Improving sustainable seed yield in Wyoming big sagebrush

by

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GRADUATE COMMITTEE APPROVAL

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ABSTRACT

Improving Sustainable Seed Yield in Wyoming Big Sagebrush

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As part of the Great Basin Restoration Initiative, the effects of browsing, competition removal, pruning, fertilization and seed collection methods on increasing seed production in Wyoming big sagebrush (*Artemisia tridentata* Nutt. spp *wyomingensis* Beetle & Young) were studied. Study sites were located in Idaho, Nevada, and Utah. A split-plot design with a complete factorial arrangement was implemented to determine the effects of the treatments. Removal of competition from Wyoming big sagebrush shrubs increased seed production significantly ($P \leq 0.05$) at both the regional and site levels, and yielded 300% more seed per m^2 (26.8 g/m^2) than shrubs without competition removal (8.5 g/m^2). Fertilization was significant ($P \leq 0.05$) at the regional level, and yielded 140 % more seed per m2 (21.1 g/m^2) than the unfertilized shrubs (14.2 g/m^2). Sites in different states varied in results, but the removal of competing vegetation stood out as the best method for increasing seed yield. Method of collection did not affect seed yield.

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Introduction:

This project was funded through the Great Basin Restoration Initiative (BLM 1999), which is an effort to restore damaged Great Basin ecosystems to their proper function before the problems associated with fire and unstable watersheds are so severe that they can not be repaired. While fire has always been an integral part of Great Basin ecosystems, many species native to the Great Basin are not tolerant of high frequency fire. The invasion of annual grasses such as cheatgrass, *Bromus tectorum* L., has increased the frequency and intensity of fire in these ecosystems to a point where the native grass, forb and shrub species can not be sustained (D'Antonio and Vitousek 1992).

Part of restoration is the reestablishment of native shrubs, integral to the proper function of these ecosystems (BLM 1999). There is great demand for supplies of seeds from native shrubs in the United States for revegetation efforts by federal agencies and private landowners. Policies associated with recent environmental legislation have included mandates to use native species, "plants naturally occurring that evolved with or migrated naturally to a particular environment or region and that were not introduced directly or indirectly according to historical record or scientific analysis," in revegetation projects where feasible (Richards et al. 1998).

Affordable and reliable seed supplies are especially critical for federal land agencies charged with managing our federal lands. Unfortunately, supplies of native seeds are often unavailable, or at least minimal, with prices beyond the limited budgets of land management agencies (Meyer 1994).

Due to the use of native species in restoration efforts, the collection of wild seed has become an important aspect of multiple-use on public lands. A thriving seed industry has developed around the collecting, processing, and sale of wild seed. Unfortunately the cost of this seed is often prohibitive because the seeds are hand collected, relatively scarce, and often not in available quantities adequate to revegetate large acreages disturbed by large wildland fires. According to Meyer (1994), "Nearly all big sagebrush seed sold has been collected from wildland stands." The establishment of managed shrub stands on federal lands for seed production has been presented as a partial solution to the problem of costly and often unavailable seed. According to Welch (2005), "to obtain the necessary volume of big sagebrush seeds for seeding onto a large disturbance where just a limited number of remnant plants exist, seed production gardens may be needed."

This project focused on quantifying the augmentation of seed production in native shrub communities, by manipulation of plants with various mechanical and chemical treatments to maximize seed production. We also evaluated the effects of various seed collection methods on shrub survival and seed production. If native seed availability can be increased, the high cost of these seeds may be reduced. This could allow for more effective revegetation efforts and sustained or increased biodiversity on public and private lands.

Materials and Methods:

Study Species

The shrub chosen for this study was Wyoming big sagebrush, (*Artemisia tridentata* Nutt. spp *wyomingensis* Beetle & Young). This shrub is native to North America. It has a wide distribution and is often included in native seed mixes for revegetation efforts (Booth and Roos 2003). This shrub is of particular concern to land management agencies because it is native to so many sites that need revegetation. Wyoming big sagebrush is not fire adapted, so it does not re-sprout or grow from the seedbank after wildfires (Hemstrom et al. 2002).

Wyoming big sagebrush is adapted to shallow, well drained, warm soils, and ranges from North Dakota and Washington to Arizona and New Mexico at elevations of 1520 to 2150 m (Mahalovich and McArthur 2004). It is wind pollinated, has small seed (2-3 mm long, 1 mm wide, obovoid, brownish, flattened, pubescent, resinous; pappus absent) with the inflorescence primarily above the shrub canopy (Stubbendieck et al. 2003). Sagebrush flowers in the late summer through mid fall, with fruit development commencing nearly simultaneously with flowering (Welsh et al. 2003). It sets seed in the fall usually between the first of October and the end of December (Welch 2005). Seeds shatter within one week after maturation, and a moderate-sized plant can produce 350,000 seeds per season, while a large mature plant can produce upwards of one million seeds (Goodwin 1956). Reproduction occurs largely when water is limiting and temperatures are extreme (USDA–NRCS PLANTS Database 2006). The seeds from big sagebrush are poorly developed for wind dispersal, and most seeds will disperse less than 30.5 m from the mother plant (Beetle 1960).

Where sagebrush is a major component of the ecosystem, several sagebrush obligate species exist: the sage thrasher (*Oreoscoptes montanus*), Brewer's sparrow (*Spizella breweri breweri*), and sage sparrow (*Amphispiza belli*), while many other birds and mammals have a facultative relationship with sagebrush. Welch (2005) identifies 91 bird species, 88 mammal species and 58 reptile species which have a facultative relationship with sagebrush. Wyoming big sagebrush is used heavily in the winter by big game (Tweit and Houston 1980), and is a very palatable subspecies of big sagebrush for big game species (Schlatterer 1973). When an area is revegetated using only introduced grass species, the animal component present in the natural community is often unable to be reestablished (Williams et al. 2002).

Study sites

This study consisted of three sites, one in each of three states, Utah, Idaho and Nevada (Fig. 1). The Utah site is located in central Utah (40° 05'42.26" N, 112° 35'29.66" W), approximately 8.5 miles west of Vernon, Utah, at an elevation of 1809 m. This site receives an average of 26.8 cm of total precipitation per year (Western Regional Climate Center 2007). It has Abela very gravelly loam soil (Web Soil Survey 2006). The Idaho site is located in south central Idaho (42° 25'24.26", 115° 15'42.40" W), approximately 36 miles northwest of Rogerson, Idaho, at an elevation of 1484 m. This site receives an average of 25.5 cm of total precipitation per year (Western Regional Climate Center 2007). It has Arbidge-Buncelvoir-Chilcott complex loamy soil (Web Soil Survey 2006). The Nevada site is in Ruby Valley (40° 17'18.22" N, 115° 27'42.16" W), approximately 42 miles southwest of Elko, Nevada, at an elevation of 1824 m. This site receives an average of 33.7 cm of total precipitation per year (Western Regional Climate Center 2007). It has Pyrat-Tosser association loamy soil, and has a slightly saline component within 76 cm of the soil surface (Web Soil Survey 2006). The site selection was coordinated through Utah State Lands, the US Department of the Interior (USDI) Bureau of Land Management, and the US Department of Agriculture (USDA) Forest Service, respectively, for Utah, Idaho and Nevada. All appropriate clearances were obtained and surveys completed prior to the initiation of the project.

Experiment 1

The first aspect of this study focused on testing methods for improving seed production in Wyoming big sagebrush. At each site a split plot design with a complete factorial arrangement was used to determine any interaction between the treatments. The treatments were competition removal, selective pruning, and fertilizer application. The complete design (Table 1) was replicated on five shrubs at each site for each treatment combination. For the regional analysis, meaning all sites combined, the three sites were considered the replications using the mean of the five replicates for each treatment. The by-site analysis used the five replicate shrubs at each site as the replications.

The plot was split between a grazed and non-grazed treatment. Approximately 1/2 ha exclosures were established within grazing allotments to exclude large herbivore grazing or browsing in order to determine any effects that grazing or browsing may have on these treatments. These 2.6 m tall exclosures were constructed with wire mesh field fencing, and measure approximately 70 m on each side. The treatments to increase seed production were applied inside and outside of the exclosures.

The first treatment applied to the shrubs was the removal of all competition from adjacent plants. All woody and herbaceous material was removed from the perimeter and understory of the shrub out to approximately one meter radius from the drip line of the shrub. The removal of the competing woody shrubs was accomplished with a chainsaw or pruning loppers, and the herbaceous material was removed with non-selective herbicide (Round-up or Gly-4 [Isopropylamine salt of glyphosate, 41 %]) applied each spring. Since water is a limiting resource in arid Great Basin environments, removal of plants in direct competition for water resources may encourage seed production on sample units.

The second shrub treatment to attempt to increase seed yield was selective pruning of the lowermost limbs and decadent branches on the shrub. The dead or decadent branches were all removed, and the live branches near the base of the shrub were removed to allow the reallocation of resources to the upper canopy's flowering leaders.

The third shrub treatment to attempt to increase seed yield was broadcast application of a 25-5-10 slow release fertilizer with 4.8 % iron. This is a standard commercially available fertilizer with nitrogen derived from: urea, ammonium sulfate, ammonium phosphate, and sulfur coated urea; phosphorous from ammonium phosphate; and potassium from muriate of potash. Iron was from iron sucrate which is more available to plants. Fertilizer was applied over the root zone of the shrub, approximately 1 m^2 around the base of the shrub. This fertilizer was hand applied at the recommended rate 39 g/m^2 in the spring of 2004, 2005 and 2006. Soil samples from control shrubs and fertilizer treated shrubs were taken in the fall of 2006 and sent to the Brigham Young University soils analysis lab. They were analyzed for soil nutrients using standard analysis methods (AOAC 1995).

Experiment 2

The second aspect of this study was to determine the effects of aggressive seed collection on subsequent year's seed yield. Treatments consisted of methods of seed collection that imitate two different collecting practices (USDA–NRCS PLANTS Database 2006). The two treatments included beating and hand clipping. Beating is a standard practice which involves collecting seed by beating the shrub with a flail, such as a tennis or badminton racket, and catching seed in a hopper (Mahalovich and McArthur 2004). Hand clipping involves clipping the inflorescences with shears. The seed collection experiment was only applied within the exclosure to eliminate any confounding affects caused by large herbivore damage to treated shrubs. Grams of pure seed collected were quantified and compared for each collection method.

Methods Modification

During data collection in the fall of 2005, an unforeseen treatment effect was observed. The seeds on the shrubs treated with the mechanical and chemical treatments ripened before those on the untreated shrubs. Due to this accelerated, and uneven, ripening of seeds most of the seeds on the treated shrubs had already shattered when seed collection was attempted.

In 2006, in order to compensate for the accelerated and uneven ripening effect observed in 2005, fine mesh bags (ankle-length nylon stockings) were placed around the inflorescences and secured with a nylon zip-tie to capture any seeds that ripened and shattered before collection. These bags were put on the inflorescences after flowering and pollination, but before seed ripening.

The length and weight of each bagged inflorescence was measured while still in the bags, since removing the bags caused much of the seed to come off. The bags and nylon zip-ties were saved and weighed together, and then this value was subtracted from the sum of the combined inflorescence and bag weights to get the true average weight of the inflorescences.

In order to standardize the seed yield to the size of each treated plant, a sub-sample of the inflorescences on each shrub was collected. Six bagged inflorescences were collected from each shrub. The average of the seed produced per inflorescence was calculated, as well as the amount of seed from each shrub based on the sub-sampling and a count of the inflorescences on the shrub. This sub-sampling was done by dividing the shrub canopy into four sections and randomly choosing one section in which to count the inflorescences. Calculation for Seed per m^2 per shrub was as follows:

Inflor per shrub (inflor/shrub) = inflorescences (inflor) per section * 4
Shrub canopy area (m^2) = Canopy length (cm) * canopy width (cm) ÷ 10,000
Inflor per m^2 (inflor/m^2) = Inflor/shrub ÷ shrub canopy area (m^2)
Average weight of pure seed (g) per inflor = Sum of inflor weights (g) – bag and tie weight (g) ÷ number of inflor
Seed per m^2 per shrub = Inflor / m^2 * Average weight of pure seed (g) per inflor

The seed cleaning process involved removing the bag from the inflorescence over a stainless steel beaker, 30 cm diameter and 30 cm deep. The inflorescence was vigorously beaten against the sides of the beaker to shake free any remaining seeds, and the material in the bag was dumped into the beaker. This material was then sifted using a round screen, with .18 cm round openings, to sift the seeds from the larger flower materials. This material was weighed and then cleaned in a seed blower, Hoffman Seed Blower Model 67-HMC (Hoffman Manufacturing Inc). The blower uses a fan that blows the seeds and other material up into a glass tube to separate the heavier seed from the lighter flower parts that were not caught by the screen. The heavier seed stays in the tube, while the lighter material is blown into a hopper. The hopper was checked after each sample for seeds that may have been blown into the hopper. The cleaned seed material was then weighed.

The blower gave varying degrees of seed purity. This was due to the variation in the types of plant material that made it through the initial screening. Nearly all of the flower parts were blown out of the blower, but some stem and other vegetative materials were heavy as or heavier than the seed, so they remained in the machine-cleaned samples. In order to correct for this variation, a sub-sample of 70 samples was carefully cleaned by hand to separate the seeds from the remaining chaff. The seed weights were determined by subtracting the chaff from the total weight of the machine-cleaned sample. This correct seed value was regressed with the machine-cleaned seed weight. The regression equation was

y (pure seed in grams) = 0.7472x (machine-cleaned seed in grams) - 0.1483, R^2 = .9757.

This equation was used to correct the machine-cleaned seed weights to obtain the actual weight of seed in each sample (Fig. 2).

Due to the unforeseen ripening effect, the only data that was collected in 2005 was inflorescence and leader length and weight data in Utah. The Idaho and Nevada sites had all of the inflorescences damaged in the initial collection. These data were compared to the length and weight data collected in 2006. It was hoped that the length, weight or both would correlate to seed production in 2006 and that inferences could be drawn about 2005 results.

Statistical Analysis

These data were statistically analyzed using the SAS (SAS 2006) mixed model procedure. For all analyses, $\alpha = 0.05$ was used for statistical significance. The Tukey method was used for mean separation.

Experiment 1 used two models to determine treatment effects on grams of seed per meter^2, a regional model, which used the four treatments (browse, competition removal, pruning, and fertilizer) as fixed effects and the sites as the random variable. The site model analyzed each site individually, using the four treatments as fixed effects, and the 5 shrub replicates at each treated site as the random variable.

Experiment 2 was analyzed to compare the effects of the two collection methods, beating and hand clipping. The fixed effects for this model were the sites and the treatments, beating and hand clipping. The random variable was the replicates at each site.

Results

During both the 2005 and 2006 collection periods, damage to the inflorescences and leaders of both treated and untreated shrubs was observed. These inflorescences and leaders were observed lying on the ground, cleanly clipped from the plant (Fig. 3). Various rodents and black-tailed jackrabbits (*Lepus californicus*) were observed in the area regularly eating inflorescences of both treated and untreated shrubs. Incisor marks were observed on the bases of these parts. This occurred both within and without the exclosure, and decimated the inflorescences to be collected in 2005 and some inflorescences in 2006.

Experiment 1

In the application of treatments to increase seed production, the regional model showed that only two treatments had significant effects on seed production. The removal of competition was significant across all sites. Shrubs with competition removal yielded

300 % more seed per m^2 (26.8 g/m^2) than shrubs without competition removal (8.5 g/m^2) (Fig. 4). Application of fertilizer was also significant. Application of fertilizer produced 140 % more seed per m^2 (21.1 g/m^2) than the unfertilized shrubs (14.2 g/m^2) (Fig. 4).

Removal of competition significantly increased seed production at each site. In Idaho, competition removal yielded more than 600 % more seed (24.9 g/m^2) than shrubs without competition removal (3.9 g/m^2). At the Nevada site, removal of competing plants yielded more than 250 % more seed (19.5 g/m^2) than shrubs without competition removal (7.6 g/m^2). At this site, shrubs in the browse treatment yielded more than 200 % more seed (18.4 g/m^2) than those within the exclosure that had no ungulate browsing (8.7 g/m^2). In Utah, competition removal and the browse/fertilizer interaction were significant. Competition removal yielded more than 250 % more seed (35.9 g/m^2) than shrubs with no competition removal (13.9 g/m^2). Unbrowsed and fertilized shrubs had more than 100 % more seed than the other combinations (Fig. 5).

When the seed is fully developed, it shatters within a week (Goodwin 1956). This factor caused the loss of all of the data which would have been collected in 2005. Attempts to salvage 2005 data using regression of 2006 inflorescence weights and seed yield were unsuccessful. Data will again be collected in 2007 using the same methodology as 2006.

Experiment 2

No significant differences were found in the grams of seed collected among different collection methods, at either the regional or site scale. It is interesting to note, that while not significantly different, at the regional scale the hand clipping treatment yielded 1.6 g of seed per shrub on average, and the beating treatment yielded an average of 0.8 g of seed per shrub. Much of the seed had shattered prior to the data collection for experiment 2, which accounts for the lower seed yields compared to experiment 1. Results at the site scale were inconclusive.

Discussion

Rodent damage

Parmenter et al. (1987) studied the effect of rodent damage on big sagebrush in Wyoming and found that 3 species of rodent regularly feed on sagebrush: the long-tailed vole (*Microtus longicaudus*), the deer mouse (*Peromyscus maniculatus*), and the sage vole (*Lagurus curtatus levidensis* (Goldman)). According to Parmenter et al. (1987) the long-tailed vole and the deer mouse both feed on the bark and cambium of sagebrush when green vegetation is not available and the sage vole feeds on sagebrush regularly, but was not responsible for winter shrub damage. The deer mouse uses the bark of sagebrush to line its nests (Parmenter et al. 1987). McAdoo et al. (1987) compared jackrabbit use in new and old range seedings and documented jackrabbit preference for crested wheatgrass (*Agropyron cristatum* [L.] Gaertn) seedings. Our Idaho site, which had the worst inflorescence damage, is adjacent to a crested wheatgrass stand.

Effects of grazing and browsing

The removal of grazing can benefit shrub communities. Comparisons of sagebrush on reclaimed mine-land and rangeland showed that fencing decreased browsing of inflorescences and increased seed production, although seed quality was not affected (Booth et al. 2003). Anderson and Holte (1981) found that grazing removal on the Idaho National Engineering Laboratory (INEL) in southeastern Idaho produced a 154

% increase in sagebrush cover in 25 years. The exclusion of grazing can increase the amount of plant material produced (Yeo 2005). Mule deer were found to prefer Wyoming big sagebrush over all other sub-species of big sagebrush except for mountain big sagebrush, and sagebrush composed as much as 52 % of mule deer diets in winter (Wambolt 1996). Wambolt (1996) also noted that many of the study sagebrush shrubs that were browsed in winter did not survive. Austin et al. (1994) found that shrub survival decreased with both mule deer browsing and horse grazing. Mule deer browsing was found to increase mortality on mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana* [Rydb.] Beetle) in Utah (McArthur et al. 1988). Sagebrush stands protected by fencing were found to yield more seed than unprotected stands in Wyoming mine reclamations (Booth and Roos 2003). Flowering in big sagebrush can be completely eliminated with even minimal browsing of terminal buds where flowers are produced (Bilbrough and Richards 1993).

Grazing did not have a significant regional effect in this experiment, but in both Nevada and Utah there was an effect shown for those sites. This experiment did not regulate the amount of grazing, nor did it impose a grazing treatment. The sites were merely located within public grazing allotments with the expectation that grazing would occur, but they were not grazed by the same class of animal, nor were they grazed at the same rate. The Idaho site was grazed by cattle, but the treated area was near a crested wheatgrass stand. Cattle were seen grazing in this area in the early summer of 2006, but no evidence of grazing was observed in 2005. The study site was probably not grazed heavily due to its proximity to a stand of grass.

The Nevada site had a much unexpected response to grazing. The treatment area open to grazing showed a positive response to the grazing treatment rather than the ungrazed exclosure. Shrubs that were open to grazing and browsing produced 200 % more seeds per m^2 than shrubs that were protected from grazing. This is contrary to the expected outcome based on literature and the outcome of the other sites. No animals were seen grazing or browsing at this site, so there may not have been a treatment imposed. Also, small mammals were seen eating inflorescences inside of the exclosure. This was not observed outside of the exclosure. These small mammals may have exhibited a preference for shrubs within the exclosure because of the protection it afforded from predators, which may explain the results, but without more data, these results are unexplainable.

The Utah site was grazed by sheep in the early summer of 2006. It showed an interaction between browsing and fertilization. It is obvious from these results that the removal of grazing and browsing, along with an application of fertilizer, increased seed production in Utah.

As Bilbrough and Richards (1993) suggested, even minimal browsing can damage flowering in sagebrush. Aside from the anomalous results of grazing exclusion in Nevada, our study and the majority of the literature suggests that the removal of large herbivore grazing or browsing is beneficial to sagebrush seed production.

Competition Removal

In this study, competition removal was the most effective treatment for increasing seed yield in Wyoming big sagebrush. This treatment was significant both regionally and at each site. Since the availability of water is a major limitation for plant growth on arid lands, it follows that the removal of plants in direct competition for water increased seed production in the remaining shrubs. Blaisdell (1949) studied competition between sagebrush and grasses in new grass seedings in sagebrush stands and found that "…competition between sagebrush and grass was the chief factor influencing their relative yields rather than the inability of the plants to become established." Hubbard (1957) reported that the elimination of grass competition on bitterbrush seedlings increased survival and production significantly. The Utah and Idaho sites in this study received an average of less than 27 cm of annual precipitation (Western Regional Climate Center 2007). The Nevada site received over 33 cm, but has a saline layer near the surface. The electrical Conductivity (EC_e) was reported as 2.0 to 4.0 mmhos/cm, at this salinity level the growth of sensitive plants may be restricted (Western Regional Climate Center 2007 and Web Soil Survey 2006). The shrubs that would have competed for the deeper water such as other sagebrush plants were removed, and the grasses and forbs that compete for water in the moist spring and early summer were also removed. This likely allowed the target shrubs to utilize previously unavailable water resources, while those with the competing plants left in place did not have this benefit. Wyoming big sagebrush has a layered root system, both a deep taproot and shallow lateral roots. The deep root system allows big sagebrush to utilize deep water from winter recharge, while the lateral root system allows it to utilize infrequent summer rainfall (Donovan and Ehleringer 1994). Donovan and Ehleringer (1994) also found that rubber rabbitbrush (*Chrysothamnus nauseosus* [Pall.] Britt.) was the least water stressed of the shrubs they studied. All of our sites had rubber rabbitbrush that was removed from the perimeter of targeted big sagebrush plants. Since both are efficient water users, the removal of one would certainly benefit the other. Cline et al. (1977) found that cheatgrass stands exploited 8 cm of soil water during the growing season, while sagebrush/bunchgrass stands exploited 15 cm of soil water per growing season. With limited soil water available each growing season, and with cheatgrass and other annual and perennial grasses competing with sagebrush for water, each would suffer. The removal of both grasses and competing shrubs helped increase seed production of target shrubs. This treatment has application for large scale herbicide control of annual species and for shrub thinning (Petersen and Ueckert 2005).

Pruning

Very little research has been done on the effect of pruning on sagebrush seed production. The pruning of new leader growth has been used to simulate moderate browsing, which has increased twig growth in bitterbrush (Bilbrough and Richards 1993). Other researchers have found that moderate to heavy browsing increased twig growth, but damaged flower growth and seed yield (Garrison 1953).

Our treatments did not mimic the pruning effect of browsing. Rather, the lower branches were trimmed to facilitate seed collection and all dead and decadent branches in the canopy were removed. The pruning treatment of decadent branches and lower limbs had no effect on seed production. It was originally thought that pruning of lower branches would allow for better collection using bins to beat seed into for collection. Since the collection methodology was changed to prevent data loss following the 2005 season, this potential benefit was not realized. Coombs et al. (1992) suggested that limb removal of unproductive plant parts may allow a reallocation of resources to more actively growing plant tissue. This increase was not observed at the regional or site scale.

If vegetative production is increased by pruning, and initially reduces seed production, it follows that increased photosynthetic material may translate into increased seed yield in subsequent years. The pruning treatment may still show an increase in seed yield in future year's production.

Fertilizer application

Petersen and Ueckert (2005) reported that application of nitrogen fertilizer increased seed production in dryland stands of fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.). Spring applications of nitrogen increased sagebrush seed production in Cache County, Utah (Bayoumi and Smith 1976). The deficiency of nitrogen on range sites has been established as a significant growth-limiting factor in rangeland production (Rogler and Lorenz 1974). Fertilizer application significantly increased seed production on a regional scale (+140 %) and was more effective on unbrowsed shrubs.

Fertilizer application can enhance seed yield, and broadcasting may be the most economical delivery method for fertilizer application on a large scale. Broad scale range fertilization has not been a common practice due to high costs and possible ecological impacts (Wight and Black 1979). The fertilizer in this study focused the application around the shrub. This eliminated the waste of fertilizer on other species, which would occur with a broad application. Though time consuming, application of fertilizer on a small scale may be more economical and reduce possible negative ecological impacts, such as encouraging herbaceous growth and water use.

Welch (2005) suggested that broad application of fertilizer may also enhance growth of weedy species which may become the sole nutrient beneficiaries, or also increase competition for water resources. Wight and Black (1979) reported a 114 %

increase in herbage production in average years with fertilizer application. This was also observed to be the case in our study. Visual observation at each site showed that cheatgrass and other annual grasses were much taller under shrubs that had fertilizer applied than those without fertilizer application.

If competition removal is not feasible, fertilization of sagebrush stands increases the production of sagebrush seed, but to be most effective and cost efficient, fertilizer should be applied only to the target shrubs.

Collection Methods

While no significant differences in seed yield were found with beat collection versus hand clipping collection methods, we did notice that some of the shrubs which had seed collected by beating were becoming decadent, or in some cases dead or nearly so. It may become evident upon data collection in subsequent years that the shrubs from which seed is collected with the beating method stop producing seed due to damage to the shrub, or die. If mortality does occur, collection from sagebrush seed gardens will need to utilize a less destructive method, such as hand clipping. Hand clipping removes only the deciduous inflorescence stems not perennial vegetative matter.

Management Implications

The removal of competing vegetation was the most effective method of increasing seed production in Wyoming big sagebrush. Utilizing this treatment, shrubs produced more than 26 g of seed per m^2, which yields between 3100 to 4500 seeds per gram (Young and Young 1992 and Bai et al. 1997). Unfortunately, the competition removal treatment was the most labor intensive and time consuming. Each shrub had to be manually treated, both with herbicide and by removing other shrubs. This treatment would require significant labor inputs. If manual competition removal is not available or feasible, broad scale application of herbicide that would leave a percentage of the big sagebrush intact, while removing competition would need to be employed. McDaniel et al. (2005) reported that using Tebuthiron to control sagebrush gave 80 % to 90 % control. This level of control would kill too much of the sagebrush to be beneficial for seed collection. If herbicide is used, selective application, rather than broad application may need to be utilized.

Regardless of the initial method used to remove competition, control of annual grasses and forbs would still need to be practiced each year. Thelenius and Brown (1974) reported that the application of 2,4-D (2,4-Dichlorophenoxyacetic acid) reduced canopy cover of sagebrush by 8 % to 42 %, but this was replaced with increased grass production. Visual observation at each site confirmed this in our study. If competition from annual grasses and forbs increases, the benefit achieved from competition removal would be negated in the years following application.

Most importantly, if sagebrush seed is to be collected from a particular treated stand, the seed on the treated shrubs needs to be monitored as flowering ends and seed development begins. We found that sagebrush seed shatters rapidly after it is fully developed.

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Tables

Table 1 Treatment matrix. Split-plot design with a complete factorial arrangement. Complete design was applied to five shrubs per browse treatment at each site.

Treatment matrix				
Split				
browse	1	competition removal	selective pruning	fertilizer
	2	competition removal	selective pruning	NO fertilizer
	3	competition removal	NO selective pruning	fertilizer
	4	competition removal	NO selective pruning	NO fertilizer
	5	NO competition removal	selective pruning	fertilizer
	6	NO competition removal	selective pruning	NO fertilizer
	7	NO competition removal	NO selective pruning	fertilizer
	8	NO competition removal Control	NO selective pruning	NO fertilizer
No browse	1	competition removal	selective pruning	fertilizer
	2	competition removal	selective pruning	NO fertilizer
	3	competition removal	NO selective pruning	fertilizer
	4	competition removal	NO selective pruning	NO fertilizer
	5	NO competition removal	selective pruning	fertilizer
	6	NO competition removal	selective pruning	NO fertilizer
	7	NO competition removal	NO selective pruning	fertilizer
	8	NO competition removal Control	NO selective pruning	NO fertilizer

Figures

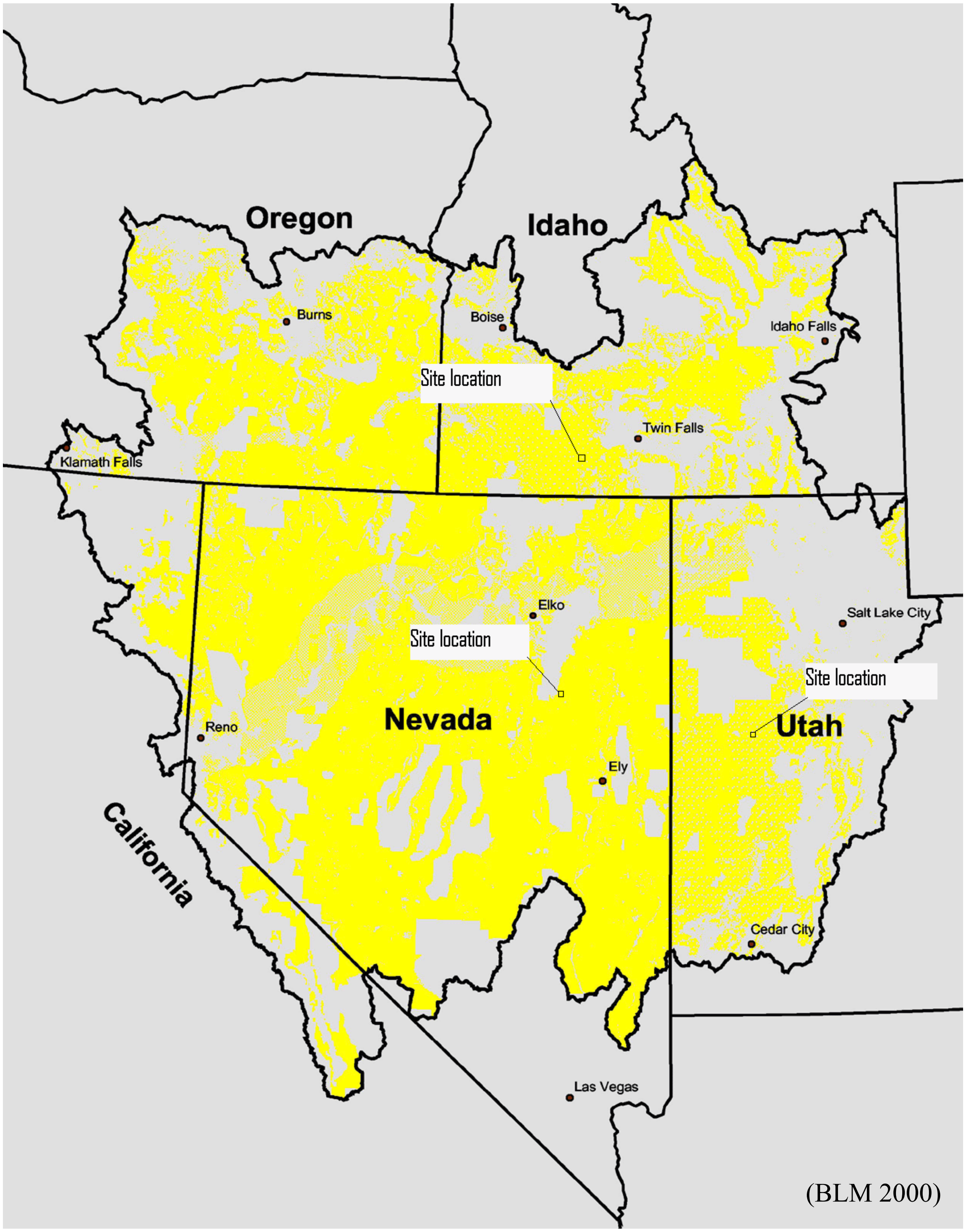

Figure 1 Study sites were located in Utah, southeast of Eureka, in Idaho, northwest of Rogerson, and in Nevada, in the Ruby Valley.

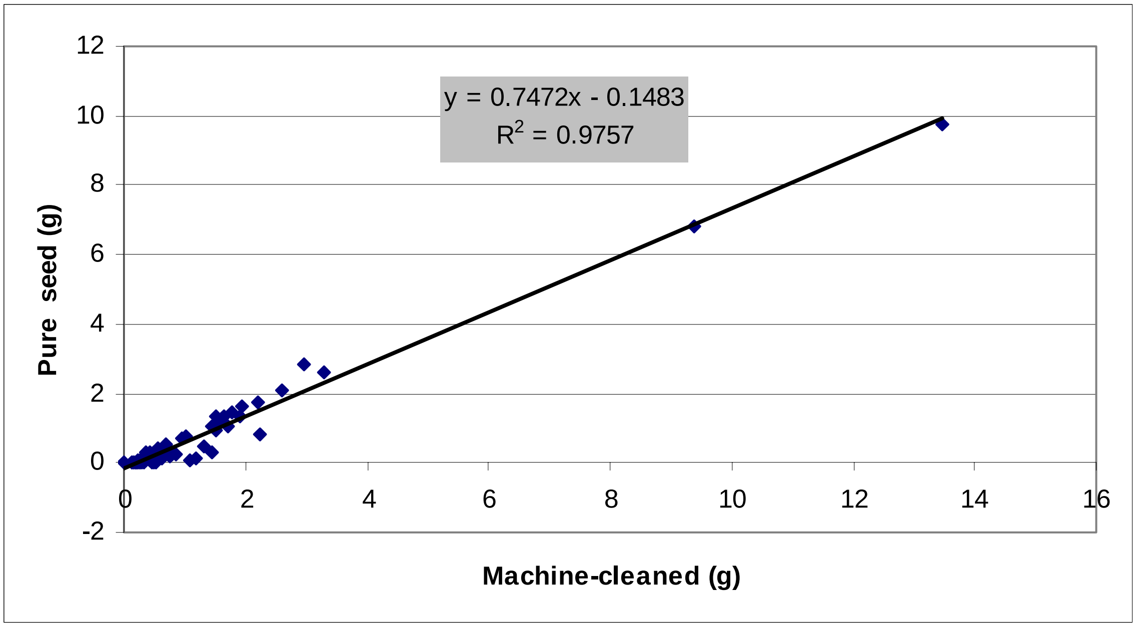

Figure 2 Correlation of machine-cleaned seed and actual seed weights (n = 70). This regression was used to correct all samples to pure seed weights.

Figure 3 Clipped inflorescences. At all sites, in both years, both rodents and jackrabbits clipped both inflorescences and new leader growth from the plants. No preference to our treatments could be determined as both treated and untreated plants were affected

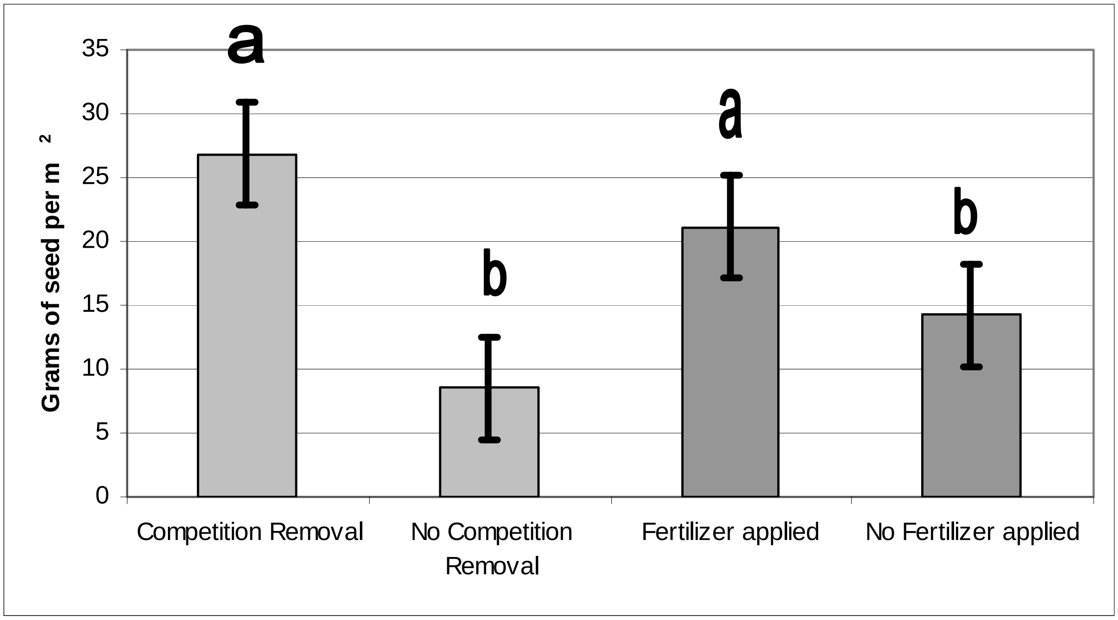

Figure 4 Regional treatment effects for experiment 1, seed increase treatments. Shrubs with competition removed yielded 300 % more seed per m2 (26.8 g/m2) than shrubs without competition removed (8.5 g/m2). Application of fertilizer was also significant. Shrubs which had fertilizer applied produced 140 % more seed per m2 (21.1 g/m2) than the unfertilized shrubs (14.2 g/m2).

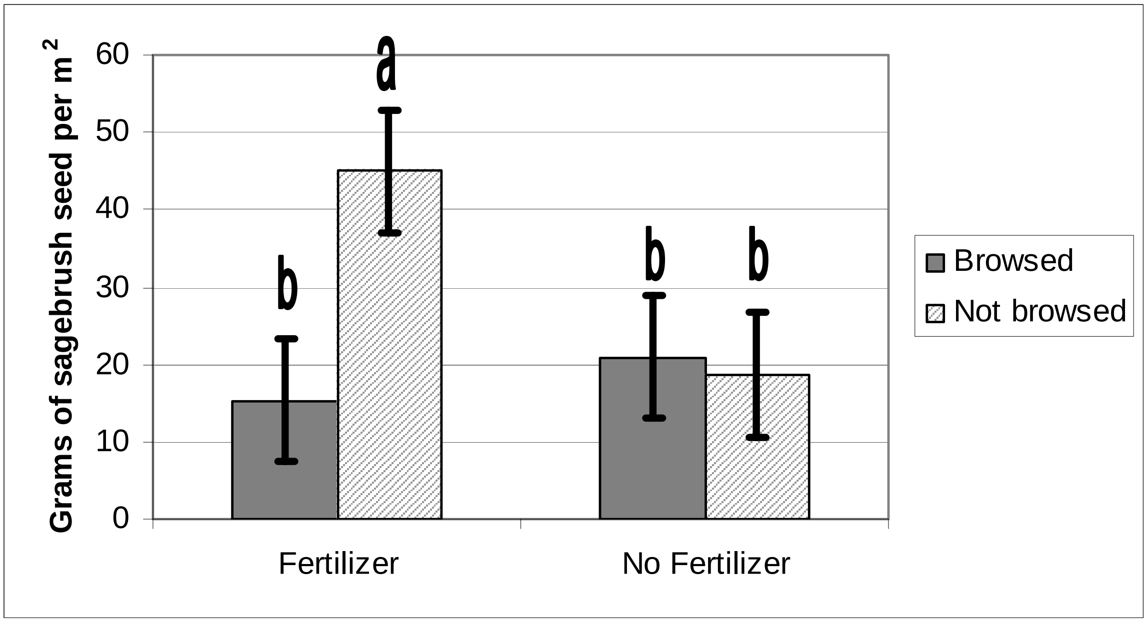

Figure 5 Utah site interaction between browse and fertilizer treatments. Protection from browsing and fertilizer application had the highest yield by more than 200 %, though the means are not significantly different than means of other treatments.