years was related to seed dormancy, the continual development of "safe sites" for seed germination and establishment (Harper 1977) and improved climatic conditions (precipitation and temperature) in subsequent years.

Research has shown that seeding a mixture of shrub species also results in greater overall density, species diversity, and structural diversity than is achieved by a single shrub species (Gores 1995, Booth et al. 1999 and Olson et al. 2000). Gores (1995) and Olson et al. (2000) also reported that sites seeded to several shrub species resulted in higher diversity indices of reclaimed sites compared to those where only fourwing saltbush was seeded (Figure 3). Greater species and structural diversity greatly enhance wildlife habitat quality.

*Figure 3. Diversity indices for fourwing saltbush/grass (denoted by *) and fourwing saltbush/big sagebrush/grass sites. Refer to Booth et al. 1997 for a list of seeding mixture used at each site. (Olson et al. 2000)*



Conclusions/Summary

Research reviewed in this paper has answered many questions related to establishment of Wyoming big sagebrush on mined lands; however, not all issues/concerns have been fully addressed. Current research assessing the effects of sagebrush seeding rates and multiple levels of grass competition on sagebrush establishment should further aid in defining and developing a big sagebrush establishment technology. The fact that big sagebrush has exhibited some seed dormancy and has been shown to retain seed viability for several years after being seeded greatly increases the probability of a good "precipitation and temperature year" occurring while the seed is still viable. This fact alone may make it desirable to seed big sagebrush at a higher rate than previously recommended to ensure an adequate seed bank for germination and establishment over several years. Even though big sagebrush seed is relatively expensive, this cost would be much lower than having to mobilize equipment and a contractor a second year to ensure adequate and desired sagebrush densities are achieved.

Evidence does not seem to support the fact that more easily established shrubs, such as fourwing saltbush, enhance establishment of big sagebrush; however, inclusion of multiple shrub species in the seed mixture has been shown to increase total shrub seedling density and greater plant community diversity.

Research has repeatedly highlighted the many benefits of direct-placed topsoil, such as AM inoculum, better soil physical characteristics, seedbank of native species, healthy microbial populations that ensure good nutrient cycling, and enhanced water infiltration and water storage capacity. Enhanced drought stress tolerance of big sagebrush seedlings when AM associations are present highlights an important factor in improving seedling survival in an arid/semiarid environment where soil moisture levels fluctuate dramatically in the surface few centimeters of the soil.

Mulch has also been shown to be critical to formation of "safe sites" for big sagebrush germination and establishment through microclimate modification. Stubble mulching is a desired practice over the use of straw mulch which is more costly, more labor intensive and has a greater potential to introduce non-desired and noxious weed species into reclaimed lands. Use of a stubble mulch has also been shown to have long-term benefits for water infiltration into the reconstructed soil profile (Schuman et al. 1980).

Reclamationists have recommended and in some instances planted big sagebrush in small islands with the intention that these islands serve as seed banks for further spread of the species into the revegetated areas. However, data by Gores (1995) and Lyford (1995) showed that natural recruitment of big sagebrush into revegetated mine lands from native stands of big sagebrush was generally limited to a few meters after 10-15 years. Lyford (1995) stated that natural recruitment decreased 50-fold when distance to the seed source exceeded 100 m. Therefore, this approach to aiding establishment of big sagebrush will probably not be effective within the bonding time frame.

Research within the last decade has produced a much better understanding of seedbed ecology of big sagebrush. Research aiding development of a seeding strategy for big sagebrush should also benefit establishment of other native shrub species.

References

Allen, E.B. 1984. Vesicular-arbuscular mycorrhizae and colonizing annuals: Implications for growth, competition and succession. p. 41-51. In: S.E. Williams and M.F. Allen (eds.) VA Mycorrhizae and Reclamation of Arid and Semiarid Lands. August 17-19, 1982, Dubois, WY. Wyoming Agr. Exp. Stn. Rpt. No. SA1261, Laramie.

.Beetle, A.A. and K.L. Johnson. 1982. Sagebrush in Wyoming. Wyoming Agr. Exp. Stn.Bull. 779. University of Wyoming, Laramie.

.Booth, D.T. 1985. The role of fourwing saltbush in mined land reclamation: A viewpoint.J. Range Manage. 38:562-565

.Booth, D.T., Y. Bai, and E.E. Roos. 1997. Preparing sagebrush seed for market: Effects of debearder processing. J. Range Manage. 50:562-565.

Booth, D.T., J.K. Gores, G.E. Schuman, and R.A. Olson. 1999. Shrub densities on pre-1985 reclaimed mine lands in Wyoming. Restoration Ecology. 7:1-9.

Call, C.A. and C.M. McKell. 1982. Vesicular-arbuscular mycorrhizae-a natural revegetation strategy for disposed oil shale. Reclamation and Revegetation Res. 1:337-347.

Federal Register. 1996. Office of Surface Mining and Enforcement. 30 CFR Part 950. Wyoming Regulatory Program-final rule; approval of amendment. Vol. 61: (152):40735.

Fortier, M.I., G.E. Schuman, and A.L. Hild and L.E. Vicklund. 2000.Effects of seeding rates andcompetition on sagebrush establishment on mined lands. p. 304-311. In: Striving for Restoration, Fostering Technology and Policy for Reestablishing Ecological Function. Proc., 2000 Billings Land Reclamation Symposium, March 20-24, 2000, Billings, MT. Reclamation Research Unit Publ. No. 00-01, Montana State University, Bozeman.

Gores, J.K. 1995. The evaluation of big sagebrush and fourwing saltbush establishment on pre-1985 Wyoming reclaimed mine sites. M.S. Thesis, University of Wyoming, Laramie.

Harniss, R.O. and W.T. McDonough. 1976. Yearly variation in germination in three subspecies of big sagebrush. J. Range Manage. 29:167-168.

Harper, J.L. 1977. The recruitment of seedling populations. p. 111-147. In: Population Biology of Plants. Academic Press, New York.

Jones, G.P. 1991. Seedling survival and adult plant water relations of black sagebrush and big sagebrush in the Laramie Basin. Ph.D. Dissertation, Dept. of Botany, University of Wyoming, Laramie.

Kriger, J.A., W.A. Berg, J.T. Herron, C.M. Phillips, and R.G. Atkinson. 1987. Shrub establishment in the mountain shrub zone. p. L-3-1 through L-3-6. In: Proc., 4th Biennial Symposium on Surface Mining and Reclamation of the Great Plains and 4th Annual Meeting of the American Society of Surface Mining and Reclamation, March 16-20, 1987, Billings, MT. Reclamation Research Unit Rpt. 8704, Montana State University, Bozeman.

Loree, M.A.J. and S.E. Williams. 1984. Vesicular-arbuscular mycorrhizae and severe land disturbance . p. 1-14. In: Proc., VA Mycorrhizae and Reclamation of Arid and Semiarid Lands. August 17-19, 1982, Dubois, WY. Wyoming Agric. Exp. Stn. Sci. Rpt. No. SA1261, Laramie.

Lyford, M.E. 1995. Shrub establishment on drastically disturbed lands. M.S. Thesis, University of Wyoming, Laramie.

McDonough, W.T. and R.O. Harrniss. 1974. Effects of temperature on germination in three subspecies of big sagebrush. J. Range Manage. 27:204-205.

McKell, C.M. and J.R. Goodin. 1973. United States arid shrublands in perspective. p. 12-18. In: Proc., Third Workshop of U.S./Australia Rangelands Panel, Tucson, AZ. Society for Range Management, Denver, CO.

Meyer, S.E. 1990. Shrubland restoration-an ecologist's perspective. Handout: Workshop on Plant Species and Wildlife Habitat Establishment Successes and Failures. Billings, MT. Intermountain Research Station, Shrub Sciences Laboratory, USDA, FS, Provo, UT.

Olson, R.A., J.K. Gores, D.T. Booth, and G.E. Schuman. 2000. Suitability of shrub establishment on Wyoming mined lands reclaimed for wildlife habitat. Western North American Naturalist. 60(1): 77-92.

Schuman, G.E. and D.T. Booth. 1998. Strategies for establishment of big sagebrush (*Artemisiatridentata* ssp. *wyomingensis*) on Wyoming mined lands. Final Report, Abandoned Coal Mine Land Research Program, Office of Research, University of Wyoming, Laramie and Wyoming Department of Environmental Quality, Abandoned Mine Land Program, Cheyenne, WY.

Schuman, G.E., D.T. Booth, and J.R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. J. Range Manage. 51:223-230.

Schuman, G.E., E.M. Taylor, Jr., F. Rauzi and G.S. Howard. 1980. Standing stubble versus crimped straw mulch for establishing grass cover on mined lands. J. Soil and Water Conservation. 35:25-27.

Stahl, P.D., G.E. Schuman, S.M. Frost, and S.E. Williams. 1998. Interaction of arbuscular mycorrhiza and seedling age on water stress tolerance of *Artemisia tridentata* ssp. *wyomingensis*. Soil Sci. Soc. Am. J. 62: 1309-1313.

Stahl, P.D., S.E. Williams, and M. Christensen. 1988. Efficacy of native vesicular-arbuscular mycorrhizal fungi after severe soil disturbance. New Phytol. 110:347-354.

Young, J.A. and R. Evans. 1989. Dispersal and germination of big sagebrush (*Artemisia tridentata*) seeds. Weed Sci. 37:201-206.

Effects of Seeding Rates and Competition on Sagebrush Establishment on Mined Lands

M.I. Fortier[1], G.E. Schuman[2], A.L. Hild[1], and L.E. Vicklund[3]

Abstract

Shrub establishment on reclaimed coal mines of the Powder River Basin in Wyoming is a vital component of reclamation. Efforts to revegetate using xerophytic shrubs have been unsuccessful due to competition for moisture, poor seedling vigor, and altered edaphic conditions. As a result, methods to re-establish Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) are needed to meet shrub density standards. This study examines effects of grass competition and sagebrush seeding rate upon establishment of big sagebrush seedlings at the Belle Ayr Coal Mine near Gillette Wyoming. Experimental plots seeded with three sagebrush rates (1, 2, and 4 PLS kg/ha) and seven rates of a grass mixture (0, 2, 4, 6, 8, 10, and 14 PLS kg/ha) were used to assess effects of sagebrush seeding rate and grass competition on seedling density and survival. Data from four sagebrush seedling counts (June 30, August 3, August 31, and October 25, 1999) show fewer sagebrush seedlings at higher grass seeding rates, although not statistically significant. Sagebrush seedling density differed among sagebrush seeding rates. On all four sampling dates, sagebrush seedling density was greater for the 4 kg/ha sagebrush seeding rate than the 2 and 1 kg/ha rates. Mean seedling counts on June 30 differed among all three sagebrush rates whereas on August 3, 31, and October 25 the 2 and 1 kg/ha rates had similar seedling densities. Sagebrush seedling density and grass and forb production determined in 2000 will provide us with further information about treatment effects on sagebrush seedling establishment and survival. We anticipate that this study and other recent research on the effects of other cultural practices on sagebrush establishment will enable proposal of a seeding strategy for Wyoming big sagebrush.

Introduction

In arid and semiarid rangelands, where mining has occurred, re-establishment of key vegetative species is critical to maintain function, structure, diversity, and stability of the landscape. Key shrub species have evolved to exploit the limited resources of these regions, and are a vital component of rangeland function. Shrubs provide many benefits to humans and animals including erosion control, industrial products, ornamentals, medicine, functionality of rangeland ecosystems, and wildlife browse and cover (McKell 1989). Precipitation and available soil moisture dictate the distribution of xeriphytic shrub communities across North America (McKell 1989), and their drought tolerance make them well suited to dominate arid and semiarid regions. As a result, shrub communities are

[1] Department of Renewable Resources, University of Wyoming, Laramie, WY 82072
[2] USDA-ARS, High Plains Grasslands Res. Stn., 8408 Hildreth Rd., Cheyenne, WY 82009
[3] Belle Ayr Coal Mine, RAG Coal West, Inc. Gillette, WY 82716

found in saline valleys, dry deserts, broad valleys, and on xeric slopes. Shrub restoration is an important science across the western United States because of recent attention and heightened ecological awareness paid to surface mine reclamation.

Efforts to re-establish shrubs on coal mined lands was heightened upon adoption of a specific shrub density standard, 1 shrub/m^2 on 20% of reclaimed lands, by the Wyoming Department of Environmental Quality (Wyoming DEQ 1996). Attaining shrub density standards for Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis*) in the Powder River Basin of Wyoming have proven difficult. Problems encountered with sagebrush re-establishment include low seedling vigor, slow growth habits, poor seed viability, disease, injury or excessive browse from livestock and wildlife, and competition from herbaceous species (Harniss and McDonough 1976, DePuit 1988, Young and Evans 1989, Schuman et al. 1998).

Past studies have shown that sagebrush seedling establishment is dependent upon moisture availability (Jones 1991), arbuscular mycorrhizal infection (Allen 1984, Stahl et al. 1998), and herbaceous competition (Schuman et al. 1998). There are a number of approaches to resolve competition and water stress on shrub seedlings. For example, straw and stubble mulches can be used to enhance soil water retention, reduce diurnal temperatures, increase microbial activity, and to enhance "safe-site" development for seed/seedlings (Schuman et al. 1980, 1998). Practices such as mowing, interseeding, and two-phase seeding can alleviate competitive pressures on shrub seedlings (DePuit 1988). The rate and time of seeding can also influence shrub seedling survival. Although rate of seeding can be manipulated to reduce environmental and competitive stresses, successful guidelines have not been established for mined lands. Successful reclamation techniques require proper and effective seeding rates to accelerate and direct plant succession toward desired conditions.

This study examines sagebrush seeding rate and herbaceous competition treatment effects on Wyoming big sagebrush establishment. Guidelines for proper seeding rates of native shrubs, especially Wyoming big sagebrush, are vital management strategies for mined lands of the Powder River Basin.

The objectives of this study are to investigate three factors affecting sagebrush seedling establishment on mined lands: 1) influence of grass competition on Wyoming big sagebrush germination, emergence and establishment 2) effects of sagebrush seeding rates on sagebrush seedling density and survival, and 3) the interaction of sagebrush seeding rate and grass competition on sagebrush seedling establishment and survival.

Materials and Methods

The study area is located at Belle Ayr Coal Mine, RAG Coal West, Inc. 29 km southeast of Gillette, Wyoming. The Powder River Basin is situated between the Black Hills and Big Horn Mountains in northeastern Wyoming. This area has a continental, temperate, semiarid climate. The landscape is characterized by rolling plains and divides with steep escarpments separating plain-like areas from dissected areas with terraces and sloping alluvial fans along streams. Average annual precipitation at the Belle Ayr Mine is 380 mm and average temperature is 7.2°C (L.E.Vicklund, unpublished data, 1998). Snowfall averages 132 cm, most of which falls between October and April. Fifty percent of the precipitation occurs between April and July (Bjugstad 1978).

Pre-mining vegetation of the Powder River Basin is northern mixed-grass prairie, which includes localized concentrations of big sagebrush in a matrix of cool- and warm-season perennial grasses. Black sagebrush (*Artemisia nova*) is common to shallow soils while big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) is commonly found on well-drained uplands. Plains cottonwood (*Populus sargentii*) and willow species (*Salix* sp.) surround larger streams in the Powder River Basin. Greasewood (*Sarcobatus vermiculatus*) and salt-tolerant grasses are limited to broad drainage bottoms and some playas in the area. Local soils either formed from Tertiary and Upper Cretaceous aged shale, sandstone, and limestone or from alluvial terraces and fans. Most soils have a carbonate horizon 40-76 cm deep in the soil profile (Glassey et al. 1955).

Experimental units of the study are located on a 36-ha reclaimed site at Belle Ayr Mine. During December 1997 and January 1998, topsoil from a seven-year-old stockpile was spread at 56 cm in depth over spoil material (70 m deep). In April the study area was seeded to 'Steptoe' barley (*Hordeum vulgare*) at the rate of 17 kg/ha. Barley was mowed late summer and again in early fall to provide a stubble mulch.

Experimental Design

The experimental design was a randomized block design with four replicate blocks (27 x 45.5 m). Grass seeding rate treatments of 0, 2, 4, 6, 8, 10, and 14 kg PLS/ha were randomly applied within each block (6.5 x 27 m) and seeded in early December 1998. Three species of grasses, western wheatgrass (*Pascopyrum smithii*), slender wheatgrass (*Elymus trachycaulus*), and thickspike wheatgrass (*Elymus lanceolatus*) were mixed on an equal seed number basis to form a cool-season perennial grass mixture. This mixture was seeded at the seven rates described earlier to provide a variety of grass competition levels. Grass treatments were seeded using a 1.5 m wide double disk drill and seeded about 1.5 to 2.0 cm deep. Each grass treatment plot was divided into 6.5 by 9 m randomly assigned subplots for sagebrush seeding rate treatments. Sagebrush seed collected near Gillette in the fall 1998 was broadcast seeded at 1, 2, and 4 kg PLS/ha in March 1999 within each subplot.

Sampling Methods

Six 1-m^2 permanent quadrats were established within each sagebrush by grass treatment subplot (6.5 x 9 m) to assess sagebrush seedling densities during two summer seasons, 1999 and 2000. Sagebrush seedlings were counted on June 30, August 3, August 31, and October 25, 1999. In June 1999 grass and forb biomass, collected in 28 - ½ m^2 quadrats, was used to assess production relative to grass seeding rate treatments. Sagebrush density will be determined in June and October of 2000 and cover and production of grasses and forbs will be evaluated in July 2000.

Soil moisture content was determined biweekly at 0-5 cm and 5-15 cm depths from June 17 through August 30. Soil core samples were taken in seven random subplots within two replications. Soil temperature was recorded at 5 cm and 15 cm soil depths at the site. In addition, minimum/maximum air temperature and precipitation were recorded on a weekly basis. Soil temperature, air temperature and precipitation were monitored April through October, 1999, and will be monitored again in 2000. Soil samples taken in seven locations at three depths (0-15 cm, 15-30 cm, and 30-46 cm) will be analyzed for soil pH, electrical conductivity, particle size separation, cation concentration (potassium, calcium, sodium, and magnesium), organic carbon, total nitrogen, and phosphorus concentration.

Data Analysis

Analysis of variance was accomplished using a split-plot, randomized block design to assess sagebrush seedling establishment relative to grass and sagebrush seeding rate treatments on each sampling date and across sampling dates. Grass seeding rates are main plot treatments while sagebrush seeding rates are subplot treatments. Least significant difference (LSD) mean separation was used to indicate differences in sagebrush seedling density among the sagebrush and grass seeding rates. Repeated measures analysis of variance was used to determine differences within sagebrush and grass seeding rate treatments over time. Comparison of October 1999 seedling densities with June 2000 densities will be used to evaluate seedling survival. Grass and forb biomass samples were analyzed to find significance among the seven grass seeding rates. Soil moisture data for six sampling dates were analyzed to determine significance between grass seeding rate and soil water content during the 1999 growing season. Treatment effects and mean separations were evaluated at P# 0.05.

Results

Precipitation in spring and summer 1999 exceeded normal at the study area. April, June, and July precipitation were 7.8, 9.6, and 5.2 cm respectively which was 79, 39, and 54 % above the 67-yr average for Belle Ayr Coal Mine. Total grass and forb biomass collected in 1999 averaged 4084 kg/ha (3228 forb, 193 grass, 663 barley), exhibiting no differences among grass seeding rates. As a result of vigorous forb growth the study area was mowed, with small plot mowers, in late July to aid in assessment of sagebrush seedlings and to mimic management practices used on adjacent reclaimed lands. Mowing was maintained at 10-15 cm in height to prevent sagebrush seedling damage.

Soil moisture content declined from June to late July with further declines in late August (Table 1). At 0-5 cm soil depths, soil moisture content differed among sampling dates, irrespective of grass seeding rates. June 17 and August 13 exhibited higher soil moisture content than all other sampling dates. Soil moisture content at 5-15 cm soil depth differed among grass seeding rates, depending on sampling date. Differences in soil moisture were observed on July 1 and August 13 among the grass seeding rates; however, there were no consistent trends.

Table 1. Soil moisture (%) at 0-5 cm and 5-15 cm depths in seven grass seeding rates during summer 1999 at Belle Ayr Mine.

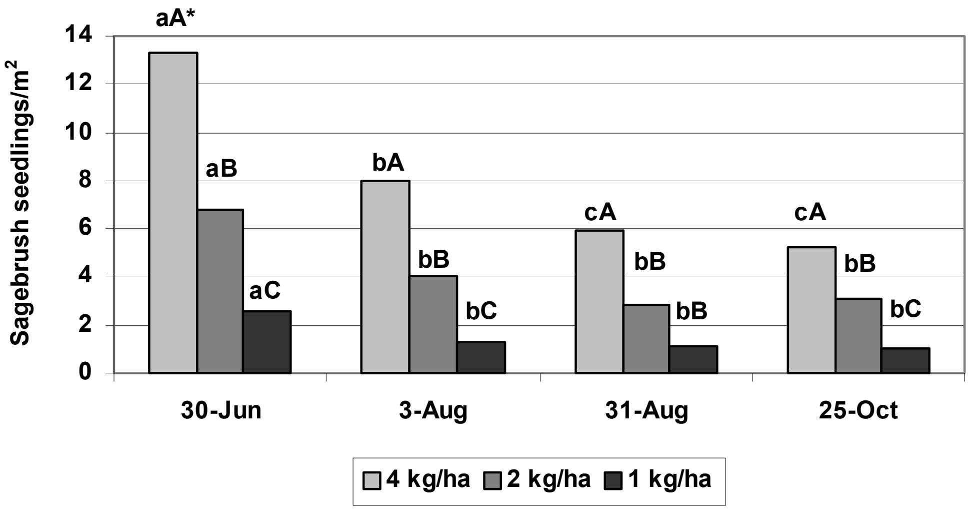
Sampling date	**June 17**		**July 1**		**July 15**		**July 29**		**August 13**		**August 30**	
Soil Depth (cm) Grass rate (kg/ha)	0-5*	5-15**	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15
0	12.7	15.0 Aa	8.80	9.9 ABbc	6.2	10.5 Ab	5.1	8.9 Abc	18.4	16.9 Aa	4.8	6.6 Ac
2	15.6	18.5 Aa	11.1	12.9 Ab	5.9	8.90 Acd	6.3	9.9 Abc	14.0	11.5 Bbc	5.7	6.2 Ad
4	14.8	16.2 Aa	7.90	8.60 Bb	7.4	8.30 Ab	5.6	9.9 Ab	16.1	15.4 Aa	5.2	7.0 Ab
6	14.6	17.7 Aa	8.70	11.6 ABb	7.1	10.6 Abc	5.8	9.4 Abc	12.1	10.0 Bbc	5.5	7.7 Ac
8	14.6	15.4 Aa	10.9	12.4 Aab	6.2	10.1 Abc	6.9	8.4 Ac	15.1	11.9 Bab	5.7	8.3 Ac
10	14.6	17.7 Aa	9.30	11.3 ABb	7.3	9.50 Abc	4.9	7.3 Ac	17.0	12.1 Bb	5.8	7.2 Ac
14	14.1	16.9 Aa	9.20	12.9 Ab	6.7	8.80 Ac	5.1	8.4 Ac	14.9	10.0 Bbc	6.4	8.7 Ac
Date Mean	14.4 x		9.40 y		6.7 z		5.6 z		15.4 x		5.6 z	

*Within 0-5cm soil depth dates differ; means with the same letter (x, y, z) are not significantly different.

**Within 5-15cm soil depth, grass means within a date with the same uppercase letters do not differ; within grass seeding rate, dates with the same lowercase letters do not differ, P $\geq$ 0.05 LSD.

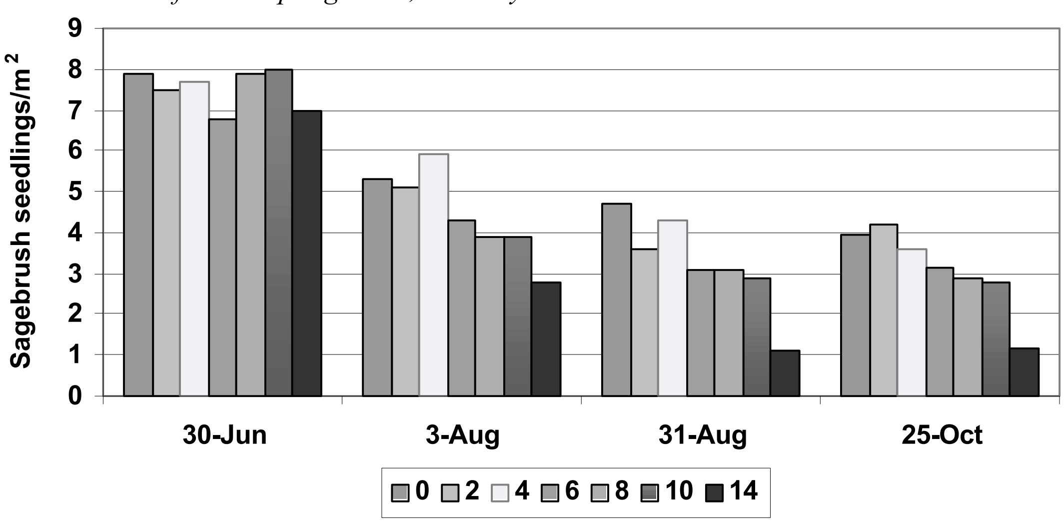
Sagebrush seedling density differed among the three sagebrush seeding rates (Figure 1); seedling density at 4 kg/ha sagebrush seeding rate was greater than the 2 and 1 kg/ha rates on all four sampling dates in 1999. The number of sagebrush seedlings declined during the first growing season in all sagebrush seeding rates. When averaged across sagebrush seeding rates, fewer sagebrush seedlings were observed in the higher grass seeding rates; however, this effect was not statistically significant (Figure 2).

Figure 1. Density of sagebrush seedlings measured from three sagebrush seeding rates on four sampling dates, Belle Ayr Mine in 1999.



*Uppercase letters indicate mean separation among sagebrush rates within a date. Lowercase letters indicate mean separation among dates within a specific rate. Means with the same letter are not statistically different, LSD.

Figure 2. Density of sagebrush seedlings measured from seven grass seeding rates on four sampling dates, Belle Ayr Mine in 1999 .



Discussion

Results from the first growing season (1999) suggest limited effects of grass competition on sagebrush establishment. Since precipitation was above normal for spring and early summer months this moisture availability may explain the lack of significant differences in sagebrush seedling densities among grass seeding rates. Soil moisture data at 5-15 cm does show an interaction between grass seeding rate and date, which suggests that grass has a greater influence on soil moisture at deeper soil depths. The 0-5 cm soil samples were more variable in soil moisture over time, as we would expect.

Higher sagebrush seedling density was achieved using 4 kg PLS/ha, although all three rates resulted in sagebrush seedling densities of $\$ 1/m^2$ in the first growing season. Sagebrush seedling mortality ranged from 49 to 62% with the 1 and 4 kg/ha seeding rates exhibiting the greatest mortality. Mortality of sagebrush seedlings over the growing season could be attributed to lower soil moisture content in late summer.

We anticipate that normal or below normal precipitation and the development of the grass community will cause greater competitive effects of the grass on sagebrush seedling survival in the next growing season. Furthermore, mortality of sagebrush seedlings over the winter may also significantly alter sagebrush seedling density. It appears that with any over-winter mortality the 1 kg/ha sagebrush seeding rate will result in a seedling density $< 1/m^2$ unless further germination and establishment occurs in 2000. Schuman (1999) suggests that higher sagebrush seeding rates, than are normally recommended, be used to ensure the desired density of sagebrush since the seed has been shown to retain viability in the field for several years. He believes this would greatly increase the probability of a good/optimum "precipitation and temperature year" occurring for germination and establishment of big sagebrush without the cost of repeated seeding attempts.

The influence of grass and sagebrush seeding rates on sagebrush seedling establishment will provide us with valuable information about seeding methodology. Our evidence along with recent findings of Schuman et al. (1998) on cultural revegetation methods will furnish reclamationists with guidelines to improve shrub establishment on reclaimed mined lands.

References

Allen, E.B. 1984. Vesicular-arbuscular mycorrhizae and colonizing annuals: Implications for growth, competition and succession. pp. 41-51. In: S.E. Williams and M.F. Allen (eds.) VA Mycorrhizae and Reclamation of Arid and Semiarid Lands. Wyoming Agr. Exp. Stn. Rpt. No. SA1261, Laramie.

Bjugstad, A.J. 1978. Reestablishment of woody plants on mine spoils. pp. 3-12. In: R.A. Wright (ed.) The reclamation of disturbed arid lands. Univ. of New Mexico Press, Albuquerque.

DePuit, E.J. 1988. Shrub establishment on drastically disturbed lands. pp. 55-60. In: Proc. of the Seventeenth Wyoming Shrub Ecology Workshop. June 21-22, 1988, Jackson, WY.

Glassey, T.W., T.J. Dunnewald, J. Brock, H.H. Irving, N. Tippetts, and C. Rohrer. 1955. Campbell County Soil Survey, Wyoming. USDA, Soil Conservation Service. No. 22, U.S. Government Printing Office, Washington, D.C.

Harniss, R.O. and McDonough, W.T.. 1976. Yearly variation in germination in three subspecies of big sagebrush. J. Range Manage. 29:167-168.

Jones, G.P. 1991. Seedling survival and adult plant water relations of black sagebrush and big sagebrush in the Laramie Basin. Ph.D. Diss., University of Wyoming, Laramie.

McKell, C.M. 1989. The Biology and Utilization of Shrubs. Academic Press, San Diego, CA.

Schuman, G.E. 1999. Direct seeding establishment of Wyoming big sagebrush: Research Advances. In: Proc., Interactive Forum Approaching Bond Release:Revegetation, Reclamation Issues, and Surface Mining Applications in the Arid, Semi-Arid West. September 20-24, 1999, Flagstaff, AZ. Office of Surface Mining, Denver, CO.

Schuman, G.E., E.M. Taylor, Jr., F. Rauzi, and G.S. Howard. 1980. Standing stubble versus crimped straw mulch for establishing grass cover on mined lands. J. Soil and Water Cons. 35: 25-27.

Schuman, G.E., D.T. Booth, and J.R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. J. Range Manage. 51: 223-230.

Stahl, P.D., G.E. Schuman, S.M. Frost, and S.E. Williams. 1998. Arbuscular mycorrhizae and water stress tolerance of Wyoming big sagebrush seedlings. Soil Sci. Soc. Am. J. 62:1309-1313.

Wyoming Department of Environmental Quality, Land Quality Division. 1996. Coal rules and regulations, Chapter 4, Appendix A, State of Wyoming, Cheyenne, WY.

Young, J.A. and R.A. Evans. 1989. Dispersal and germination of big sagebrush (*Artemisia tridentata*) seeds. Weed Sci. 37: 201-206.

A Design Solution to Big Sagebrush Establishment: Seed Production Plots and Facilitation

Tim W. Meikle[1]

Abstract

Big Sage (*Artemisia tridentata* ssp*. wyomingensis*) has proven difficult to re-establish in the Powder River Basin of Wyoming due to drought, plant competition, economics, and other factors. Planting unit design that takes into consideration the natural reproductive strategy of big sage could have a substantial impact on the economics and success of sage establishment. In general, the reproductive strategy of sage is to produce a large amount of short-lived seed with highly variable viability over a long life span. Actual establishment of seedlings results from infrequent stochastic events that create favorable conditions for germination and growth. Thus, the concept of direct-seeding sage as a one-time event is contradictory to the reproductive strategy of sage. In addition, studies have been conducted which demonstrate that large edge-to-area ratios result in increased invasion by species into otherwise stable habitats. A re-interpretation of this concept suggests that species with invasive qualities (i.e. – big sage) and high seed production may benefit from long-linear populations and adjacent disturbed habitats. Bitterroot Restoration Inc. proposes a design solution that emulates the natural strategy of sage reproduction. The proposed design solution would utilize the planting of containerized sage into linear "seed production plots" and adjacent "facilitation beds" which receive an annual seed rain. The proposed solution is supported by both field data from an existing replicated study in Wyoming and case studies of similar projects on high cost reclamation projects. We hypothesize that this long-term view of shrub establishment based upon species reproductive strategy will result in sage stands capable of achieving bond release.

Introduction

Restoration of big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) to mined lands in Wyoming is mandated by both the Wyoming Department of Environmental Quality and the Office of Surface Mining. Current regulations require a post-mining shrub density of 1 shrub per meter^2 on 20% of the affected mining area. This requirement has stimulated substantial research into establishment techniques based upon the use of seed as the main propagule source (Meyer 1994; Schuman et al. 1998). Historically, establishment techniques based upon the use of seed have been largely unsuccessful (Chambers et al.1994; Booth et al. 1999). Although recent advances in seed quality and seeding technology have furthered the successful use of seed in reclamation, they have not produced results that will meet bond release. A second, but less publicized method with substantially higher success is the use of containerized live plant materials. By industry standards this method is generally considered to be economically prohibitive. The purpose of this paper is to

[1] Bitterroot Restoration, Inc. 445 Quast Lane, Corvallis, MT 59828

contrast seeding versus outplanting of containerized materials and to propose a hybrid establishment system which will potentially result in greater success than either of the present methodologies.

Seeding as a Restoration Technique

Seeding of big sagebrush has generally resulted in marginal establishment rates (Meyer 1990; Brown et al. 1991; Chambers et al. 1994; Booth et al. 1999). Booth and others reviewed pre-1985 reclaimed lands seeded with big sagebrush in Wyoming and found that none would meet the 1996 shrub requirement (Booth et al. 1999). Brown et al. (1991) conducted a Nevada study comparing various reclamation techniques which resulted in no establishment of sage seedlings after three years of monitoring . In a Wyoming comparison of seeding rates and live planting, Meikle et al.(1995) also failed to establish sagebrush from seed. Failure of seeding is due to many reasons including improper matching of genetics (Meyer 1990), depauperate mycorrhizal populations (Schuman et al. 1998), variable seed quality (Meyer 1994), plant competition (Cockrell et al. 1995), browse damage (Hoffman and Wambolt 1996), as well as the commonly accepted influence of droughty weather during the time of seedling establishment (several authors). The main reason for seeding failure may not be a misunderstanding of seeding strategies, but rather a lack of understanding of the reproductive biology of sagebrush.

Meyer (1994) and Mozingo (1987) both provide excellent reviews of sagebrush reproductive biology. Big sagebrush is a small-seeded species with seeds typically 1.0 mm X 0.7 mm in size. As with most small seeded species, big sagebrush produces an abundant quantity of seed. It has been estimated that a single shrub with a 1 meter crown will produce 450 flowering branches and at least 350,000 seeds. In a good year, seed production can exceed 1,000,000 on an individual plant. Seed production is subject to annual differences in moisture, frost events, intra-specific competition, and other factors. Xeric upland Wyoming big sagebrush is noted as not setting seed except in wet years. Being self-fertile, individual plants can set seed regardless of the distance to their nearest neighbor. In general, flowering occurs between August and October with subsequent seed dispersal occurring from October through January. Seed dispersal is accomplished via animals and the wind. Sage seed is generally short-lived although this has been questioned by some researchers (Cockrell et al. 1995). A majority of seed planted or produced in a given year is gone from the seed bank by the following spring (Meyer 1994). Seed is generally lost through germination in winter or spring. The fraction of the seed that enters the seed bank is less than 1% (Meyer 1994). Thus, seeding of sage in a given year is likely to fail unless weather conditions and seed viability are conducive to immediate establishment.

Recruitment of sagebrush seedlings is strongly limited by abiotic and biotic factors. Newly emerged seedlings are susceptible to frost damage, drought, and damping off disease. Some factors such as snow cover can effectively increase establishment success. In one study seedling emergence was increased substantially over controls with placement of a snow fence to capture moisture (Meyer 1994). In addition, companion plants have been demonstrated to ameliorate site conditions and allow for greater survival of seedlings and establishment (McArthur et al. 1995). Surviving seedlings begin to flower at about 4 years of age. Big sagebrush in southeastern Idaho on average survives to 4 years of age but commonly exceeds 40 years with some specimens surviving for more than 100 years (West 1988).

Ultimately, planting of big sage via seeding has failed to produce consistent stand establishment. However, these failures are understandable and predictable in light of the natural history of the species.

Outplanting as a Restoration Technique

Outplanting of containerized big sagebrush has generally resulted in high establishment rates although studies and actual monitoring data are few and far between. Fall planted seedlings have resulted in plant survival in excess of 90% over six years of monitoring on one southeastern Montana mine site (P. Martin, personal communication 1999). Survival of late spring planted seedlings on a particularly harsh Wyoming site resulted in 23% survival over five years of monitoring (Meikle 1999). Several variables that are not easily controlled in seeding operations can be controlled under greenhouse production. Plant materials produced for outplanting procedures are grown under greenhouse conditions in conical 10 cubic inch containers that promote deep-rooted seedlings. Growth in such containers bypasses the vulnerable seedling stage which seeded materials must pass prior to becoming drought and frost hardy. Small quantities of appropriate seed sources can yield large quantities of plant materials which allow for the exact matching of site genetics. In addition, vesicular-arbuscular-mycorrhizal inoculants (VAM) are currently available from several companies and can be applied to plant materials prior to or at the time of outplanting thus mediating low nutrient and soil moisture conditions. Furthermore, plants can be placed in appropriate microsites during hand outplanting operations.

Despite high survival rates, outplanting of big sagebrush is not without problems. Outplanting remains a labor intensive and costly enterprise. Although it is long-lived, it is apparent that true restoration of sage will require continual recruitment within a suitable seedbed in order to persist and dominate a site over a period of time. Thus, even though sage may be successfully planted on a site, their long-term existence is not guaranteed unless an appropriate vegetation surrounds stands and allows for continual colonization and recruitment of new individuals. However, shrub densities that could potentially meet bond release within short time periods offset these barriers.

Proposed Design Solution

Our proposed strategy is based both on species biology and design of planting units. This strategy recognizes that seeding efforts are contradictory to the reproductive strategy of big sagebrush and that long-term establishment requires continual recruitment into the existing population. Bitterroot Restoration Inc. proposes a design solution to facilitate the establishment of sagebrush from propagules using a series of “seed production plots” which act as a propagule sources and “facilitation beds” which as propagule acceptors.

The proposed planting unit design would be designed with two components: 1) seed production plots and 2) facilitation beds. The purpose of the seed production plots would be to provide a continuous source of propagules and microbial inoculum for the planting unit. Seed production plots would consist of live-planted containerized sagebrush seedlings that are inoculated with mycorrhizal fungi. Within plots, big sagebrush would be planted in linear strips similar to shelterbelts in the western United States in order to maximize the potential spread of seed rain within the planting unit. Facilitation beds will consist of specially prepared and planted spaces between the seed production plots. The purpose of these beds will be to provide an area conducive to sage establishment for an extended period of time. Facilitation beds will be prepared with a shallow topsoil layer and planted to vegetation that is characteristically susceptible to invasion by big sagebrush. For example, bunch grasses are far less aggressive than sod-forming grasses and will allow open soil microsites that will facilitate sage establishment from wind blown seed provided by the linear sage plantings.

The impacts of seed rain and other dispersal mechanisms have been evaluated in other biomes with generally positive results (Myster and Sarmiento 1998; Urbanska et al. 1998; Toh et al. 1999). Where large areas are to be revegetated, scattered plantings rather than large-scale and intensive plantings may represent an economically attractive option. This approach has been demonstrated successfully in Queensland, Australia through the use of clumped perch trees that act to attract frugiverous birds which subsequently seed tree species into previously forested areas (Toh et al. 1999).

In the western US, several researchers have recommend the planting of small islands of sage surrounded without any grass seeding on relatively flat grounds in order to facilitate establishment (Schuman et al. 1998; Meyer 1994). Dispersion of big sagebrush seed has been quantified with dispersal by wind reaching up to 30 m (Meyer 1994). Recruitment, consequently, tends to be greater on the windward side of the plant due to the prevailing wind direction on seed dispersal. Several authors have witnessed recruitment over time. Brown et al.(1991) conducted an extensive study on a Nevada waste dump site which evaluated several reclamation treatments including topsoil application, mulch application, various seeding rates, and various fertilization rates. Of several species planted by seed, only big sage and black sage failed to appear in test plots during three years of monitoring. During the final year of monitoring, big sagebrush seedlings were noted in depressions adjacent to the study site and were assumed to be the result of seed rain on adjacent native shrublands. Similarly, Meikle et al. established test plots on a northern Nevada site and located volunteer sage seedlings within two years after establishment of a planted bunchgrass community on waste rock. Schuman et al. (1998) and Meyer (1994) noted similar delays in seedling establishment in Wyoming.

The use of companion vegetation which is conducive to invasion by sage has also been recognized by others. Rubber rabbitbrush (*Chrysothamnus nauseousus*) has been noted as compatible with sage establishment (McArthur et al. 1995). Early successional grass species such as squirreltail grass (*Sitanion hystrix*) and saltbush (*Atriplex* sp.) have been noted as compatible as well. Big sagebrush colonized a matrix of dryland bunchgrasses dominated by bluebunch wheatgrass (*pseudorpegneria spicata*), basin wildrye (*Leymus cinerus*), and Sandberg bluegrass (*Poa secunda*) in Nevada (Meikle and Lu 1997). In general, seedling survival is a function of both light availability, plant size and gap size. Big sagebrush seed requires light for germination and plant canopies which allow for greater penetration of light increase the potential for invasion. Subsequently, shelter from adult plants increases plant survival as long as sufficient gap space exists.

Cheatgrass (*Bromus tectorum*) and high fertility agronomic grasses tend to eliminate entirely the recruitment or establishment from seeds. Chambers et al. (1994) states that highly competitive forage species have resulted in limited establishment of native species on reclaimed lands. The result is that 14 years after reclamation on a southeast Idaho study site, big sagebrush had not re-invaded the study plots. This may have been aggravated by addition of legumes such as alfalfa (*Medicago sativa*) and sweet clover (*Melilotus sp.*) which increase soil nitrogen levels. In addition, litter cover on sites excludes the invasion of certain species. This may be particularly relavent to sage invasion onto sites. Chambers et al. (1994) concluded that changes to current reclamation methods will need to be made to facilitate natural successional processes which encourage establishment of native species. Particularly those later successional species which require disturbance and open space for establishment.

Conclusion

Successful sage restoration will require an understanding of the reproductive biology of big sagebrush, a planting strategy which reflects this, and an appropriate understanding of "ecological time." The proposed design approach uses containerized plantings as a source of continuous seed rain into adjacent facilitation beds that contain companion plants with growth characteristics conducive to big sage establishment. Given the large areas areas to be restored, highly designed scattered plantings relying upon containerized plant materials rather than large-scale and intensive plantings may represent an economically attractive option to reclamationists in the western US.

References

Booth, D. T., J. K. Gores, G.E. Schuman and R.A. Olson. 1999. Shrub densities on pre-1985 reclaimed mine lands in Wyoming. Restoration Ecology. 7(1): 24-32.

Brown, R. W., R. C. Sidle, M.C. Amacher, J. Kotuby-Amacher, B.D. Williams, and J.C. Chambers. 1991. Reclamation Research Results on the Borealis Mine: Progress Report 1987-1990. USDA Forest Service Intermountain Research Station Forestry Sciences Laboratory, Logan, UT. 69 p.

Chambers, J. C., R. W. Brown, and B.D. Williams. 1994. An evaluation of reclamation success on Idaho's phosphate mines. Restoration Ecology. 2(1): 4-16.

Cockrell, J. R., G. E. Schuman, and D.T. Booth. 1995. Evaluation of cultural methods for establishing wyoming big sagebrush on mined lands. pp. 784-795. In: G.E. Schuman and G.F. Vance (eds.) Decades Later: A Time For Reassessment. June 3-8, 1995, Gillette, WY. American Society for Surface Mining and Reclamation, Princeton, WV.

Hoffman, T. L. and C. L. Wambolt 1996. Growth response of Wyoming big sagebrush to heavy browsing by wild ungulates. pp. 242-245. In: Proc., Shrubland ecosystem dynamics in a changing environment, May 23-25, 1995, Las Cruces, NM. USDA Forest Service, Intermountain Research Station, General Technical Report INT-GTR-338, USDA, Forest Service, Ogden, UT.

McArthur, E. D., R. Stevens, and S.B. Monsen. 1995. Adaptation and success of big sagebrush and rubber rabbitbrush on disturbed sites. pp. 811-823. In: G.E. Schuman and G.F. Vance (eds.)

Decades Later: A Time For Reassessment. June 3-8, 1995, Gillette, WY. American Society for Surface Mining and Reclamation, Princeton, WV.

Meikle, T. W. 1999. Shrub Establishment Plot Monitoring, Report to Triton Coal Corp,. Gillette, WY. Bitterroot Restoration, Inc., Corvallis, MT. 5 p.

Meikle, T. W., L. Ballek, B. Briggs, and J. Noble. 1995. Big sage: an initial comparison of seedling survival between direct seeding and planting containerized stock. pp. 796-800. In: G.E. Schuman and G.F. Vance (eds.) Decades Later: A Time For Reassessment. June 3-8, 1995, Gillette, WY. American Society for Surface Mining and Reclamation, Princeton, WV.

Meikle, T.W. and S. Lu 1997. Grassland establishment study, Report to Getchell Gold Corp.,. Golconda, NV. Bitterroot Restoration Inc., Corvallis, MT. 21 p.

Meyer, S. E. 1990. Seed source differences in germination under snowpack in northern Utah. pp. 2184-199. In: F.F. Munshower and S.E. Fisher (eds.), Proc., Fifth Billings Symposium on Disturbed Land Rehabilitation, March 25-30, 1990, Billings, MT. Montana State University, Reclamation Research Unit Publ. No. 9003, Bozeman.

Meyer, S. E. 1994. Germination and establishment ecology of big sagebrush: implications for community restoration. pp. 244-251. In: S.B. Monsen and S.G. Kitchen (eds.) Proc., on Ecology and Management of Annual Rangelands, May 18-21, 1992, Boise, ID. USDA Forest Service, Intermountain Research Station, Ogden, UT.

Mozingo, H. 1987. Shrubs of the Great Basin. Unversity of Nevada Press, Reno.

Myster, R. W. and F. O. Sarmiento 1998. Seed inputs to microsite patch recovery on two tropandean landslides in Ecuador. Restoration Ecology. 6(1): 35-43.

Schuman, G. E., D. T. Booth, and J.R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. J. Range Manage. 51: 223-230.

Toh, I., M. Gillespie, and D. Lamb. 1999. The role of isolated trees in facilitating tree seedling recruitment at a degraded sub-tropical rainforest site. Restoration Ecology 7(3): 288-297.

Urbanska, K. M., S. Erdt, M. Fattorini. 1998. Seed rain in natural grassland and adjacent ski run in the swiss alps: a preliminary report. Restoration Ecology 6(2): 159-165.

West, N. E. 1988. Intermountain Deserts, Shrub Steppes, and Woodlands. pp. 209-230. In: M. G. Barbour and W. D. Billings (eds.). North American Terrestrial Vegetation.Cambridge University Press, New York.

Demographic Characteristics of Three *Artemisia Tridentata* Subspecies

B.L. Perryman[1], A.M. Maier[2], A. L. Hild[1], and R.A. Olson[1]

Abstract

Previous research suggests that woody plant recruitment may occur in pulses in semi-arid areas. In 1997, approximately 75 stem cross sections were collected from nine stands of each of three subspecies of big sagebrush along elevation and climatic gradients in Wyoming. Annual growth-rings were used to identify year of establishment and demographic characteristics were analyzed from age-class frequencies. Mean stand ages of the three subspecies were different (P=0.002), and subsequent analysis revealed that Wyoming and mountain big sagebrush stand ages (32 ± 9 and 26 ± 9 respectively) were significantly older than basin big sagebrush (17 ± 3) stand ages (LSD, "=0.05). Mean recruitment intervals (years) were shorter for basin (1.6) than for Wyoming (2.3) and mountain (2.2) sagebrush (P=0.01). The number of cohorts did not differ among the subspecies (P=0.11), however, the percent of years with recruitment was significantly higher for basin (59%) compared to Wyoming (37%) and mountain (39%) big sagebrush (P<0.0001). Age-class frequency distributions of each stand and regional stand combination were assessed for dispersion across each associated period of record. Chi-square goodness-of-fit tests were performed for the negative binomial distribution. All stands (with one exception) and all three regional stand combinations fit the negative binomial distribution. Age-class frequency patterns of all subspecies indicate that recruitment is clustered or aggregated across each period of record. Recruitment in big sagebrush stands occurs in pulses throughout Wyoming.

Introduction

All three subspecies of big sagebrush, basin (*Artemisia tridentata* Nutt. ssp. *tridentata*), mountain (*A. tridentata* ssp. *vaseyana* [Rydb.] Beetle), and Wyoming (*A. tridentata* ssp. *wyomingensis* Beetle and Young) are dominant constituents of many rangeland communities, occupying approximately 150,800 square kilometers of rangelands in Wyoming (Beetle and Johnson 1982). Big sagebrush has a wide ecological range and occupies a diversity of habitats (Beetle 1960), playing crucial roles in reducing erosion potential, providing wildlife habitat, and improving rangeland aesthetics (Vale 1974).

Big sagebrush subspecies identification is based on leaf morphology, growth form, and geographic location (Beetle and Johnson 1982). Distribution is related to elevation, temperature, and soil moisture (Cawker 1980). Wyoming sagebrush occurs at low to mid elevations on fine-textured soils. Basin sagebrush is also found at low to mid elevations but on deep, well-developed soils.

[1] Department of Renewable Resources, University of Wyoming, Laramie,WY 82071
[2] Department of Rangeland Ecosystem Science, Colorado State University, Ft Collins, CO. 80523.

Mountain sagebrush is distributed from mid to high elevations where cooler temperatures, higher precipitation, and developed soils are prevalent (Beetle 1960).

West et al. (1979) concluded that threetip sagebrush (*Artemisia tripartita* Rydb.), and granite pricklygilia (*Leptodactylon pungens* [Torr.] Nutt.) age-class frequency distributions do not usually deviate from the log-normal model, however high recruitment rates were observed in certain years. Pulses of recruitment in desert plant communities were suggested by Went (1955) and demonstrated for creosote bush (*Larrea tridentata* [DC.] Cov.) (Chew and Chew 1965; Barbour 1969). Unusual climatic events and high soil moisture conditions are suggested as major contributing factors (Noy-Meir 1973; Cawker 1980). A pulse is defined as an infrequent recruitment of large numbers of individuals into a population. Cawker (1980) demonstrated evidence of climatic control of big sagebrush survival in British Columbia. If rare or infrequent climatic events control pulses of big sagebrush recruitment, these events should be evident within the population age structure as variations in age class frequency. Demography patterns of big sagebrush in Wyoming have not been assessed. This project was conducted to examine the age structure of nine stands of each of the three subspecies on 27 native sites within three geographic areas of Wyoming.

Specific objectives were to: 1) determine plant and stand ages; 2) compare stand ages, periods of record, number of cohorts, percent of years with recruitment, and recruitment intervals between subspecies; and 3) assess the dispersion of age-class frequencies through time.

Materials and Methods

Big sagebrush stands having a variety of cohorts, similar soil characteristics and topography, and minimal herbivory disturbance were selected for this study. Sites were selected to minimize microsite effects that increase or decrease supplemental moisture conditions, thereby minimizing potential variations in recruitment and survival rates between sites (Roughton 1972; Bonham et al. 1991).

Stem sections for *wyomingensis* were collected from three stands in northeast Wyoming near Rochelle; three stands in the South Fork of the Powder River watershed, northwest of Casper in central Wyoming; and three stands in southwest Wyoming near Pinedale. Stem sections for *tridentata* were collected from three stands near Pinedale; three stands near Worland, on the west slope of the Bighorn Mountains; and three stands near Farson, in southwest Wyoming. Stem sections for *vaseyana* were collected from three stands near Pinedale; three stands near Buffalo, on the east slope of the Bighorn Mountains; and three stands west of Laramie, near Elk Mountain in south central Wyoming. The three stands in each regional grouping were located within a 15 mile radius. All stand locations were permanently recorded with a Global Positioning System, and latitude/longitude coordinates and elevations were reported by Perryman and Olson (2000).

A stratified, random sampling method was used to collect stem cross-sections from each stand. A permanent 100 m baseline transect was located within each stand, and 10, 100 m perpendicular transects were established at randomly selected points along the baseline transect. Along each perpendicular transect, eight random points were selected, and the closest individual big sagebrush plant was sampled. If the closest individual was not suitable for accurate age determination (e.g., damaged stem), another random point was selected until a suitable individual was found.

Stem cross-sections were obtained by sawing the plant below ground level (Ferguson 1964) to ensure that the pith and first annual growth ring were included. The stem was then cut approximately 10 cm from the bottom, providing a 10 cm long stem section. Sampling was conducted during the summer of 1997. Between 75 and 80 stem sections were collected from each stand (Cawker 1980).

In the laboratory, the bottom portion of each stem section was sanded sequentially with 60, 80, 320, and 400 grit sanding belts. Annual growth-rings were examined using a 10 power stereo microscope, and enumerated once by two different technicians for a total of two observations per sample.

Annual growth-rings are formed when the secondary xylem forms concentric rings around the stem during the growing season. Rings are easily distinguishable from one another by a distinct cork layer 8-18 cells wide (Ferguson 1964). This layer is produced throughout the growing season between the old and new xylem.

Inter-annual or false rings have not been encountered in big sagebrush at northern latitudes and higher elevations (Diettert 1938, Moss 1940, Ferguson 1964, Perryman and Olson 2000). Global positions and elevation of sites in Wyoming fulfill both of these criteria. Locally absent rings do occur, however complete absence of rings are almost never encountered due to the unique nature of annual growth-ring formation in big sagebrush (Ferguson 1964, Perryman and Olson 2000).

Many older stems are “lobed” or “rosette” in form and lack radial symmetry. Often the decumbent and decadent form of older stems leads to open pith exposure and loss. Accurate age assessments are not possible when the pith is absent. Our sampling was biased for single-stemmed plants with intact piths over individuals without radial symmetry. As a result, some older plants with decadent stems were excluded.

Mean recruitment intervals, period of record, number of cohorts, and percent of years with recruitment were calculated for each subspecies. Age-class frequency distributions were constructed for each subspecies at 2 geographic scales, stand and regional stand combination. Age-class frequency dispersion through time was assessed by chi-square goodness-of-fit tests for both Poisson and negative binomial distributions (Ludwig and Reynolds 1988; Zar 1999).

Results and Discussion

Individual plants and stands were generally younger than those found in previous big sagebrush dendrochronologic studies (Ferguson 1964, Roughton 1972, Cawker 1980). Prior research indicated that individual big sagebrush plant age often exceeds 100 years (Blaisdell 1953, Ferguson 1964) in the southwestern U.S. The oldest plant (81 years) in this study was a mountain sagebrush plant located in the Bighorn Mountains. The oldest Wyoming sagebrush plant (75 years) was from the Powder River Basin, and the oldest basin sagebrush plant (55 years) was found near Pinedale, WY. Young seedlings, 5-10 years old, were common in all stands.

Analysis of variance indicated that mean stand ages of the three subspecies were different (P= 0.002), and subsequent analysis revealed that Wyoming and mountain sagebrush stand ages (32, $\pm$ 9 and 26, $\pm$ 9 years respectively) were older than basin sagebrush (17, $\pm$ 3) stand age (LSD, α=0.05). Mean and median ages for stands and geographic stand combinations by subspecies are listed in Table 1. Analysis of variance indicated no difference in stand ages between geographic region (P=0.60).

Table 1. Mean and median stand and regional stand combination ages (years) by subspecies in Wyoming, 1997.

Subspecies, Stand, and Regional Combination	Mean	Median	n
wyomingensis			
R1	28	25	78
R2	23	19	73
R3	26	28	73
Northeast WY	26	25	224
TT1	32	33	61
TT2	30	29	58
TT3	21	16	59
Central WY	27	29	178
MW1	45	46	69
MW2	50	50	65
MW3	39	39	67
Southwest WY	45	46	201
vaseyana			
EM1	19	19	67
EM2	21	17	69
EM3	26	18	69
Southcentral WY	22	18	205
ES1	23	19	67
ES2	15	16	81
ES3	17	17	76
Central WY	18	17	224
P1	44	47	60
P2	34	35	57
P3	31	25	67
Southwest WY	36	35	184
tridentata			
WS1	22	21	76
WS2	22	21	70
WS3	14	13	78
Central WY	19	21	224
BS1	20	20	70
BS2	15	14	73
BS3	14	12	68
Southwest WY[1]	17	14	211
BP1	14	13	74
BP2	17	17	76
BP3	16	16	72
Southwest WY[2]	16	16	222

[1]West slope of the Green River Basin [2]East slope of the Green River Basin

Analysis of variance results for recruitment intervals, period of record, number of cohorts, and percent of years with recruitment are in Table 2. Recruitment intervals (by stand) ranged from 1.9 to 2.7 years for Wyoming sagebrush; 1.3 to 2.7 for basin sagebrush; and 1.2 to 2.9 for mountain sagebrush. Mean recruitment intervals were shorter for basin sagebrush (1.6) than for Wyoming (2.3) and mountain (2.2) sagebrush (P= 0.01). Years with high age-class frequencies occurred at irregular intervals. This supports the hypotheses by Went (1955) and West et al. (1979) that successful recruitment in arid and semi-arid plant communities occurs in pulses, often with many years of no seedling survival between successful years. Shorter intervals reflect more frequent, favorable recruitment conditions and higher rates of seedling survival. Less favorable climatic conditions may lengthen intervals in regions where Wyoming and mountain sagebrush plants occur (West 1978, Cawker 1980).

The number of cohorts did not differ among the subspecies (P= 0.11), however, the percent of successful recruitment years was significantly higher for basin sagebrush (59%) than for the Wyoming (37%) and mountain (39%) subspecies (P< 0.0001). A shorter mean period of record for basin sagebrush may explain the higher recruitment rate and shorter recruitment intervals. However, big sagebrush recruitment is episodic, and our data suggest that for Wyoming big sagebrush, statewide recruitment occurred in only 33 of the past 75 years.

Table 2. Mean recruitment intervals (years), mean number of cohorts in the period of record, mean percent of recruitment years in the period of record, and mean period of record (years) by subspecies sampled across 27 sites in Wyoming, 1997.

Subspecies	**Interval (yr)[1]**	**# of Cohorts**	**% Recruitment Years**	**Period of Record**
wyomingensis	2.3^a (± 0.7)	23^a (± 1.9)	37^a (± 5)	62 (± 6)
vaseyana	2.2^a (± 0.7)	21^a (± 4.1)	39^a (± 6)	54 (± 14)
tridentata	1.6^b (± 0.6)	20^a (± 2.4)	59^b (± 9)	34 (± 8)

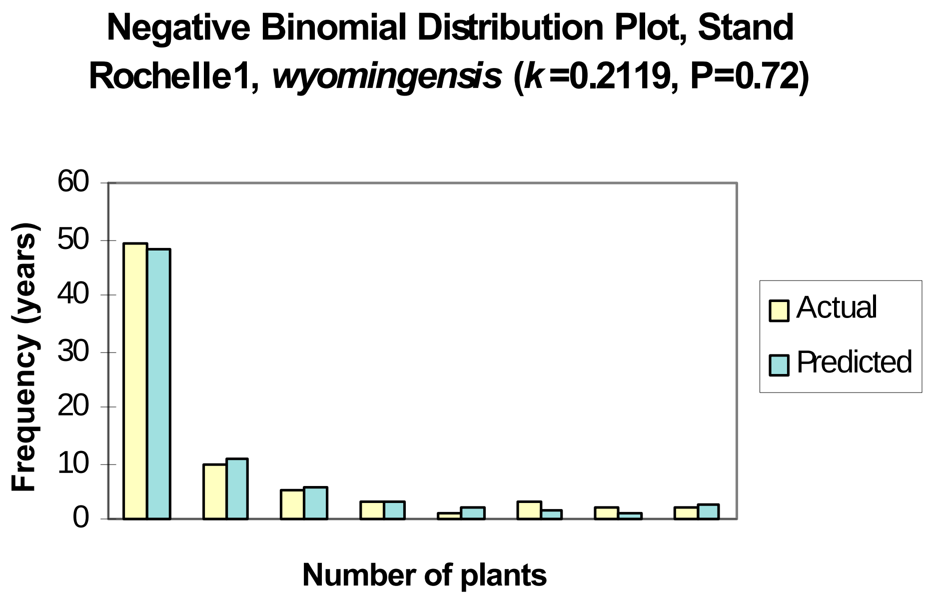
[1] Means with the same superscript within a column are not significantly different (P>0.05, LSD).

Age-class frequency distributions of each stand and regional stand combination were assessed for dispersion across each associated period of record. Chi-square goodness-of-fit tests were performed for both the Poisson and negative binomial distributions (Table 3). No stands or regional stand combinations fit the Poisson distribution and all variances were greater than the mean, indicating that recruitment is not random, but clustered, aggregated, or contagious (Zar 1999) across a period of record. All stands (with the exception of one mountain sagebrush stand) and all three regional stand combinations fit the negative binomial distribution. Means were different for each stand and stand combination so k-exponent values were different for each goodness-of-fit test (Table 3).

Cohort or age-class negative binomial distribution patterns were characterized by a relatively large number of years with no recruitment, a moderate number of years with minimal recruitment, and relatively few years with relatively high recruitment. Graphs of actual frequency probabilities for a representative stand and regional stand combination are displayed in Figure 1.

Fig. 1. Negative binomial distribution plots from Chi-square goodness-of-fit tests of (a) a representative stand and (b) a regional combination of stands for Wyoming sagebrush, sampled in northeast Wyoming, 1997.

(a)



(b)

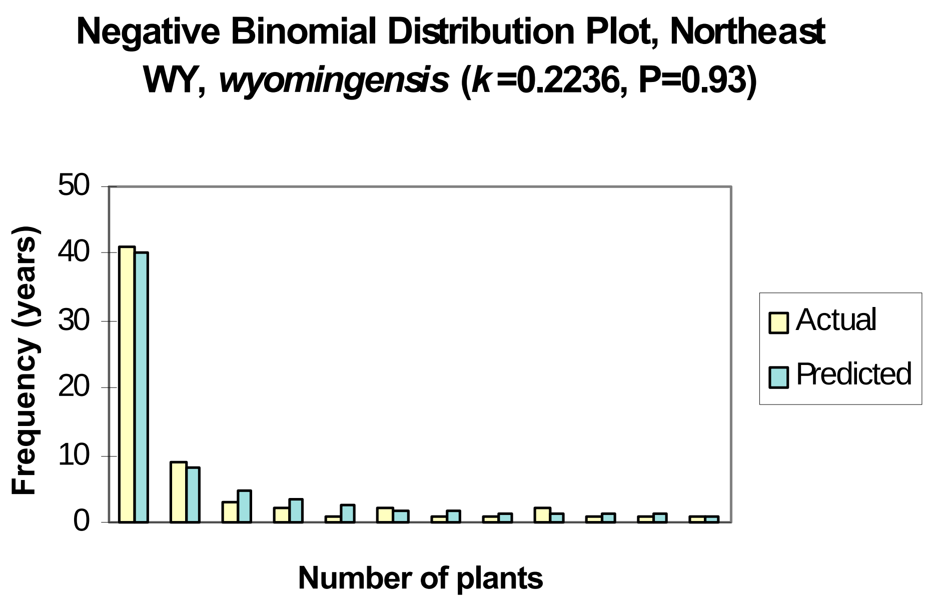


Table 3. Results of Chi-square goodness-of-fit tests for the negative binomial (p-value and k-exponent value) distribution of individual stands and regional stand combinations, across Wyoming, 1997. (Poisson distribution tests were all significant at $P \leq 0.0001$).

Stand, and Regional Combination	**Negative Binomial**	***k***
wyomingensis		
Rochelle1	0.22	0.2387
Rochelle2	0.83	0.2119
Rochelle3	0.64	0.2145
Northeast WY (Rochelle 1,2,3 combined)	0.50	0.2236
TT Ranch1	0.19	0.3612
TT Ranch2	0.23	0.5818
TT Ranch3	0.44	0.3962
Southwest WY (TT Ranch 1,2,3 combined)	0.35	0.5377
Midwest1	0.75	0.2499
Midwest2	0.32	0.3043
Midwest3	0.56	0.3218
Central WY (Midwest 1,2,3 combined)	0.71	0.3667
vaseyana		
Elk Mountain1	0.56	0.4662
Elk Mountain2	0.99	0.3052
Elk Mountain3	0.32	0.2348
Southcentral WY (Elk Mtn. 1,2,3 combined)	0.67	0.2674
East Slope1	0.23	0.3029
East Slope2	0.59	0.1538
East Slope3	0.84	0.2509
Central WY (East Slope 1,2,3 combined)	0.45	0.1659
Pinedale1	0.91	0.2337
Pinedale2	0.81	0.3322
Pinedale3	0.009*	0.3480
Southwest WY (Pinedale 1,2,3 combined)	0.34	0.3698
tridentata		
West Slope1	0.31	0.4497
West Slope2	0.51	0.4889
West Slope3	0.54	0.4069
Central WY (West Slope 1,2,3 combined)	0.11	0.4111
Big Sandy1	0.14	1.2299
Big Sandy2	0.76	0.3408
Big Sandy3	0.68	0.6599
Southwest WY[1] (Big Sandy 1,2,3 combined)	0.318	0.683
Big Piney1	0.40	0.6382
Big Piney2	0.69	0.4016
Big Piney3	0.79	0.2247
Southwest WY[2] (Big Piney 1,2,3 combined)	0.87	0.2403

[1]West slope of the Green River Basin [2]East slope of the Green River Basin
*Only stand or stand combination that did not fit the negative binomial distribution.

Conclusion

These results suggest that big sagebrush plants that dominate much of the current vertical structure of plant communities in Wyoming are relatively young. However, mean stand ages of Wyoming big sagebrush in northeast and central Wyoming are approximately 3 to 4 times older than the mean fire-free interval (8 years) for the area (Perryman 1996). Fire suppression activities are often associated with woody plant invasion of northern mixed-grasslands (Kucera 1981; Fisher et al. 1987; Steinaur and Bragg 1987).

Irregular pulses of recruitment are characteristic of big sagebrush stands in Wyoming. These results support hypotheses by Went (1955), West et al. (1979), and Cawker (1980), that recruitment in semi-arid regions occur only in years with favorable climate. Age-class frequency of big sagebrush stands follow the negative binomial distribution. Characteristically, there are a large number of years of no recruitment, an intermediate number of years with some recruitment, and a few years of high recruitment. Recruitment intervals are longer for Wyoming and mountain big sagebrush than for basin big sagebrush. We believe these results reflect general trends of demography in other big sagebrush communities in Wyoming. The large sample size (approximately 2200 individual plants) and regional consistency of results support our conclusion.

Future research must address mortality and survivorship curves of big sagebrush to fully understand the demography of this species. However, this study describes age frequency distributions and pulse recruitment phenomena of big sagebrush in Wyoming.

References

Barbour, M.G. 1969. Age and space distribution of the desert shrub *Larrea divaricata*. Ecology 50:679-685.

Beetle, A. A. 1960. A study of sagebrush, the section *Tridentatae* of *Artemisia*. Wyoming Agr. Exp. Sta. Bull. No. 368, Laramie.

Beetle, A. A. and K. L. Johnson. 1982. Sagebrush in Wyoming. University of Wyoming, Wyo. Agr. Exp. Sta. Bull. No. 779, Laramie.

Blaisdell, J.P. 1953. Ecological effects of planned burning of sagebrush-grass range on the Upper Snake River Plains. U.S. Dept. of Agr. Tech. Rep. No. 1075. U.S. Government Printing Office, Washington, D.C.

Bonham, C.D., T.R. Cottrell, and J.F. Mitchell. 1991. Inferences for life history strategies of *Artemisia tridentata* subspecies. J. of Veg. Sci. 2:339-344.

Cawker, K.B. 1980. Evidence of climatic control from population age structure of *Artemisia tridentata* Nutt. in southern British Columbia. J. of Biogeogr. 7:237-248.

Chew, R.M. and A.E. Chew. 1965. The primary productivity of a desert shrub (*Larrea tridentata*) community. Ecol. Monogr. 35:355-375.

Diettert, R.A. 1938. The morphology of *Artemisia tridentata* Nutt. Lloydata 1:3-74.

Ferguson, C.W. 1964. Annual rings in big sagebrush. Papers of the Laboratory of Tree-Ring Research No. 1. The University of Arizona Press, Tucson.

Fisher, R.F., J.J. Jenkins, and W.F. Fisher. 1987. Fire and the prairie-forest mosaic of Devil's Tower National Monument. Am. Mid. Nat.117:250-257.

Kucera, C.L. 1981. Grasslands and fire. *In*: Fire Regimes and Ecosystem Properties. USDA For. Serv. Gen. Tech. Rep. WO-26, 594p.

Ludwig, J.A. and J.F. Reynolds. 1988. Statistical Ecology: A Primer on Methods and Computing. John Wiley & Sons, New York.

Moss, E.H. 1940. Interxylary cork in *Artemisia* with reference to its taxonomic significance. Am. J. Bot. 27:762-768.

Noy-Meir, I. 1973. Desert ecosystems: environment and producers. Annual Review of Ecology and Systematics. 4:25-51.

Perryman, B.L. 1996. Fire history of the Rochelle Hills area of Thunder Basin National Grasslands. Ph.D. Dissertation, Univ. of Wyoming, Laramie.

Perryman, B.L. and R.A. Olson. 2000. Age-stem diameter relationships of big sagebrush and their management implications. J. Range. Manage. 53:342-346.

Roughton, R.D. 1972. Shrub age structures on a mule deer winter range in Colorado. Ecology. 53:615-625.

Steinauer, E.M. and T.B. Bragg. 1987. Ponderosa pine (*Pinus ponderosa*) invasion of Nebraska Sandhills prairie. Am. Mid. Nat. 118:358-365

Vale, T.R. 1974. Sagebrush conversion projects: An element of contemporary environmental change in the western United States. Biol. Conserv. 6:274-284.

Went, R.W. 1955. The ecology of desert plants. Sci. Amer. 192:68-75.

West, N.E. 1978. Basic synecological relationships of sagebrush dominated lands in the Great Basin and Colorado plateau. pp. 33-41. *In* The sagebrush ecosystem, A symposium, Logan, UT, College of Natural Resources, Utah State Univ., Logan.

West, N.E., K.H. Rea, and R.O. Harniss. 1979. Plant demographic studies in sagebrush-grass communities of southeastern Idaho. Ecology 60:376-388.

Zar, J.H. 1999. Biostatistical Analysis, 4th Ed. Prentice Hall, Upper Saddle River, NJ

Historical Sagebrush Establishment Practices in the Powder River Basin

Laurel E. Vicklund[1]

Abstract

The Powder River Basin of Wyoming is a semi-arid area dominated by sagebrush grassland vegetation communities. This region includes 15 surface coal mines. Reclamation of mined lands requires re-establishment of native species to meet the post mine land use. The Wyoming Department of Environmental Quality (WDEQ) serves as the regulatory authority for the State's surface coal mines. Wyoming statutes require that the disturbance from surface coal mining activities be reclaimed to a condition at least equal to the pre-mine condition.

Big sagebrush (*Artemisia tridentata)* is one of the major shrub components of the pre-mine vegetation communities. Because of sagebrush's dominance in various portions of the basin, shrub density requirements were developed by the State and have evolved to a current shrub density standard. The evolution of the shrub density requirement has been paralleled by development of myriad shrub establishment techniques.

Successful shrub re-establishment is vital for final bond release. Most final reclamation will be evaluated for the shrub density standard on 20% of the post-mined surface. The most successful techniques should be evaluated from the over 20 years of shrub establishment experience. To see where we are going, we need to look at where we've been.

Introduction

The Powder River Basin of Northeast Wyoming includes 15 surface coal mines. Surface coal mining expanded significantly in the early 1970's. The volume of coal exported from the Basin rose steadily through the 1980's to a current total of approximately 317 million tons in 1999. (Wyoming Mining Association 1999)

The national Surface Mining Control and Reclamation Act (SMCRA) of 1977 regulates the reclamation of mined lands. The Wyoming Environmental Quality Act (WEQA) defined Wyoming's program and the Wyoming Department of Environmental Quality (WDEQ) serves as the regulatory authority for the State's surface coal mines. Wyoming statutes require mined land disturbances be reclaimed to a condition equal to the pre-mine condition and require demonstration that the land is capable of sustaining pre-mine land use. (U.S. Congress 1977, WEQA 1973)

Pre-mining land use in northeastern Wyoming is primarily grazing and wildlife habitat. The wildlife habitat portion of the land use dictates the re-establishment of the pre-mine shrub component which in this area, is Wyoming big sagebrush (*Artemesia tridentata* ssp. *wyomingensis)*.

[1] Belle Ayr Mine, RAG Coal West, Inc., P.O. Box 3039, Gillette, WY 82717

The purpose of this report is to present a brief history of regulations, planting techniques, and research in shrub re-establishment in Wyoming with particular emphasis on the Powder River Basin. Mines within the Powder River Basin were surveyed to obtain information regarding their sagebrushreclamation efforts. This history is divided into the following periods: Pre-1980, 1980 - 1989, 1990 - 1999, and 2000 and beyond.

Historical Summary

Pre-1980, Before State Program Approval

Regulation

Prior to 1980, the federal program required surface coal mine operators to restore shrubs and trees to an average density of 450 stems per acre (Code of Federal Regulations 30CFR 816.116). The original WEQA required operators to reclaim shrubs and trees to a density equal to the pre-mine density. On average, this is a difference of about nine times the stems per acre. Such a large difference in regulatory requirements caused much discussion and regulatory action after 1980 between the operators and the regulatory agencies.

Techniques

Of the mines surveyed, three were opened prior to 1980. None of those mines opened before 1980 reported planting any sagebrush in their reclamation program.

Research

Research before 1980 basically discussed the importance of soil moisture competition effects on sagebrush establishment. Cook and Lewis (1963) and McDonough and Harniss (1974) theorized sagebrush was difficult to establish due to the methods used to harvest seed, seed microclimate, and seed dormancy. Harniss and McDonough (1976) hypothesize that poor establishment from direct seeding resulted from poor seed viability. Research by Howard et al. (1979) showed that woody plants may survive the climate and soil conditions of Wyoming and Colorado, but growth was slowed by wildlife predation. These early research topics form the basis for future papers.

1980 – 1989 Period

Regulation

In 1983, the Office of Surface Mining Reclamation and Enforcement (OSMRE) adopted regulations requiring minimum shrub and tree stocking and planting arrangements for areas to be developed for fish and wildlife habitat. The planting rates were to be specified by the regulatory authorities based on local and regional conditions after consultation with State agencies responsible for the administration of the forestry and wildlife programs. Several environmental groups and the coal industry promptly sued OSMRE. A court ruling was completed in 1987 and OSMRE revised the federal rules.

During the four years of court proceedings, Governor Herschler appointed a Task Force on Regulatory Reform. One of the subcommittees was charged with developing an alternative to the

100% shrub replacement requirement. The WDEQ Land Quality Division (LQD) Rules and Regulations proposed operators meet a 10% shrub goal of the pre-mining density. This goal is one shrub per square meter on 10% of the affected area. The regulation was promulgated in 1986 with OSMRE's approval before final court ruling.

The Wyoming Game and Fish Department (WGFD) petitioned WDEQ/LQD for a new shrub density standard in 1989 that would increase the density and specify the composition of shrubs to be used. The proposal would change the 10% goal to a 20% standard and address the pre-mining shrub community composition. The 20% standard was defined as 1 shrub per square meter on 20% of the land area.

The 20% standard was debated before the Land Quality Advisory Board (LQAB) several times during 1989. Subsequently the LQAB requested a committee be formed consisting of LQD, WGFD, and coal industry personnel to negotiate a compromise.

Techniques

In 1980, two mines started to incorporate big sagebrush into their permanent reclamation seed mix. Initial seed rates in 1980 through 1983 varied from 0.1 to 20 pounds of sagebrush seed per acre. The seed was broadcast with a Brillion seeder and drill seeded with a Truax drill and other types of disk or shoe drills. Vegetation sampling from one site indicated that drill seeding obtained a shrub density of 0.02 shrubs per square meter.

From 1980 to 1983 at the above-mentioned mines, grass hay mulch was applied at the rate of 2 tons per acre and 10 pounds of winter wheat per acre was seeded as a cover crop. One mine applied fertilizer regularly at the rate of 20 pounds of nitrogen and 20 pounds of phosphorus per acre. Vegetation sampling showed no sagebrush established at these sites.

By 1985, more mines included big sagebrush in their permanent reclamation seed mix. By 1989, all mines surveyed had included sagebrush in their permanent reclamation seed mix. Seeding rates were less varied and ranged from 1 to 6 pounds per acre. Fertilizers were no longer used. The technique of using a small grain stubble mulch and interseeding sagebrush was common practice at the majority of mines surveyed. Vegetation sampling of the sites planted during this time frame showed sagebrush establishment densities of 0.16, 0.46 and 1.06 shrubs per square meter.

Other methods were also being utilized to establish big sagebrush during the 1980's. Some mines purchased and planted sagebrush tublings. One mine built a range pad cutter and harvested pads of native rangeland with mature, established sagebrush plants for placement in reclaimed areas. Vegetation sampling showed little or no recorded success. No documentation described any special considerations regarding seed procurement or seed treatment practices.

Research

Research during the 1980's began to look at sagebrush establishmnet issues in greater detail, paralleling the trend of in-depth research of other disturbed lands issues. Williams et al. (1981 added to the pool of research by identifying vesicular arbuscular mycorrhizae (VAM) as a factor affecting sagebrush seedling establishment. Their work specifically studied VAM inoculum levels and longevity in long-term topsoil stockpile storage.

Pfannensteil and Wendt (1984) studied enhancing the establishment of sagebrush on reclamation in Colorado by direct haul placement of topsoil. C. Wayne Cook (1988) reviewed the reclamation research literature and concluded that current research was not widely available and in particular, stated that some shrubs were still difficult to establish. His ultimate question was, "Has research contributed significantly to mined land reclamation." By 1989 other researchers were debating the proposed shrub density increase regulation. Tessmann and Kleinman (1989) wrote a point/counterpoint paper that echoed some of the same issues discussed by Colbert and Colbert (1983) about the validity and need of using sagebrush in revegetating mined lands.

1990 – 1999 Period

Regulation

The joint shrub committee consisting of WGFD, LQD, industry personnel and special interest groups held work sessions in 1990, 1991, and 1992 to discuss the 20% standard. Finally, the Environmental Quality Council (EQC) approved a proposal for a shrub density standard of 1 shrub per square meter on 20% of the affected area. The State rule submitted in October 1992 was filed and submitted to OSMRE for public comment. The federal public comment period ran through April 1993.

Meanwhile, the 1993 Wyoming Legislature passed Enrolled Act No. 86 which became law without the Governor's signature. Enrolled Act No. 86 inserted several paragraphs into the standards. The Enrolled Act No. 86 basically required operators, who reclaim grazing land, to re-establish shrubs on 10% of the affected surface to a density of 1 shrub per 9 square meters or to a pre-mine density, whichever is less. Shrubs stipulated for use in reclamation consisted of native shrubs from the general area identified in pre-mine surveys, but the dominant pre-mine shrub need not be the dominate post-mine shrub.

Enrolled Act No. 86 was submitted to OSMRE as a formal program amendment. After the extended public comment period, OSMRE requested that the State clarify the conflicting rule and statutory language. Wyoming responded by outlining the conflicting portions of the rule and statute and requested that OSMRE determine whether the amended statute was as stringent as the Federal law.

By January 1994, OSMRE rejected the State rule and State statute and required six amendments be added to Wyoming's program. The legislature responded by drafting proposed changes in Enrolled Act 86. Governor Sullivan signed Enrolled Act No. 24 (1994) that fulfilled part of OSMRE's requirements and the State requested a time extension to address the remainder of amendments.

Additional draft legislation was proposed to satisfy the remainder of OSMRE's required amendments. The changes were signed into law, in February 1995, by Governor Geringer as Enrolled Act No. 8. This Act changed the definition of critical and crucial fish and wildlife habitat and resulted in subsequent changes to the vegetation related rules and regulations. Re-establishment of shrubs basically required operators who reclaim mined lands to re-establish shrubs on 20% of the affected surface to a density of 1 shrub per square meter. Three other variations on this shrub density requirement allowed operators to develop site specific shrub reclamation bond release commitments to reflect the pre-mining shrub vegetation community.

Operators were required to delineate the land currently affected as of August 6, 1996 that would still be regulated by the 1980-1989 regulation of 1 shrub per square meter on 10% of the affected lands. Lands affected after that date would be subject to the new 20% shrub density rule.

Techniques

While mail between Wyoming and OSMRE was flying fast and furious, operators continued to plant sagebrush. Rates of pure live seed in approved mixes varied between the mines surveyed from 0.5 pounds per acre to 10 pounds per acre. The majority of sagebrush was broadcast through a drill or by hand, and one mine still applied small amounts of sagebrush seed by hydroseeding. One mine planted a few small areas with sagebrush tublings. None of the surveyed mines were applying nitrogen any more, although a few occasionally applied phosphorus.

All were using a grain stubble mulch or cover crop to assist in sagebrush establishment. By 1995, most were showing results in sagebrush density through vegetation surveys. Many operators established and monitored permanent shrub transects to evaluate sagebrush re-establishment success.

Densities reported from these surveys ranged from 0.01 sagebrush per square meter to 2.72 sagebrush plants per square meter. One mine showed slightly elevated densities in areas where topsoil was directly placed. Some transects showed increasing density trends; some showed declining trends, and die-off of previously observed sagebrush plants.

More mines showed seed origin as Wyoming instead of unknown, indicating the increased awareness of obtaining locally grown seed. The above planting techniques also indicate that these operators were incorporating the state-of-the-art technology into their shrub reclamation programs.

Research

In the 1990's, research seemed to become further focused. Cockrell et al. (1995) and Schuman et al. (1998) conducted extensive field research on the effect of topsoil management, mulching practices, and plant competition on initial sagebrush seedling establishment. McArthur et al. (1995) reviewed establishment attributes of big sagebrush and rubber rabbitbrush (*Chrysothamnus nauseosus*) and their use and performance in reclamation plantings.

The Wyoming Abandoned Coal Mine Land Research Program (AML) has provided funds and a platform for many reclamation research projects. Through the AML program, Schuman et al. (1998) examined effective strategies to establish big sagebrush on mined lands in the Powder River Basin. Booth et al. (1996) added to available information on post-harvest and pre-planting seed treatment on sagebrush seedling vigor. One of the most recent AML studies still in progress is research to evaluate the seeding rate of cool-season grasses and their competitive effect on sagebrush seedling establishment, as well as sagebrush seeding rate effects on sagebrush re-establishment density (Fortier et al.1999).

2000 and Beyond

Several things became noticeable during the review of the history of the shrub establishment regulations. It appeared that mines are incorporating actual sagebrush seeding and establishment techniques from the wealth of successful research results and that sagebrush is beginning to be successfully established in reclaimed areas.

Sagebrush reclamation success and research has shown a consistently inproving trend. By comparison, the development of shrub regulations was erratic. This might suggest that the attention focused on the increasing regulations, not the presence of the regulations themselves, led to the increased focus on sagebrush establishment research.

Future issues in sagebrush establishment might include; techniques to ensure long-term survival of plants after initial re-establishment; and development of other vital wildlife habitat features. As stated in the beginning of this paper, not only is industry required to reclaim mined land disturbances to a condition equal to the pre-mine condition; they are also required to demonstration that the land is capable of sustaining the pre-mine land use. Reclamation of wildlife habitat consists of more components than big sagebrush. However, regulations and rules, from the early 1980 to present, have focused on sagebrush establishment. Perhaps it is time, with out extensive regulations and rule making that accompanied sagebrush, to expand reclamation efforts to include other components of wildlife habitat.

Acknowledgments

The author expresses appreciation to Roy Liedtke, Jacobs Ranch Coal Company for sharing shrub data and regulatory documentation and Debbie Messenheimer, Cordero Rojo Complex, for sharing shrub data from Caballo Rojo Inc. and Cordero Mining Co.

The references listed represent only a small portion of the wealth of research that has been and is currently being conducted on sagebrush.

References

Booth, D. T., . E. Roos and Y. Bai. 1996. The influence of post-harvest and pre-planting seed treatment on sagebrush seedling vigor. Project Review Seminar. Abandoned Coal Mine Land Research Program. November 6, 1996. Gillette, WY.

Code of Federal Regulations. Title 30, Chapter VII, Subchapter K, § 816.

Cockrell, J. R., G. E. Schuman, and D. T. Booth. 1995. Evaluation of cultural methods for establishing Wyoming big sagebrush on mined lands. pp. 784-795. In: G.E. Schuman and G.F. Vance (eds.). Decades Later: A Time for Reassessment. June 3-8, 1995, Gillette, WY. American Society for Surface Mining and Reclamation, Princeton, WV.

Colbert, T. A. and M. A. Colbert. 1983. Revegetating with sagebrush, who's right? Rangelands 5: 33-35.

Cook, C. W. and C. E. Lewis. 1963. Competition between big sagebrush and seeded grasses on foothill ranges in Utah. J. Range Manage. 16: 245-250.

Cook, C. W. 1988. Has research contributed significantly to mined land reclamation? In: Proc., High Altitude Revegetation Workshop No. 8. Information Series No. 59: 230-239. Water Resources Research Institute. Colorado State University, Ft. Collins.

Fortier, M. I., G. E. Schuman, A. L. Hild, and L. E. Vicklund. 1999. Effects of seeding rates and competition on sagebrush establishment on mined lands. Project Review Seminar. Abandoned Coal Mine Land Research Program. November 17, 1999, Gillette, WY.

Harniss, R. O. and W. T. McDonough. 1976. Yearly variation in germination in three subspecies of big sagebrush. J. Range Manage. 29: 167-168.

Howard, G. S., F. Rauzi, and G. E. Schuman. 1979. Woody plant trials at six mine reclamation sites in Wyoming and Colorado. U.S.D.A., Ag. Production Research Report No. 177. U.S. Government Printing Office, Washington, D.C.

McArthur, E., Durant, Richard Stevens, and Steven B. Monsen. 1995. Adaptation and success of big sagebrush and rubber rabbitbrush on disturbed sites. pp. 811-823. In: G.E. Schuman and G.F. Vance (eds.). Decades Later: A Time for Reassessment. June 3-8, 1995, Gillette, WY. American Society for Surface Mining and Reclamation, Princeton, WV.

McDonough, W. T. and R. O. Harniss. 1974. Effects of temperature on germination in three subspecies of big sagebrush. J. Range Manage. 27: 204-205.

Pfannensteil V. R. and G. W. Wendt. 1984. Enhancing shrub establishment by utilizing direct haul topsoil on mine spoils in western Colorado. pp. 1-14. In: Proc., Symposium on the Reclamation of Lands Disturbed by Surface Mining: A Cornerstone for Communication and Understanding. July 13-14, 1984. Owenboro, KY. Amer. Society of Surface Mining and Reclamation, Princeton, WV.

Schuman, G. E., D. T. Booth, and J. R. Cockrell. 1998. Cultural methods for establishing Wyoming big sagebrush on mined lands. J. Range Manage. 51: 223-230.

Tessmann, S. A. and L. H. Kleinman. 1989. Should the mining industry be required to increase the amount of sagebrush planted at reclaimed sites—point/counterpoint. The Wyoming Mining Claim. 15(2): 8-11.

U. S. Congress. 1977. Surface Mining Control and Reclamation Act (SMCRA). 1977 Public Law (30 USC 1201 et seq.). Washington, D. C.

Williams, S. E., M. A. J. Loree and P. C. Singleton. 1981. The effects of long term storage on fertility and biological activity of topsoil. Abstract. In: Proc., Fifth North American Conference on Mycorrhizae. August 1981, Quebec City, Quebec, Canada.

Wyoming Environmental Quality Act (WEQA). 1973. Wyoming Statute. Cheyenne, WY.

Wyoming Mining Association. 2000. 1999 Coal Production Report. Cheyenne, WY.

Sagebrush and Mine Reclamation: Whats Needed From Here?

Larry H. Kleinman[1] and Timothy C. Richmond[2]

Abstract

The Wyoming Environmental Quality Act requires coal mines to include shrubs in the reclamation revegetation species mix and further specifies planting patterns and density required to achieve full reclamation bond release. Wyoming big sagebrush (*Artemesia tridentata* ssp. *wyomingensis*) is a principal shrub component in many of the vegetative communities found in the coal mining districts of Wyoming and elsewhere in the western United States. Efforts to establish Wyoming big sagebrush on reclaimed areas by the coal mining companies in Wyoming have met with mixed success. The University of Wyoming, through its Abandoned Coal Mine Lands Research Program funded by the Abandoned Mine Land Division of the Wyoming Department of Environmental Quality, has sponsored several research projects beginning in 1991 to better understand the requirements of Wyoming big sagebrush revegetation and to find more cost effective and dependable methodologies for meeting the legislative and regulatory requirements. The research to date has been less than conclusive; seed is germinating, but seedlings seldom reach a mature, dominant, or co-dominant position on reclaimed sites. One study found natural sagebrush stands are even-aged, suggesting only certain, unique climatic or weather conditions may be a requisite for stand establishment, or perhaps some catastrophic event such as fire, may be required. Further research is needed to find economic methods for Wyoming big sagebrush establishment and survival. Current seeding methodologies may add as much as five cents to the cost of producing one ton of coal. Coal contracts are won or lost by as little as five cents subtracted or added to the cost per ton of coal. What are the economic cut-offs for "transplanting and seeding"? What types of cultural practices will ensure seed germination and seedling survival each year, instead of just when climatic conditions are ideal? Cultural practices may include, but are not limited to soil chemical and physical characteristics, surface manipulation, mulches, cover crops and heavy livestock grazing. This information is needed before the mining industry can satisfy the regulatory requirements in a cost-effective manner.

Introduction

The Wyoming Environmental Quality Act at § 35-11-415(b)(vii) requires mine operators to "Replace as nearly as possible, native or superior self-regenerating vegetation on land affected, as may be required in the approved reclamation plan" (WEQA 1998). The Land Quality Division of

---

[1]Reclamation Manager, Kiewit Mining Group, Black Butte coal Company, Point of Rocks, Wyoming.
[2]Project Officer, Abandoned Mine Land Division, Wyoming Department of Environmental Quality, Cheyenne, Wyoming.

the Wyoming Department of Environmental Quality promulgated rules and regulations in 1996 specifying a shrub standard to be achieved as part of the revegetation success requirements for coal mines seeking reclamation bond release. Chapter 4 of the Rules and Regulations, “Environmental Protection Performance Standards for Surface Coal Mining Operations,” at Section 2 (d)(i) requires the operator to “…establish on all affected lands a diverse, permanent vegetative cover of the same seasonal variety native to the area or a mixture of species that will support the approved postmining land use in a manner consistent with the approved reclamation plan. The cover shall be self renewing and capable of stabilizing the soil.” Section 2 (d)(x)(E) further requires “The post mining density, composition, and distribution of shrubs shall be based upon site specific evaluation of premining vegetation and wildlife use. Shrub reclamation procedures shall be conducted through the application of best technology currently available.” Finally, Subsection 2 (d)(x)(E)(I) states “Except where a lesser density is justified from premining conditions in accordance with Appendix A, at least 20% of the eligible lands shall be restored to shrub patches supporting an average density of one shrub per square meter. Patches shall be no less than .05 acres each and shall be arranged in a mosaic that will optimize habitat interspersion and edge effect….This standard shall apply to all lands affected after August 6, 1996” (LQD 1998). Although big sagebrush (*Artemesia tridentata*) and its subspecies are not specifically mentioned in the above cited requirements, because of the requirements to replace or restore the vegetation existing prior to the mining disturbance, the replacement of big sagebrush is specified by default.

The coal mining industry has included sagebrush in its revegetation efforts for the past decade with mixed success. Schuman and Booth (1998) and others have suggested the cause for the mixed results may be low seedling vigor, competition from herbaceous species, altered soil conditions, and reduced levels of arbuscular mycorrhizae in the reclaimed mine soils.

Recent Big Sagebrush Establishment

The Abandoned Coal Mine Land Research Program (ACMLRP), administered by the University of Wyoming and funded by the Abandoned Mine Land Division of the Wyoming Department of Environmental Quality, was established in 1991 to sponsor research for abandoned and active coal mine reclamation. The ACMLRP has funded four research projects on big sagebrush establishment, with emphasis on the subspecies *wyomingensis*. Four major studies have been undertaken since 1991, three of which have been completed and one is still in progress.

One study, “Climatic Control of Sagebrush Survival for Mined-Land Reclamation” (Perryman et al. 1999), looked into climatic and environmental factor relationships with natural sagebrush stand establishment. This study evaluated stands of the Wyoming, basin (*vaseyanna*), and mountain (*tridentata*) subspecies from locations throughout Wyoming. Significant findings include stands are generally even-aged and establishment is episodic. Mean stand ages of Wyoming big sagebrush in northeast and central Wyoming are approximately 26 to 32 years. This is 3 to 4 times older than the mean fire-free interval of 8 years for these areas. Irregular pulses of recruitment appear to be characteristic of big sagebrush stands in Wyoming.

This study further found that above average December and January precipitation following initial establishment of Wyoming big sagebrush seedlings was a common occurrence associated with stand establishment. It would appear that the deeper snow cover associated with the above-average precipitation at that time of year provides protection from winter desiccation as well as additional soil moisture during the spring growing season. For basin big sagebrush, there was higher recruitment in those years with higher than average June precipitation during the first growing season, followed by higher than average precipitation in March, May and June of the second growing season. Mountain big sagebrush did not follow this pattern as precipitation in the higher mountain environments means lower temperatures, not conducive to germination and growth at those times of the year.

Perryman et al. (1999) further found that big sagebrush stand age might be estimated by stem diameter measurements of the larger plants within the stand with reasonable accuracy. They obtained good correlation with approximately 1 mm of stem diameter per year.

A second study, “The Influence of Post-harvest and Pre-planting Seed Treatment on Sagebrush Seedling Vigor,” was initiated in 1993 (Booth et al. 1996). Analyses were performed on big sagebrush seeds collected from several locations during the late winter. Processing through a 48-inch commercial debearder did not appear to reduce seed quality. Moisture percentages in the seed ranged from 2.3 to 9.0% and seed weights ranged from 0.022 to 0.032 g/100 seeds. Germination percentages were highest, and germination most rapid, from the heavier seeds.

This study also evaluated moisture uptake (hydration) by big sagebrush seed in storage during a 15-day period at 2°, 5°, 10°, and 15°C. Hydration occurred slowly at the cooler temperatures while the maximum rate of hydration occurred at 10°C. The differences in hydration rates did not appear to influence sagebrush seed germination or seedling vigor in laboratory tests.

Big sagebrush seeds, when exposed to seven water potentials ranging from 0.00 to –1.5 MPa, exhibited greatest germination at 0.00 Mpa. The authors also observed that the pericarp reduces water uptake and that pericarp removal enhanced germination between –0.50 and –1.00 Mpa. Booth et al. (1996) recommended, however, not to remove the pericarp, as they believed it is important in retaining seed viability in the soil until more favorable soil moisture conditions occur. They implied normal seed processing would result in an adequate quantity of naked seed without the need for further pericarp removal.

As an extension to the previous study, Booth et al. (1998) in “Wyoming Big Sagebrush Seed Production from Mined Lands and Adjacent Unmined Rangelands,” evaluated big sagebrush seed production from reclaimed coal mine lands and undisturbed, native ground. This study was done at the Dave Johnson Coal Mine in central Wyoming from July 1995 through October 1998. Big sagebrush plants observed ranged in age from 10 to 20 years. They found the number of seed stalks per plant, seed quantities, and seed weights were greater from plants on reclaimed mine land than from comparison plants on adjacent undisturbed sites. Some plants had been fenced to observe the effects of wildlife browsing. It was observed that the unfenced plants produced lighter and drier seeds than the plants that were fenced. It was also observed, unexpectedly, that the fences apparently provided some environmental modification comparable to the effects of mulch and wind protection treatments applied as part of the study. Soil moisture conditions varied considerably from year to year. However, when averaged across all variables, soil moistures on reclaimed and mulched native sites was higher than on no-mulch reclaimed and no-mulch undisturbed sites.

In the study “Strategies for Establishment of Big Sagebrush (*Artemesia tridentata* ssp. *Wyomingensis*) on Wyoming Mined Lands” initiated in 1991, Schuman and Booth (1998) looked at coal mine reclamation practices and their relationships with big sagebrush establishment. They found that direct placed topsoil did not act as a seed bank for big sagebrush as compared to stockpiled topsoil. They did find, however, that direct placed topsoil consistently had higher soil moisture and greater arbuscular mycorrhizae spore counts than did stockpiled topsoil. As a result, the direct placed topsoil sites had 40% more big sagebrush seedlings than stockpiled topsoil sites the first season of establishment and from one to two orders of magnitude more the following season.

Schuman and Booth (1998) looked at the differences in mycorrhizal infection between direct placed topsoil and stockpiled topsoil. In spite of a nearly 33% greater spore count in direct placed topsoil, there was no apparent difference in the number of mycorrhizal infected big sagebrush seedlings between the two soil treatments. The authors note this may be because the non-infected seedlings had already died prior to the observations. There was a positive effect of mycorrhizae on drought stress tolerance by big sagebrush seedlings (Stahl et al. 1998).

Stubble mulch and crimped straw mulch were found to provide greater big sagebrush seedling establishment than was no mulch or stubble and straw mulch together. Grass competition was further observed to have reduced big sagebrush seedling density throughout the duration of the Schuman and Booth study.

A final aspect of the study, "Strategies for Establishment of Big Sagebrush (*Artemesia tridentata* ssp. *wyomingensis*) on Wyoming Mined Lands," was to study the relationship and effect of seeding fourwing saltbush (*Atriplex canescens*) as a pioneer species for later big sagebrush establishment. There were no effects, either positive or negative, shown by this phase of the study. It was observed, however, that the increase in total shrub density was favorable in helping to meet the shrub density regulatory standard for reclamation bond release.

An important finding from the Schuman and Booth study is that big sagebrush seed apparently maintains its viability for a much longer time than previously thought. New seedlings were noted three and five years after the initial seeding.

The study "Grass Competition and Sagebrush Seeding Rates: Influence on Sagebrush Seedling Establishment" (Fortier et al. 1999) is in its first year and only preliminary results are reported. First growing season data for big sagebrush seedling performance under three sagebrush seeding rates and seven grass seeding rates were mixed. Heavy spring and early summer precipitation masked the expected effects of increasing grass competition. However, big sagebrush seedling density did show a direct relationship with seeding rates, and big sagebrush seedling density was lower at the higher grass seeding rates. Big sagebrush seedling density declined with decreasing precipitation and soil moisture content throughout the summer for all seeding rates, and the greatest seedling loss was seen in the highest big sagebrush seeding rates. All three big sagebrush seeding rates of 1 kg/ha, 2 kg/ha, and 4 kg/ha met the regulatory required density of 1 shrub per square meter at the end of the first growing season.

Summary

The research conducted under the Wyoming ACMLRP has shown that the establishment of natural big sagebrush stands is episodic and appears to be dependent upon winter and early spring precipitation patterns immediately following seedling establishment. Other findings of significance are:

Big sagebrush seedlings are sensitive and susceptible to winter desiccation.

Big sagebrush seedlings are sensitive to late growing season moisture stress.

Big sagebrush seedlings are intolerant of grass and/or herbaceous competition, apparently for the above stated reasons.

Direct placed topsoil is not an apparent source of big sagebrush seed or propagules.

Mycorrhizae are important in helping big sagebrush seedlings survive periods of moisture stress.

Direct placed topsoil generally has higher soil moisture content and mycorrhizal spore counts, both of which are beneficial to big sagebrush seedling establishment and survival, than does stockpiled topsoil.

Big sagebrush should be seeded a season or two before herbaceous species or to seed herbaceous species at a lower rate than typically used to aid sagebrush seedling establishment.

Stubble mulch or straw mulch provides protection to big sagebrush seedlings from winter desiccation and to maintain soil moisture contents for longer periods of time.

Big sagebrush seed has an apparent longer viability than previously thought, up to three to five years.

Research Needs

Further research is needed to find cost-effective methods for Wyoming big sagebrush establishment and survival. Current seeding methods, following many of the preceding recommendations, may add as much as $0.05 per ton ($0.055 per metric ton) of coal produced, which is substantial considering that Powder River Basin coal is selling on the spot market for less than $3.50 per ton ($3.85 per metric ton). Contracts are won or lost by as little as five cents per ton of coal.

Transplanting and seeding costs are a substantial part of the total reclamation costs. The cost of transplanting containerized stock can be more than $2.00 per stem. It would require 809 stems per acre (2,000/ha) or $1,618.00 per acre ($4,000/ha) to meet the regulatory requirement of one shrub per square meter over 20% of the area just for planting only the big sagebrush.

Seeding costs are much less than transplanting but at a much greater risk of establishment failure. One 1999 contracted seed price for Wyoming big sagebrush was just over $32.00 per PLS pound ($70.40/kg). At a seeding rate of one-half pound PLS per acre (0.625 kg/ha), the cost for the seed alone would be $3.52 per acre ($8.80/ha) for the shrub density requirement of 20% of the area. This does not include the cost of planting, which, when including seedbed preparation, seeding, and mulching, will approach $500.00 per acre ($1,250.00/ha). Recent research has been recommending 3-8 PLS pounds per acre (3.4 – 9.1 kg/ha) seeded for best results. Six PLS pounds/acre (6.82 kg/ha) of big sagebrush seed at the current price is $192.00 per acre ($480.00/ha) or $38.00 per acre ($96.00/ha) plus seeding costs for 20% of the area. It is clear the costs of planting materials alone for big sagebrush become quite high considering the establishment success that has been achieved. It is imperative to find more efficient and cost-effective ways of meeting the shrub density and vegetative performance requirements of the Wyoming Land Quality Division’s Coal Rules and Regulations.

Next Generation of Research

Research in two basic areas is needed. Are there new cultural practices for establishing big sagebrush that have not yet been explored? What are the costs and economics of those cultural practices and methodologies that are, or will be, proven to result in big sagebrush stand establishment? How can these costs be improved?

Different types of cultural practices to ensure seed germination and seedling survival each year should be explored. Cultural practices may include, but are not limited to, soil chemical and physical characteristic modifications, surface manipulation, mulches, cover crops, and even heavy livestock grazing.

What are the soil chemical characteristics that drive big sagebrush germination and establishment? Are there nutrient characters such as organic matter or nitrogen that aid in the growth of big sagebrush? What are the soil physical characteristics or surface manipulation that will increase water holding capacity until such a time that the seed needs it to germinate or seedlings need it to continue growth and survival? Can the use of mulches and cover crops be used more effectively to increase soil moisture and protect new seedlings? We know that heavy livestock grazing will inhibit grass growth and allow sagebrush to increase. Can grazing be utilized to speed up the process of sagebrush establishment?

Only a few ideas have been given for future research that may provide those of us in the industry with the knowledge needed to make good decisions. Western coal is a very competitive business and new and more cost-effective ways of competing must be found if the coal business is to survive. Finding better, more dependable, cost-effective ways to successfully establish big sagebrush is one very important way to remain competitive while maintaining compliance with the reclamation regulations.

References

Booth, D. T., E. E. Roos, and Y. Bai. 1996. The influence of post-harvest and pre-planting seed treatment on sagebrush seedling vigor. Project Review Seminar. Abandoned Coal Mine Land Reclamation Program. November 6, 1996. Gillette, Wyoming.

Booth, D. T., Y. Bai, and E. E. Roos. 1998. Big sagebrush seed production from minedlands and adjacent unmined rangelands. Project Review Seminar. Abandoned Coal Mine Land Reclamation Program. November 5, 1998. Gillette, Wyoming.

Fortier, M. L., G. E. Schuman, A. L. Hild, and L. E. Vicklund. 1999. Grass competitionand sagebrush seeding rates: influence on sagebrush seedling establishment. Project Review Seminar. Abandoned Coal Mine Land Reclamation Program. November 17, 1999. Gillette, Wyoming.

Land Quality Division. 1998. Coal rules and regulations. Wyoming Department of Environmental Quality. Cheyenne, Wyoming.

Perryman, B. L., R. A. Olson, Ann L. Hild, and A. M. Maier. 1999. Climatic control of sagebrush survival for mined-land reclamation. Project Review Seminar. Abandoned Coal Mine Land Reclamation Program. November 17, 1999. Gillette, Wyoming.

Schuman, Gerald E. and D. Terrance Booth. 1998. Strategies for establishment of big sagebrush (*Artemesia tridentata* ssp. *Wyomingensis*) on Wyoming mined lands. Final Project Grant Report. USDA, Agricultural Research Service. High Plains Grasslands Research Station. Cheyenne, Wyoming.

Stahl, P.D., G.E. Schuman, S.M. Frost, and S.E. Williams. 1998. Interaction of arbuscular mycorrhiza and seedling age on water stress tolerance of *Artemisia tridentata* ssp. *wyomingensis.* Soil Sci. Soc. Am. J. 62:1309-1313.

Wyoming Environmental Quality Act and Industrial Development Information and Siting Act. 1998. Wyoming Department of Environmental Quality. Cheyenne, Wyoming.