Reseeding Big Sagebrush: Techniques and Issues

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Abstract—Reestablishing big sagebrush on rangelands now dominated by native perennial grasses, introduced perennial grasses, or exotic annual grasses, particularly cheatgrass (*Bromus tectorum*), serves to stabilize soil, improve moisture availability and nutrient recyling, increase biological diversity, and foster community stability and resiliency. A first priority in reseeding is identifying the subspecies of big sagebrush native to the site and procuring adapted, high-quality seed of that subspecies from a similar site. Seed should be planted on firm seedbeds and pressed into the soil to provide good seed-to-soil contact. Competition from invasive species and other seeded species must be minimized by site preparation practices and use of appropriate seeding strategies and equipment. Precipitation is often a major factor in determining seeding success on drier sites. Postseeding monitoring and careful management are necessary to maintain stands and provide feedback for improving future seeding efforts. Additional research and technological developments are required to better estimate and maintain big sagebrush seed quality, provide required seedbed conditions, and reestablish mixed seedings of big sagebrush and associated natives.

The sagebrush (*Artemisia* spp.) biome encompasses approximately 63 million ha of the Western United States, but little of this area has remained unaltered since Euro-American settlement. Vast tracts have been lost to agriculture, urbanization, and other human activities. Of the remaining area, it has been estimated that 50 to 60 percent has been converted to nonnative annual grasslands or contains exotic annual grasses in the understory (West 2000). Even though more than 70 percent of the sagebrush-steppe is publicly owned, less than 3 percent is protected in National Parks or other Federal reserves (Knick and others 2003). The increasingly rapid and widespread degradation, fragmentation, and, in some areas, near total loss of sagebrush has resulted in its being rated one of the most imperiled ecosystems in North America (Noss and Peters 1995). Some have advocated that a regional objective of no net loss of sagebrush be adopted to prevent further declines in biodiversity (Paige and Ritter 1999; West 2000).

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More than 20 sagebrush species and subspecies occur within the sagebrush biome (Goodrich, this proceedings; Rosentreter, this proceedings). It is spatially complex, with variable soils, topography, parent materials, climates, landscape patterns, and disturbance histories (Miller and Eddleman 2001). Sagebrush populations display a strong alliance to certain habitats, with morphological specializations and adaptations evolving along environmental gradients (Schultz 1986). Prior to Euro-American settlement, fire regimes were equally complex across this region and contributed significantly to landscape heterogeneity. With the shift in fire regimes that has occurred over the past 100 years, largely due to the spread of nonnative plant introductions into voids created by postsettlement livestock grazing, this once complex landscape has become increasingly homogeneous. All of these factors contribute to the enormous difficulty that land managers experience in attempts to restore native plant communities where natural recruitment is often limited by a lack of propagules, drought, a competitive exotic understory, disruption of hydrologic functioning, and changes in soil structure and biota as a result of past disturbances.

Early seeding success with introduced grasses contributed to their widespread use for soil stabilization and to type conversion of sagebrush landscapes for increased forage production; the latter is an objective that dominated our use of this biome for much of the twentieth century (Holechek and others 1998). From the 1930s into the 1970s, an estimated 2 to 6 million ha of sagebrush habitat was burned, sprayed, or treated mechanically to reduce sagebrush (Braun 1998; Vale 1974). Due to health concerns, use of 2,4-D and 2,4,5-T was curtailed in the 1980s, but other treatments continued through that decade. The total acreage impacted is unknown, but it has been estimated to exceed 20 to 25 percent of the total remaining sagebrush-dominated landscape (Braun 1998).

Concern for big game habitat loss increased as these large treatments continued. Monocultures of any one species do not constitute healthy or desirable rangelands (Stevens and others 1981), and generalist animals such as grasshoppers (*Orthoptera*), deer mice (*Peromyscus* spp.), horned larks (*Eremophila alpestris*), and introduced chukars (*Alectoris chukar*) occur in seedings of introduced grasses (Maser and others 1984). Public concern led to the increased use of browse species in wildlife habitat treatments. Blaisdell (1972) reported that research in shrub ecology had contributed to the identification of about 75 shrubs as promising for improving big game habitat (see Plummer and others 1968). Four shrubs, big sagebrush (*A. tridentata*), fourwing

saltbush (*Atriplex canescens*), antelope bitterbrush (*Purshia tridentata*), and rubber rabbitbrush (*Chrysothamnus nauseosus*), were considered primary species to be promoted. The use of big sagegrush and other shrubs in rangeland rehabilitation treatments on Federal lands has gradually increased since the mid to late 1980s. More recently, the decline of sage-grouse and other sagebrush obligate species has given additional impetus to restoration of big sagebrush habitats. Although an additional two decades have passed, we still have much to learn about restoring this landscape dominant and its associated species to disturbed lands. Here we provide a review of recent big sagebrush restoration literature and recommendations for reestablishment and management of this species and its communities.

Natural Regeneration of Big Sagebrush

Most *Artemisia* species, subspecies, and ecotypes are easily killed by fire. They do not resprout and therefore must regenerate from seed. Of the five subspecies in the big sagebrush complex (table 1), only subalpine big sagebrush (*A. t.* spp. *spiciformis*) can resprout from root crowns or lower stem bases after being top-killed by burning (Winward 1985). Fire passing through a Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*) plant will usually kill it (Britton and Clark 1985).

A big sagebrush plant may produce 500,000 seeds in a typical year (Welch and others 1990), but annual production varies greatly (Young and Evans 1975). Big sagebrush seeds are small and exceedingly light; those of basin big sagebrush (*A. tridentata* ssp. *tridentata*) are generally lighter (0.018 g/100 seeds) than those of mountain and Wyoming big sagebrush (0.025 g/100 seeds) (Meyer and others 1987). Big sagebrush seeds are dispersed primarily by gravity. Maximum dispersal distances are only about 30 m from the parent plant; 85 to 90 percent of all seeds fall within 1 m of the edge of the mother plant (Wagstaff and Welch 1990; Young and Evans 1989). Consequently, long-distance dispersal by wind is ineffective in recolonizing large burns or other disturbances (Meyer 1994).

Artemisia seeds rarely survive in the soil for more than a year (Caldwell 1978; McDonough and Harniss 1974; Walton and others 1986). However, some seed may carry over if buried and not exposed to light (Hassan and West 1986; Meyer 1994; Meyer and Monsen 1990; Richardson and others 1986). Schuman and others (1998) found that Wyoming big sagebrush seed survived up to 4 years when applied with mulch on mine spoils in Wyoming.

Table 1—Big sagebrush complex.

Common name	Scientific name
Subalpine big sagebrush	*Artemisia tridentata* ssp. *spiciformis*
Basin big sagebrush	*A. t.* ssp. *tridentata*
Mountain big sagebrush	*A. t.* ssp. *vaseyana*
Few-flowered mountain big sagebrush	*A. t.* ssp. *vaseyana* f. *pauciflora*
Wyoming big sagebrush	*A. t.* ssp. *wyomingensis*
Xeric big sagebrush	*A. t.* ssp. *xericensis*

Rapid reestablishment of most big sagebrush subspecies is more likely on sandy or gravelly soils that are well suited for supporting the species. Big sagebrush returns more slowly on fine-textured soils that have a greater potential for production of herbaceous species (Blaisdell and others1982; Hironaka and others1983). Xeric big sagebrush (*A. t.* ssp. *xericensis*) is the only taxon in the big sagebrush complex adapted to fine-textured clay soils.

Natural postfire reestablishment of big sagebrush has not been widely documented. During years of low precipitation, few Wyoming big sagebrush plants may establish, and it may take many years before recolonization takes place. Even under favorable conditions, site recovery may require 60 to 100 years. On dry Wyoming big sagebrush sites, several years may pass before conditions favoring establishment of new seedlings occur (Clifton 1981; Lowe-Dalzell and others 2003; Wambolt and Payne 1986; West and Hassan 1985; Young and Evans 1978). Because of these factors, big sagebrush must be artificially reseeded on sites where seed sources have been lost.

Postfire, Pretreatment Site Evaluation

Prior to treatment, it is imperative that a site evaluation be conducted to assure that artificial restoration measures are needed and that natural recovery will not occur within an acceptable time frame (fig. 1). If recovery is not anticipated without seeding, the preburn density of exotic annuals and the postburn seed bank of these species must be estimated to determine the potential for restoring the site, the overall objectives must be established, and the approach for accomplishing the seeding or planting must be selected.

The characteristics of various ecological sites and their distribution within a given management area should be thoroughly understood. Site characteristics vary according to the potential natural community, species present, soil depth and texture, effective precipitation, erosion potential, elevation, aspect, and other factors (National Research Council 1994). Burned big sagebrush sites that receive less than 250 mm of annual precipitation, particularly where the understory is cheatgrass (*Bromus tectorum*) dominated, have a low probability of regenerating naturally and providing preburn cover and structure in a reasonable length of time. This is due to inadequate seed supplies on surviving plants or in the soil seed bank and the combined effects of low and erratic precipitation and herbaceous competition from exotic annuals (Boltz 1994). It is these lands that are in the most urgent need of restoration, but are the most risky to treat. For such sites, a greater investment of time and money will be required, and priorities, objectives, and resource availability are particularly important considerations. Adapted species and subspecies must be planted using procedures that remove competition and create suitable seedbeds. Developing measures to remove or diminish competition is difficult, but failure to implement all proven site improvement measures significantly reduces the chance of success (Monsen and McArthur 1995; Stevens and Monsen 2004). For example, herbicide application or the use of container or bareroot transplant stock may be necessary

Figure 1—Site evaluation form.

Site Evaluation Form

Name _____ Date _____

Fire name _____ Fire No. _____

Date fire started _____ Date fire controlled _____

District or Forest _____ Elevation _____

Acres burned and ownership: _____ total acres _____ public _____ State _____ private

Preburn vegetation types and estimated acres of each: _____

_____

_____

_____

Preburn ecological site(s) and estimated acres of each:

Range/ecological condition: _____

Precipitation zone(s) _____

Fire severity: _____ acres low _____ acres moderate _____ acres high

Soil series/name _____ Soil depth according to survey _____

Soil description and texture _____

_____

Current land use(s) _____

Grazing season of use/type of system (specific dates) _____

_____

Acres/AUM _____ No. pastures _____

Range condition _____

_____

Is use pattern map available? _____ (if so, please attach copy)

Key wildlife seasonal habitat? _____

Noxious weeds? Species and occupied acres (attach map) _____

_____

Resource objectives: _____

_____

Fencing (describe preburn and identify additional needs) _____

_____

_____

Recommended treatments (include for noxious weeds) _____

_____

_____

Seed mix(es), rates, method of application, PLS cost:

Drill seeded—Seed mix 1	Drill seeded—Seed mix 2	Aerial seeded—Seed mix 3
species/subspecies/rate/cost	species/subspecies/rate/cost	species/subspecies/rate/cost
Totals:	Totals:	Totals:

under such conditions. Evaluation forms such as figure 1 may be used to facilitate the decisionmaking process.

Stevens (2002) recommends the following four steps be followed in selecting taxa for a seeding: (1) develop a list of species and ecotypes that would occur on the proposed planting site; (2) from this list, determine which species have a significant amount of high quality seed available for planting; (3) of these available species, determine those that are compatible as young developing plants and that will ensure ecological development of a desired plant community; and (4) evaluate the final species list to determine if project objectives can be achieved or whether the initial objectives require revision.

To successfully reestablish big sagebrush, the subspecies present preburn must be determined and utilized in the seeding effort. Remnant plants may be identified using the descriptions provided by Goodrich (this proceedings) and Rosentreter (this proceedings). Subspecies and populations of big sagebrush have evolved in distinct environments. Common garden studies have revealed differences in adaptive characteristics such as drought or frost tolerance (McArthur and Welch 1982; Meyer and Monsen 1990; Welch and others 1992); movement of populations to different climatic or edaphic conditions is not advised (Mahalovich and McArthur 2004; Monsen 2000). Specific ecotypes may be especially important on droughty sites or mineral soils. Matching treatment site characteristics, such as soil type and elevation, with the seed source is critical, but this has frustrated land managers and in some cases been impossible during large fire years when seed is in high demand and production low. Consequently, it is all the more imperative that the correct big sagebrush subspecies be used.

Seed Biology and Technology

Seed Harvesting and Conditioning

Big sagebrush flowers in summer and is wind pollinated. Large numbers of tiny flowers develop on spikes, racemes, or panicles, with individual plants producing hundreds of thousands of achenes (Welch and others 1990) in years with favorable weather conditions. Seeds (achenes) ripen in late fall and are usually dispersed within a few weeks of reaching maturity, depending upon weather conditions and subspecies. Seed of mountain big sagebrush generally ripens earlier than seed of basin big sagebrush or Wyoming big sagebrush, and considerable variability in date of ripening will be found within individual plants and populations. In addition, seed production varies widely from year to year based on weather conditions, herbivory, seed predation, and other factors (Wagstaff and Welch 1991; Young and others 1989). Because of these factors, seeds should be checked carefully with a hand lens before harvesting to ensure that adequate quantities of sound seeds are present to justify harvesting. Seed harvested too early will be immature and not viable. Delaying the issuing of permits until seed has matured has been suggested as one means of discouraging early harvest on public lands (AOSA 2003). Seed harvested too late, after dispersal of most sound seeds, will include large quantities of poorly developed seeds and fruit and flower parts. An additional complication is the frequent occurrence of basin big sagebrush and Wyoming big sagebrush mosaics with the basin big sagebrush growing in deeper soils or along roadways or along riparian areas. It is essential that care be taken to collect only the target subspecies.

Seed is hand harvested by beating or stripping the inflorescences into seed hoppers, boxes, bags, or other containers. Harvesting should be done when the humidity is low because the fruits separate more easily from the inflorescences when dry. Average moisture content of fully ripened seeds of big sagebrush has not been examined carefully. Moisture content of seed and debris is often high when seed is harvested from plants that are covered with snow or frost in late fall. Seed is initially dried to a moisture content of 18 to 20 percent before cleaning to protect seed viability and to reduce the volume of material to be conditioned (AOSA 2003). Appropriate drying techniques and rates and their effects on seed quality require further investigation; rapid seed deterioration with improper handling is considered a major obstacle to maintaining big sagebrush seed viability beyond the first year (AOSA 2003).

Purity of harvested seed lots is extremely low due to the presence of inflorescence branches, leaves, bracts, poorly developed fruits, and other debris. Seed is cleaned using a barley debearder or hammermill to break up the inflorescences and other debris. Screening and fanning then removes trashy material. Big sagebrush seed is generally cleaned to 10 to 15 percent purity (Stevens and others 1996), but purities of 80 percent or more can be obtained by further cleaning with an air screen separator. Cleaning to a purity of 35 percent has been suggested as a means of reducing bulk and cost for shipping and storage, increasing the consistency and accuracy of seed sampling and seed quality testing, improving the regulation of seed moisture content in storage, and facilitating seed metering through seeding devices (AOSA 2003; Welch 1995).

For current seeding practices, purity of 10 to 12 percent and viability of 85 to 95 percent is recommended by Meyer (2005). Lambert (2005) recommended 14 percent purity and 80 percent viability as minimum standards for USDI Bureau of Land Management purchases of big sagebrush. If all large debris is removed, seed cleaned to this level can be seeded through broadcast seeders, rangeland drills, Hansen browse seeders, and other standard seeding devices (Shaw and Monsen 1990). Maximum allowable moisture content can also be listed in purchase specifications.

Seed Storage and Longevity

Following late fall harvest, big sagebrush seed must be dried, cleaned, and tested before it can be sold. Consequently, a considerable amount of newly harvested seed is not marketed before the late fall seeding period, but must be held over in storage for at least 1 year. Storing seed at moisture contents of 6 to 8 percent and a temperature below 10 °C (Meyer 2005) may lengthen viability to as much as 5 years. Storage of seed under adverse conditions, even for short periods, can negatively affect seed quality and translate into a rapid decline in viability and vigor. Thus it is advised that seed be tested for viability before purchasing or seeding in order for prices and seeding rates to be determined accurately.

Seed Testing

Testing of big sagebrush seed lots is plagued by a number of problems stemming from the small seed size, low purity levels, and the large size of marketed seed lots. Additional research is urgently needed to provide guidelines that will aid users in maintaining and more accurately measuring seed quality. Such guidelines would reduce problems related to marketing, handling, and seeding big sagebrush.

Problems in assessing purity arise from sampling procedures at the warehouse and in the laboratory. Seed lots are often large and heterogeneous. Big sagebrush seed does not flow and samples must be drawn from bags by hand, a technique that introduces more variability than use of a trier or probe; thus purity of samples drawn from a single seedlot for submission to the seed laboratory can differ substantially. Initial samples drawn from large seed lots may be too large to submit to the laboratory and will require further subsampling, thus introducing additional variability. When the submitted sample reaches the seed laboratory, the working sample is obtained by dividing the sample by hand, a less reliable technique than use of mechanical dividers used for seeds that flow readily. The AOSA (2003) suggested variability in samples might be reduced by limiting seed lot size and by marketing big sagebrush seed at purities in the 35 percent range. Seeds might then be classified as flowable, and triers and mechanical dividers could be used for sampling, thus improving sampling consistency.

Purity testing for big sagebrush is slow and costly. In addition to sampling problems, the small seed size, large amounts of debris present, and problems related to selection of pure seed increase the time required for completion of tests and reduce the accuracy of results (AOSA 2003). Again, increasing purity levels to the 35 percent range would reduce the bulk of seed and debris that must be examined, remove many of the seeds that are small, nonviable, or poorly developed; speed the testing process considerably; and reduce the variability of results.

Procedures for testing viability of members of the genus *Artemisia* are provided by AOSA (2000). Results can be obtained quickly, depending primarily on the laboratory's backlog. AOSA germination tests are available for big sagebrush, black sagebrush (*A. nova*), and Louisiana sagebrush (*A. ludoviciana*) (AOSA 2000). The germination test for Louisiana sagebrush requires 14 days. Germination tests for big sagebrush and black sagebrush require 21 days; dormant seedlots require a 14-day prechill. Meyer (2005) recommends testing nongerminating seeds for viability as not all dormant seed will respond to the short prechill. Sampling problems and identification of pure seed reduces consistency of results.

Seed shipped for purity and germination or viability testing may be packaged in paper bags or containers. Seeds shipped for moisture testing should be packed in plastic bags to maintain the water content at the same level as the seed lot. Use of the International Seed Testing Association rule for testing moisture content (drying at 105 °C for 16 hours) should be specified for determining seed water content (AOSA 2003).

Germination and Seedling Establishment

The level of seed dormancy and the light requirement for germination vary widely among big sagebrush seed sources and tend to decline with afterripening in dry storage or with a moist prechill. Compared with seed from lower elevations, seed from high elevations generally requires a longer field or laboratory stratification to release dormancy and reduce the light requirement (Meyer 2005). Seeds that have lost their dormancy germinate rapidly under favorable moisture conditions. Likewise, germination under snow occurs slowly at high elevations, while only a short period of snow cover may facilitate rapid germination of low elevation seed sources (Meyer and Monsen 1990; Young and others 1990). Germination is highly erratic on dry and windy sites where snow cover is less reliable; seeds from such locations may be capable of germinating rapidly, even at low temperatures, when moisture conditions are favorable (Meyer 1994; Meyer and Monsen 1992). Favorable microsites for germination are provided if seeds are placed at or near the soil surface and pressed into a firm, but not compacted seedbed. This provides the exposure to light required for germination and good seed to soil contact for improving water uptake. Imbibed seed produces a layer of mucilaginous material that improves adhesion to the soil. In addition, the hairs that develop on emerging hypocotyls also aid in water uptake and soil contact (Walton and others 1986; Young and Martens 1991).

Although seedlings sometimes establish in large numbers due to high seed production, favorable weather, and appropriate microsite conditions, most seedlings are generally lost to late frosts or drought, disease, inter- or intraspecific competition, herbivory, or other factors. Seeding methods or techniques that provide favorable microsites or improve snow or water catchment, as well as the presence of mature shrubs that can function as nurse plants improve establishment (Monsen and others 1992).

Seeding Considerations

Artificial seeding should only be pursued when the objective is to reestablish shrubs more rapidly than would occur by natural recovery (Shaw and Monsen 1990). However, some circumstances such as severe site conditions or degradation, complex ownership patterns, absence of crucial habitat, small size of a treatment area relative to others in need of seeding, budgetary constraints, or some combination of these factors may render seeding impractical. Decisions are best made following a field site evaluation (fig. 1).

Site preparation and seeding techniques that reduce early competition from both annual grasses and seeded species and provide suitable microsite conditions for germination and early growth (Meyer 1994) must be selected. On degraded sites, extensive site preparation and weed control will be necessary when dense stands of annuals are present preburn or are expected to develop. Not only will preparation of a firm seedbed be required, but also control of exotic annual grasses, primarily cheatgrass (*Bromus tectorum* L.) and medusahead wildrye (*Taeniatherum caput-medusae* L.), will be necessary.

Recommended big sagebrush seeding rates range from 0.11 to 0.22 kg per ha pure live seed (PLS) (Meyer 1994;

Monsen 2000); increases of up to 50 percent are recommended for broadcast seeding (Welch and others 1986). Seeding rates should be calculated on a PLS basis using results of a recent viability or germination test (Meyer 1994). Because of the extreme variation in microsites, moisture availability, and temperature conditions encountered by seeds and seedlings as well as a lack of research and monitoring data, more definitive recommendations are not possible.

Due to its small size, big sagebrush seed is usually mixed with a carrier, thus cleaning to a higher purity than the commercial lot average of 10 to 20 percent PLS may not be cost effective or necessary (Meyer 1994). However, newer drills may be able to seed lots with higher purities at acceptable rates, thus reducing the bulk of seed lots required for individual projects; additional research is required to examine this possibility.

Seeding in late fall or early winter is recommended, as this is when big sagebrush naturally disperses and soil surfaces are more likely to be moist and firm; it also permits the stratification required to attain vigorous germination if adequate moisture is present. Spring seeding should be avoided (Meyer 1994).

Seeding Techniques

Big sagebrush seed should be planted on a firm seedbed with only a light covering of soil. Smooth, compacted seedbeds do not offer good seed to soil contact. Rough seedbeds may slough and bury seeds too deeply. Big sagebrush can be seeded with other species to increase diversity; however, seeding requirements and the relative seedling growth rates of each species must be considered when writing a seeding plan. Due to their earlier maturity, seeded grasses establishing with big sagebrush have an initial advantage and suppress big sagebrush seedlings. Dense stands of seeded grasses may entirely suppress big sagebrush seedlings or prevent big sagebrush reestablishment for an indefinite period (Blaisdell 1949). Due to these concerns and as a general rule of thumb, grass should be seeded at low rates (3.6 to 5.4 kg/ha) if big sagebrush establishment is one of the treatment objectives.

Seeding has frequently been accomplished by aerial broadcasting to keep seeds near the soil surface and to plant large, rough areas rapidly. Ground broadcasting using mechanical seeders or hand seeding is also commonly used. Coverage of broadcast seed using chains, harrows, rails, or other implements is recommended (Stevens and Monsen 2005). Lysne (this proceedings) found that in southern Idaho, big sagebrush seeded aerially and not covered failed to establish on 23 of 35 fire rehabilitation projects examined, while natural regeneration occurred on about one-fourth of the projects. Elevation on her sites ranged from 810 to 1,640 m and annual precipitation from 150 to 305 mm. Overall big sagebrush density did not differ between seeded and nonseeded portions of these projects. As alternative treatments for this area, Lysne (this proceedings) and Lysne and Pellant (2004) recommended seeding methods that create a firm seedbed and press the seed into the soil, thus at least some sagebrush seed is placed near the soil surface. They suggested use of equipment such as the Oyer compact row seeder (Monsen and Meyer 1990), Brillion cultipacker seeder (Monsen and Meyer 1990), Jarbidge big sagebrush seeder (Boltz 1994), or land imprinter (Monsen 1988; Haferkamp and others 1987).

Big sagebrush can be seeded through drills if seed is dropped on or near the soil surface and covered lightly by press wheels (Lambert, this proceedings) or by pulling an implement such as a cultipacker behind the drill. For drill seedings, Richardson and others (1986) recommended that big sagebrush be planted in separate rows from grass and forb species. Otherwise, due to their rapid development, grasses and forbs will compete directly with the slower growing shrub seedlings (Richardson and others 1986) for water and other resources.

New drills equipped with multiple seedboxes, seeding depth regulators for each drop, and surface compaction attachments offer greater flexibility for planting different species in separate rows (Boltz 1994; Wiedemann 2005). Addition of a fluffy seed box to the rangeland drill has also increased options for seeding sagebrush. The Utah Division of Wildlife Resources has recently begun purchasing big sagebrush seed cleaned to 30 percent purity with a minimum of 80 percent germination giving a PLS of 24 percent. Seed harvested and purchased in late autumn is placed in cold storage by December or January and seeded the next autumn. Use of Truax drills or rangeland drills with a fluffy seed box permits use of this seed without addition of a carrier and has reduced problems associated with seed testing (Vernon 2005).

Interseeding is another approach to establishing big sagebrush and other slow growing shrubs. This technique involves disking, plowing, or spraying to remove strips of established vegetation such as introduced grass seedings or invasive species. Shrubs and other species that are slow to establish are then seeded using a Hanson seeder or thimble seeder. Interseeders have been constructed to accomplish mechanical removal of existing vegetation and seeding in one pass (Stevens and others 1981; Wiedemann 2005). The Hansen seeder has also been used to drop big sagebrush seed and other shrubs ahead of the wheels of a tractor or the tracks of a caterpillar. The wheels or tracks create a firm seedbed and press the seed into the soil. Seed of a variety of species can be planted using this method as seeds are placed over a range of depths. Grasses and larger seeded forbs are seeded through the drill.

Hydroseeding is generally impractical for large rangeland rehabilitation or restoration projects. This technique is labor intensive and expensive. In addition, many sites are difficult to access with hydroseeding equipment or water trucks. Moreover, good seed to soil contact is generally not provided by incorporating the seed into the mulch on dry sites.

Establishing early seral native grasses and shrubs such as rubber rabbitbrush on burned or otherwise disturbed sites may reduce annual weed density and permit establishment of big sagebrush seeded at a later time. Summer precipitation occurring following the senescence of native herbaceous species may enhance big sagebrush establishment. Meyer and Monsen (1990) found evidence that previously establishing rubber rabbitbrush may have facilitated colonization of big sagebrush on a mined site in Nevada. Naturally reestablishing rubber rabbitbrush (*Chrysothamnus nauseosus*) invaded mine spoils at the Beacon Pit Mine that had not been covered with topsoil (Meyer 1994). Ten years

following disturbance, more than 60 percent of the rubber rabbitbrush plants were in the adult size class, while about 70 percent of the big sagebrush plants were less than 30 cm tall. This suggests that initial establishment of the rubber rabbitbrush may have ameliorated site conditions and facilitated big sagebrush establishment. Planting disturbed areas to rabbitbrush to enhance big sagebrush establishment is feasible and ecologically practical (Monsen 2000). Rabbitbrush can be established either by seeding or transplanting. It is capable of establishing and spreading to sites occupied by cheatgrass. Rabbitbrush plants aid in trapping snow, moderating temperature extremes, and accumulating litter, all beneficial for the big sagebrush seedling environment.

Nursery Stock

To enhance shrub and forb communities in the Intermountain West, container-grown and bareroot stock have proven effective for increasing diversity (Stevens 1994). Because of the expense, the usefulness of transplanting seedlings may be limited to small, critical areas, if high shrub densities are required. Bareroot planting stock should be from 12 to 20 cm tall and over-wintered in a nonheated nursery bed or lathhouse (Welch and others 1986). Long and Trimmer (2004) reported that at the Lone Peak Conservation Nursery, 1-0 big sagebrush seedlings are root pruned at a depth of 30 cm in August. Following February or March lifting, seedlings are graded to specifications of a minimum of 15 cm shoot length and 4 mm collar diameter.

Transplanting should generally be done in spring when soil moisture and the chance of storms are greatest, temperatures are low, and frost heaving has ceased (Deitschman 1974; Stevens 1981; Welch and others 1986).

While transplanting is more expensive than direct seeding, success is often much greater and more evident. The more edaphically or climatically severe the site, the greater is the need for transplanting (Stevens 1981).

Everett (1980) found that planting containerized shrubs, including mountain big sagebrush, in late winter (February) was a viable method of establishing vegetation in the harsh environment of roadside cutbanks in the Sierra Nevada foothills (Everett 1980). Initial establishment was highly dependent on quality of planting stock and weather conditions. In every instance where small or insufficiently hardened planting stock was used, survival rates declined drastically (Everett 1980). Tiedemann and others (1976) reported on the importance of adequate transplant size for survival of shrubs in eastern Washington.

Stevens and others (1981) found that bareroot stock of many native shrubs, including mountain big sagebrush, could be planted successfully with a hand-fed tree planter in scalps 0.6 m on a side and 0.2 m deep made in heavy grass sod. The transplanting rate varied between 10 and 18 plants per minute depending on plant species, size and condition of plants, soil type, and surface conditions. Shrubs were planted at spacings of 0.9 to 2.4 m. Establishment was greater for bareroot stock than for container-grown stock. Bareroot stock with roots 15 to 30 cm long and tops at least 8 cm long were most successful.

Seeding may also be accomplished by employing the "mother plant" concept—big sagebrush transplants are planted on a 15- by 15-foot grid. These "mother plants" mature and produce enough seed in 3 to 5 years to supply the seed for natural dispersal throughout site if native grasses are reestablished to reduce weedy competition (Welch and others 1986). Mechanical or chemical treatments may be necessary to reduce competition in strips or scalps at the time of planting.

Postseeding Management

On Bureau of Land Management lands, seedings are typically excluded from livestock grazing for two growing seasons to allow establishment. Stevens (1994) found that grazing pressure must be removed from newly planted or seeded areas for a minimum of 2 years. However, others have suggested that longer periods of rest from livestock and wildlife use are probably needed, particularly when attempting to reestablish shrubs such as big sagebrush (Fisser 1981). Protected plants develop more rapidly and natural spread from seed is hastened with longer protection. Shaw and Monsen (1990) stated that 2 to 3 years of protection from livestock grazing reduces seedling losses from grazing or trampling. Richardson and others (1986) compared grazed and ungrazed treatments 7 years after seeding mountain big sagebrush on a mid-elevation site in southeastern Idaho. They found significantly lower big sagebrush densities in the grazed treatment, an effect they attributed, in part, to trampling.

Stevens and others (1996) reported that 20 to 40 percent of big sagebrush transplants in seed orchards produce seed by the second year, and 80 to 90 percent by the third and fourth years. When seed orchards are established from seed, 10 percent of the plants can be expected to produce seed by the second year, 30 to 50 percent by the third year, and 80 to 90 percent by the fourth to fifth year. On wildland sites, longer periods may be required, particularly under drought conditions.

Plummer and others (1968) stated that planted areas must not be overgrazed. Until seeded stands have become established and suppressed natives have had an opportunity to recover and become reproductive, livestock grazing should be light if permitted at all. After range restoration has been accomplished, grazing should be conservative. Either fencing or management of animals is often necessary to give young plants adequate time to attain mature stature. Protection fences are installed to protect a new seeding from grazing and trampling during the establishment period and to manage established seedings (Interagency Burned Area Emergency Stabilization and Rehabilitation Handbook 2002).

Management is also required to restrict off-highway vehicles and other human activities that may impact seeded areas. Early weed control may be required to reduce the risk of seeding failure and spread or recovery of invasive species.

Monitoring Seeding Establishment

Appropriate monitoring protocols (for example, Elzinga and others 1998) should be selected to measure the extent to which seedings are successful in meeting management goals and to provide for adaptive management. Establishment and monitoring of unseeded controls and grazing exclusion plots on seeded and unseeded areas permit evaluation of

seeded species establishment, natural recovery, and the impacts of livestock grazing (Lysne, this proceedings; Lysne and Pellant 2004). Regular monitoring during the first few years postseeding, records of seed lot history (origin, quality, storage conditions) and seeding techniques applied, a site description, site conditions during the time of seeding, and weather records are invaluable for evaluating monitoring results, establishing the time required for individual species to reach reproductive status, determining readiness for grazing, and suggesting modifications for future seeding or planting efforts.

Conclusions and Recommendations

Big sagebrush and associated native species can be seeded on sites where seed sources have been lost and natural recovery is not expected to occur. Careful planning; acquisition of adapted, high quality seed; selection of seeding techniques appropriate for individual species as well as the combination of species selected; and careful post-seeding monitoring and management are all required to maximize seeding success, permit recovery of remnant native species, and maintain established seedings. Additional research and improved technology are required to solve problems related to maintaining and evaluating seed quality, providing seeding techniques that place big sagebrush seed in appropriate microsites for germination, and protect them from herbaceous competition, whether from co-seeded or invasive species. Low and erratic precipitation on drier big sagebrush sites often limits seeding success.

A major obstacle to the increased use of big sagebrush is the problem of obtaining adequate seed supplies of the required subspecies from adapted sites when needed. The difficulty of identifying the subspecies in individual seed lots, seed lots containing mixtures of subspecies, limited shelf life of big sagebrush seed, and inadequate cold storage space contribute to this problem. Efforts to delineate seed transfer zones for *Artemisia* taxa (Mahalovich and McArthur 2004) and a recent research initiative to select and manage wildland stands of Wyoming big sagebrush for seed production seek to address this issue. In situ conservation and protection of selected big sagebrush stands in areas where reseeding is likely to be required could increase the availability and quality of adapted seed.

Current literature and knowledge on seeding and establishment of big sagebrush subspecies have been summarized by Stevens and others (2004), McArthur and Stevens (2004), Lysne and Pellant (2004), and others. Seasonal habitat requirements for sage-grouse and recommendations for restoring degraded sage-grouse habitats are described in a number of publications including Connelly and Braun (1997), Connelly and others (2000), Crawford and others (2004), and Wambolt and others (2002). The SAGEMAP Project Web site (http://sagemap.wr.usgs.gov/sage_grouse.htm) provides a library of texts and databases for all aspects of shrub steppe and sage-grouse management in the Intermountain West.

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