RESEARCH ARTICLE

A Community Participatory Project to Restore a Native Grassland

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ABSTRACT: This unique project invited community members to test sustainable techniques for restoring a weed-infested field to a native grassland community. In a cultivated *Bromus inermis* grassland at The Arboretum at Flagstaff, Flagstaff, Arizona, we randomly assigned 144 plots to weed removal and recovery treatments. The experimental design had 12 replicate plots assigned to organic herbicide, weed barrier fabric, manual removal, or control for the weed removal factor; it had seeding, plugging, or no action for the recovery factor. College, middle and high school students, and community members collected and propagated native seed, implemented restoration treatments, collected plant community data, and learned methods for implementing restoration in their own backyards. We quantified percent cover of smooth brome, other exotics, and native species cover and richness. Although no treatment completely removed *B. inermis*, manual removal was the most effective treatment for significantly reducing *B. inermis*, while significantly increasing native species richness and cover. Weed barrier fabric followed as the second most effective method, and organic herbicide was ineffective. After three months, neither seeding nor plugging significantly affected native cover. A longer response time and irrigation may improve recovery treatment success.

Widespread community support made this project possible. Post-activity evaluations indicated that students gained an appreciation and working knowledge of restoration. The goal to engage citizens in a project that will become a locally adapted seed resource for future restoration projects has shown promise in its first year, but will require more input before a weed-free native seed resource is realized.

Index terms: Bromus inermis, native seeds, public education, restoration, sustainability

INTRODUCTION

Invasive species negatively affect the environment and the economy. They often alter plant species richness, diversity, and/or composition (Alvarez and Cushman 2002). Weeds are spreading at the rate of about 81 ha per hour on western federal lands, costing the United States $1 billion annually (Howery and Ramos 2000). Departments of Agriculture in 11 western states estimate that there are about 28,327,995 ha of weeds on private, state, and federal wildlands (Asher 2001). Introduction of non-native, weedy species continues today because of increased domestic and international travel, vehicular disturbance, road building, and various forms of recreation including, but not restricted to, biking, boating, hiking, and hunting. Ironically, some invasive exotic species were introduced purposefully with the intention of benefiting people (see examples in Devine 1998). Regardless of origin, once a community is dominated by invasive species, it becomes difficult to reestablish a more diverse flora (Maar 1993). Plants that become invasive have the potential to reduce biological diversity within ecosystems and, in the extreme case, to threaten and endanger native species (Mack et al. 2000, Pimentel et al. 2000).

Because of the direct and indirect costs of land degradation, homeowners and business owners share a vested interest with public land managers in restoring private properties with native plants while reducing invasive plants. Restoring these compromised lands will require a great deal of time, money, and effort. Restoration education will help facilitate the public's working knowledge of the most suitable methods for eradicating exotics and bringing a landscape back to a more desirable condition.

In the early 1960's, on land that would later become The Arboretum at Flagstaff (a public botanical garden), a caretaker deliberately planted smooth brome, *Bromus inermis* Leyss. into one hectare of a 40-ha native grassland to provide forage for the landowners' cattle. *B. inermis* is a rhizomatous cool-season deep-rooted perennial grass from Eurasia that was introduced to the United States in the 1880's for erosion control and cattle forage (Coleman 1987, Blankespoor and May 1996). It is well adapted to arid conditions and is highly competitive in mountain valleys of the western United States (Elliot 1949, Hull 1974, Wasser and Dittberner 1986). Over the past 40 years, *B. inermis* has spread at The Arboretum at Flagstaff clonally and by seed, expanding beyond the cultivated pasture 91 m into the native grassland, creating a visual monoculture, and greatly reducing the diversity of the original grassland. While *B. inermis* is not listed as noxious in the state of Arizona, it is considered an invasive plant.

As part of a new vision for "Sustainable Living on the Colorado Plateau," in 2001, The Arboretum at Flagstaff initiated a community-based restoration program to restore the cultivated grasslands on the property to a native grassland community. The intention was to create an educational showcase for sustainable restoration techniques, to involve community members, and to expand a natural area that would support native plants and animals. Long-term goals of this project were to: (1) harvest native seed from the existing native grassland for use in restoration, (2) convert, using sustainable techniques, the *B. inermis* grassland to native grassland that will provide seed of local genotypes for local restoration projects, and (3) train community members to do restoration activities on their own property. With U.S. Forest Service plans to restore 40,469 ha of ponderosa pine forest in the Flagstaff area to more open, less dense forest using thinning and controlled burns, there is a great need for reducing the spread of exotics from private lands and for creating a locally adapted seed source for restoration projects.

The Arboretum grassland restoration project had both educational and research components. The educational component intended to provide students an opportunity to think about and participate in research that addressed a critical local and global issue (i.e., Howard and Rhoads 1998). We believed that student researchers could benefit the community by applying information they learned on invasive species, and they would have an influence in their own environment by assisting practitioners in solving immediate and pressing problems (McKernan 1991).

Nearly every aspect of the research and work enlisted the services of interested community members, educators, and students. We invited elementary, middle school, high school, and college students to participate in restoration research in the *B. inermis* grassland. Of the 1600 participants, approximately 750 were students from local high schools in grades 9-12, around 400 student researchers came from Northern Arizona University and Coconino Community College, and the remainder came from grades 5-8. Over 25% of these individuals were of Native American, Hispanic, or African American ancestry.

The research component tested which of three removal and two recovery techniques were most effective in converting a grassland dominated by *B. inermis* to a native plant community. We tested sustainable techniques that would have potential for use in situations where traditional herbicides would be unacceptable and compared these to controls where no action was taken.

METHODS

Study Site

We conducted this research in a 1-ha *B. inermis* cultivated pasture on the grounds of The Arboretum at Flagstaff (2179 m elevation), approximately 7 km southwest of Flagstaff, Arizona. Adjacent to the cultivated pasture are 40 hectares of native grassland characterized by *Festuca arizonica* Vasey, *Muhlenbergia montana* (Nutt.) A.S. Hitchc., *M. wrightii, M. rigens, Blepharoneuron tricholepis* (Torr.) Nash and *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths. The cultivated pasture lies within a 2.5 m tall elk exclusion fence surrounding the entire study site; therefore, mule deer (*Odocoileus hemionus* Rafinesque), elk (*Cervus elaphus* Erxleben), and pronghorn (*Antilocapra Americana* Ord) were excluded from the study plots, allowing us to examine vegetation changes independent of the influence of herbivory (i.e., Arnold 1950, Maschinski 2001). Soils are silty clay loam of basalt origin with pH 6.6-7 and have a high capacity to hold water.

In northern Arizona, cold winters, warm summers, and bi-seasonal precipitation generally characterize the climate. Precipitation can fall as snow or rain from November through April; it is usually minimal or absent in May and June; monsoon rains usually occur July through September. In the last 100 years, average annual precipitation has been approximately 350 mm; however, in the past seven years, the southwestern U.S. has experienced severe drought unprecedented in the past 100 years (Ghioto 2003, Kipfmueller 2003, CPLUHNA 2004). During the study years, 2001-2002, Arizona experienced a mega drought, where < 75% of average precipitation fell (Comrie 2003). Thus, this study occurred during an extreme weather event.

Restoration Treatments

To test the effectiveness in eradication of the smooth brome, we randomly assigned 144 plots to weed removal and recovery treatments. The experimental design had 12 3-m x 3-m replicate plots assigned to: (1) Organic Herbicide; (2) Weed Barrier Fabric; (3) Manual Removal; or (4) Control for the weed removal factor; and (1) Seeding, (2) Plugging, or (3) No Action for the recovery factor. Because the weed removal techniques we used disturbed the ground, the process of removing *B. inermis* potentially opened niches for opportunistic exotic and native species (Masters et al. 2001); therefore, we measured the response of native and exotic species to our treatments. A buffer path, mown every two months, separated plots approximately 1 m distant from each other, provided easy access to all plots by student researchers, and prevented plants from going to seed and thereby influencing the plot vegetation (i.e., Foster and Gross 1998).

In the autumn of 2001, interested community members, educators, and students assisted with gathering pre-treatment data on species abundance and cover. To ease determining percent cover, students used a 0.25 m^2 sampling quadrat made of PVC pipe divided into 100 interior squares with fishing line. All classes learned local plant identification and used plant ID guides with the assistance of Arboretum scientists to ensure quality in data collection. Students tossed two non-overlapping quadrat samplers randomly into each test plot a minimum of 0.4 m from each plot's edge and recorded plant species, abundance of each species, and the number of boxes within the quadrat covered by each species. They translated number of boxes within the quadrat into percent cover. Students marked the position of each sampled area with border nails placed in each corner of the quadrat. Arboretum scientists mapped quadrat locations for purposes of future measurement.

In the spring of 2002, we implemented three weed removal techniques and had many volunteers assisting us in this process. Students cut and positioned 28-mm weed barrier fabric on selected plots and placed sod staples to secure the black fabric in place for a period of 90 days. Weed barrier fabric is permeable to water, but excludes light, cutting off the photosynthetic processes of underlying plants. The Manual Removal treatment required that students use rakes, shovels, and hoes to remove all plants from plots. To make plant removal possible, Arboretum personnel tilled Manual Removal plots with a rototiller in four directions to a depth of 20 cm before a class arrived. For 90 days following the tilling, each plot required manual weed removal, because smooth brome ramets sprouted from rhizome fragments remaining in the soil. The Organic Herbicide Removal Treatment required four separate sprayings of the herbicide plots every three weeks (April 11 through July 5, 2002), using Monterey Quik Weed Killer herbicide Tm that contained the active ingredient, pelargonic acid.

Native Seed Collection and Recovery Treatments

In the autumn of 2001, students and Arboretum staff collected seed of 13 species from nearby native grasslands to assure that local genotypes would be used in the restoration project (Table 1). Arboretum staff helped students with plant identification and seed collection techniques to ensure a quality harvest. Students worked in cooperative teams during the collection process. One student clipped off the inflorescences while a second student caught the clippings in a large polyethylene bag. Students then cleaned collected inflorescences manually using mesh screens of varying sizes to separate chaff from seed. These activities occurred during the months of October and November when seeds were ripe enough for harvest. Volunteers and staff continued the seed cleaning process through the months of December and January.

Table 1. Species seeding rate / plot for 13 native species collected from grassland adjacent to study area. * indicates cold-stratification for 90 days.

Species	Seed (g)/ plot
Grasses	
Bouteloua gracilis (Willd. ex Kunth) Lag. ex Griffiths	2
Blepharoneuron tricholepis (Torr.) Nash	4
Elymus elymoides (Raf.) Swezey	3
Festuca arizonica Vasey	8
Muhlenbergia montana (Nutt.) A.S. Hitchc.	2
Muhlenbergia rigens (Benth.) A.S. Hitchc.	2
Muhlenbergia wrightii Vasey ex Coult.	1
Forbs	
Achillea millefolium L.	2
Aster falcatus = Symphyotrichum falcatum (Lindl.) Nesom var. commutatum (Torr. & Gray) Nesom	1
Erigeron divergens Torr. & Gray	1
Hymenoxys richardsonii * (Hook.) Cockerell	3
Machaeranthera canescens (Pursh) Gray	2
Penstemon virgatus * Gray	5

We stored seeds of each species separately in paper bags under dry conditions at temperatures not less than 10ºC and not exceeding 18ºC for approximately four to five months prior to use. All seed not requiring stratification received similar storage treatment, regardless of future application. Students learned propagation techniques by planting seeds into flats. Each seed flat contained 72 individual plugs with a root capacity of approximately 19 cm^3. We placed the trays directly under mist benches in the passive solar greenhouse at The Arboretum at Flagstaff in early February for 90 days. In early May, we transferred the trays to a seasonal (unheated) greenhouse to acclimate them to cool temperatures and to slow the growth. We changed watering regimes to a once-a-day saturation for all plugs and this continued for 60 days until the time of planting in the grassland.

Two species (*Penstemon virgatus* and *Hymenoxys richardsonii*) required cold-stratification for 90 days at 3ºC (Table 1). We began this process in early February by having students prepare seed flats following similar methods and utilizing identical media employed for non-stratified species. Students placed seed into flats that were moistened and covered with plastic, and put the seeds in refrigerators for a period of 90 days. In early May, we transferred stratified seeds to mist benches for a period of 30 days, initiating germination and seedling growth. In early June, we transferred the seedlings in the flats to the seasonal greenhouse where they received a daily saturated watering, similar to the non-stratified species, for a period of 30 days until they were planted in the grassland in early July.

In early July 2002, we prepared plots for the seeding or plugging treatments by removing the weed barrier fabric. To enhance germination and successful establishment, we left dead vegetation underlying the weed barrier fabric to provide shading and mulch for plugs and seed. Students, volunteers, and staff gathered pine needles from the adjacent ponderosa pine forest and stockpiled it near the plots for use as mulch for all plots.

Into each native seed recovery treatment plot, we added 36 g of a native seed mixture (Table 1). With the aid of volunteers, we raked seed into each plot and covered the plots with pine needle mulch (3 cm-deep) to retain moisture in the seedbed and enhance seed germination.

Volunteers planted plugs in the plots from 8 July through 11 July 2002. Into each plugged recovery treatment plot, we used triangular spacing of 30 cm between each plug planted using species-specific ratios correlated to those used in seeded treatments (Table 1). Plugged plots also received pine needle mulch (3 cm-deep) after planting. We watered the plugs by hand every three days for two weeks. In early August of 2002, in response to an absence of rain, we installed an irrigation system and watered plots two to three times / week for four weeks to facilitate germination and growth of the recently sown seed and plugged natives. This was an attempt to improve the success plugs and seeds (Glitzenstein et al., 2001).

In fall 2002, we again recruited students from local schools and colleges into the restoration program. They quantified species abundance and cover in the post-treatment following the same protocol given to students who did the pre-assessment. We compiled and analyzed data using repeated measures analysis of variance, where removal and recovery treatments were fixed main effects. We used Bonferroni adjustment for multiple comparisons of experimental plots (Snedecor and Cochran 1980). Because abundance and cover showed similar patterns, we report only percent cover data.

RESULTS

Bromus inermis and Exotic Species Cover

Although plots were randomly selected and appeared homogeneous, our experimental plots did have initial differences in *B. inermis* percent cover across removal and recovery plots (Figure 1). The predominant exotic species in the plots was *B. inermis*, which covered 68-80% of the ground. In comparison, other exotic species (Table 2) had 4-12% cover.

Treatment effects were dramatic. The change in *B. inermis* cover depended upon removal treatment (Figure 1, $F = 161$, $p < 0.001$, $df = 3, 276$), but not recovery treat-

Table 2. Presence of native and exotic species in all plots before and after removal treatment. Y indicates presence of the species, whereas N indicates absence of the species.

	Pre-Treatment 2001 Presence	Post-Treatment 2002 Presence
Native Species		
Achillea millefolium L.	Y	Y
Antennaria rosulata Rydb.	Y	Y
Artemisia carruthii Wood ex Carruth.	Y	Y
Dracocephalum parviflorum Nutt.	Y	Y
Erigeron divergens Torr. & Gray	Y	Y
Lotus wrightii (Gray) Greene	Y	Y
Lupinus kingii S. Wats.	Y	Y
Machaeranthera canescens (Pursh) Gray	Y	Y
Penstemon virgatus Gray	Y	Y
Potentilla crinita Gray	Y	Y
Astragalus sp .	Y	N
Bahia dissecta (Gray) Britt.	N	Y
Bouteloua gracillis (Willd. ex Kunth) Lag. ex Griffiths	N	Y
Oenothera sp.	N	Y
Exotic species		
Bromus inermis Leyss.	Y	Y
Chenopodium berlandieri Moq.	Y	Y
Convolvulus arvensis L.	Y	Y
Linaria genistifolia (L.) P. Mill.	Y	Y
Melilotus officinalis (L.) Lam.	Y	Y
Taraxacum officinale G.H. Weber ex Wigger	Y	Y
Tragopogon dubius Scop.	Y	Y
Verbascum thapsus L.	Y	Y
Thinopyrum intermedium (Host) Barkworth & D.R. Dewey	Y	N
Polygonum douglasii Greene	Y	N
Chamaesyce maculate (L.) Small	N	Y
Lactuca serriola L.	N	Y
Oxalis decaphylla Kunth	N	Y
Portulaca oleracea L.	N	Y

ment ($F = 1.68$, $p > 0.05$ df = 2, 276). Weed Mat and Manual Removal significantly reduced *B. inermis* cover, whereas Herbicide had no effect (Figure 1). Surprisingly, in comparison to controls, seeding and plugging significantly increased *B. inermis* cover in Weed Mat Plots (Figure 1).

Total exotic species response to the removal and recovery treatments mirrored the response of *B. inermis*. As was true for *B. inermis*, the change in the total exotic species cover depended upon removal treatment (Figure 1, $F = 47.23$, $p < 0.001$, df = 3, 276), but not recovery treatment ($F = 0.66$, $p > 0.05$, df = 2, 276). Weed Mat and Manual Removal treatments significantly reduced total exotic cover, whereas both Control and Herbicide groups had increased total exotic cover. In plots where *B. inermis* cover significantly decreased, there was a significant increase in non-brome exotics (Table 2, Figure 1). With the exception of *Convolvulus arvensis and Linaria genistifolia,* which are noxious weeds in the state of Arizona, most of the exotics occupying these plots (*Chenopodium berlandieri, Lactuca seriola, Tragopogon dubius*) are regarded as garden-variety weeds.

Native Species Cover

Changes in percent native species cover depended upon removal and recovery treatments (Figure 2, $F = 2.56$, $p < 0.01$, df = 6, 276). The most substantial and significant increases in native cover occurred in Manual Removal plots and in Weed Mat plots that were plugged or received no recovery treatment (Figure 2). Herbicide had no effect on native cover. Surprisingly, neither seeding nor plugging increased native cover in Control or Herbicide plots.

Native Species Richness

The change in native species richness depended upon removal treatment (Figure 3, $F = 18.45$, $p < 0.001$, df = 3, 276), but not recovery treatment ($F = 0.265$, $p > 0.05$, df = 2, 276). Weed Mat and Manual Removal treatments had significant increases in native species richness, whereas herbicide treatments had no significant change in native species richness over the course of the experiment (Figure 3). Control plots had significant decreased native species richness, especially in plots that had no recovery treatment.

Overall, species diversity in the plots was low; 15 native species and 13 exotic species grew in plots throughout the course of the experiment (Table 2). Nine of the 13 species used in the seeding and plugging treatments did not germinate or survive to the 2002 census. However, as seeded natives germinate, we expect species richness to increase.

DISCUSSION

Seed Harvesting, Processing and Storage and Community Participation

The goal of procuring locally adapted genotypes for restoration was only possible with the help of many community volunteers. At the end of the day of harvest-

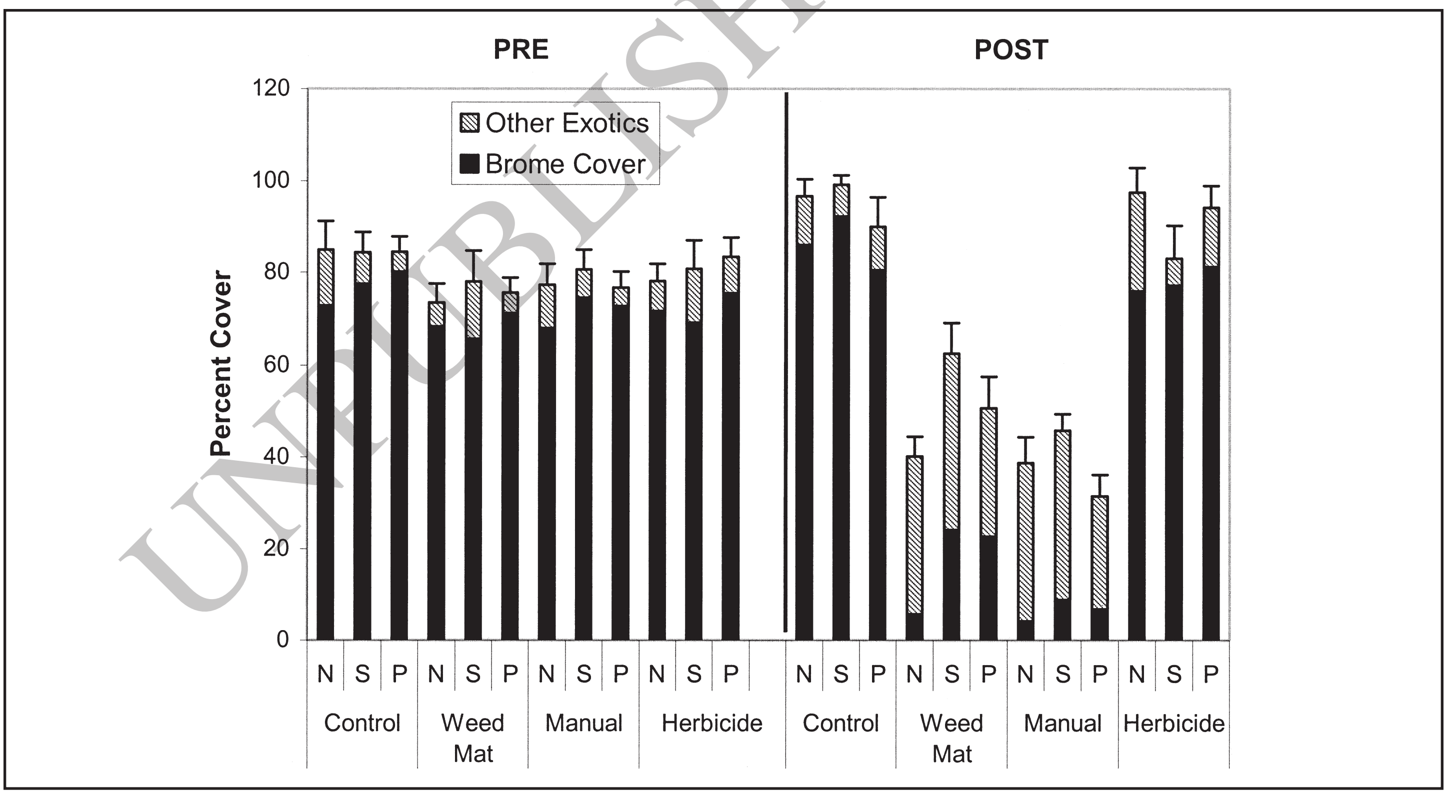

Figure 1. Mean percent cover of smooth brome (*B. inermis*) and other exotic species pre- and post-removal treatments (Control, Weed Mat, Manual removal, or Herbicide) and recovery treatments (N = None, S = Seeding with natives, or P = Plugging). Exotic species are specified in Table 2. For each removal/recovery treatment, we sampled two 25 m^2 quadrats in 12 replicate plots. Means ± 1 SE are indicated.

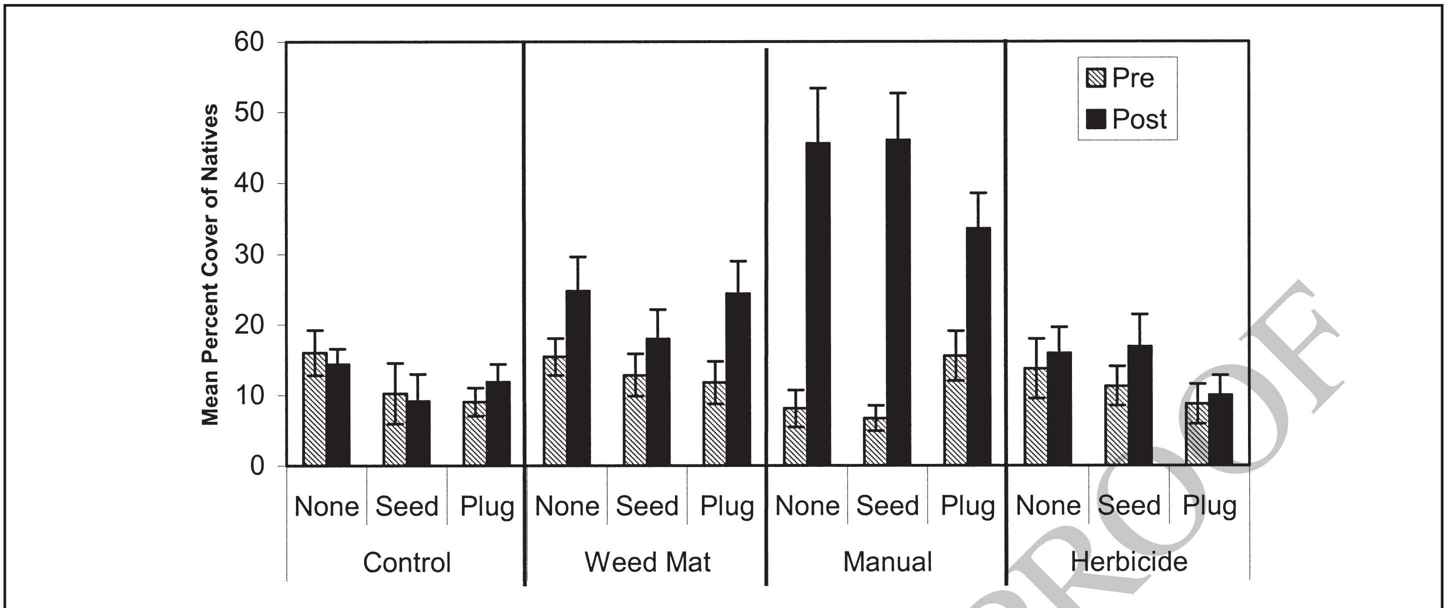

Figure 2. Mean percent cover of native species pre- and post-removal treatments (Control, Weed Mat, Manual removal, or Herbicide) and recovery treatments (None, Seeding with natives, or Plugging). For each removal/recovery treatment, we sampled two 25 m^2 quadrats in 12 replicate plots. Means ± 1 SE are indicated.

ing seed, students could capably identify four to five species of native grasses and/or forbs. It was an especially rewarding activity for students with behavioral and social disorders, as they seemed to enjoy the kinesthetic process of harvesting and cleaning the seed. In urban settings, where few children see grasses other than lawns and some do not realize that grasses flower and produce seed, this agronomic activity was tangibly rewarding.

The labor intensive and time-consuming task of cleaning seeds was challenging. Although the long awns of *Elymus elymoides* made it very difficult to clean, we considered it to be a necessary component of our seed mixes and propagated plugs, because it is one of the few early successional native grasses in northern Arizona. Other natives (*Muhlenbergia Montana, Muhlenbergia rigens and Muhlenbergia wrightii*) have seed so small that it is difficult to see and separate from chaff. These species required many hours of labor to generate enough seed for the project and often tested everyone's patience during the cleaning stages. Turning the process into a social event or competitive event helped students stay on task.

The Arboretum's many resources made seed storage, germination, and the growing processes easy. Plug establishment in our dry temperate climate required greenhouse space to ensure propagation success. Students assisted with the propagation of plugs and gained first-hand knowledge of the plant propagation techniques employed by professional horticulturists and growers. Due to time limitations of on-site visits, students only participated in one or two steps of the process and were not able to follow the entire process from collecting seed, sowing seed, observing germination, and planting plugs in the field.

Consequences of Drought

There were several consequences of the drought. Species, such as *Festuca arizonica* and *Blepharoneuron tricholepis,* which had set ample seed in 2001, failed to set sufficient quantities of seed to justify seed harvest in fall 2002. If prevailing climatic conditions continue, acquiring seed of native local genotypes may become difficult. Continuing to utilize seed from local ecotypes, as opposed to purchasing seed from out-of-state, is important in restoration efforts so as not to compromise the genotypic integrity of existing natives. However, removing seeds and plants of desired species from populations already under stress for purposes of restoration elsewhere is difficult to justify when there is potential for damaging the existing community (Cairns 1988). To minimize negative impacts of seed collections, we recommend following Center for Plant Conservation guidelines (Falk and Holsinger 1991). Specifically, practitioners should collect from plant populations with relatively large population size (> 500 individuals), harvest no more than 10% of the seed crop, and spread collections over many years (e.g., Falk and Holsinger 1991, Menges et al. 2004).

The drought of 2002 not only limited seed production, but it prevented seed germination, slowed plant growth, and/or caused plant mortality. Neither seeding nor plugging affected native species richness or cover. Seeds did not germinate or become established in the study plots. It is possible that native seeds we introduced are still alive in the seed bank; however, long-term monitoring will be required to document any change in the success of the treatments (Zavoleta et al. 2001). Even though plugged plots were mulched with pine needles, plugs had high mortality. We installed an irrigation system in August, but it may have been too little, too late. Irrigating from early July could

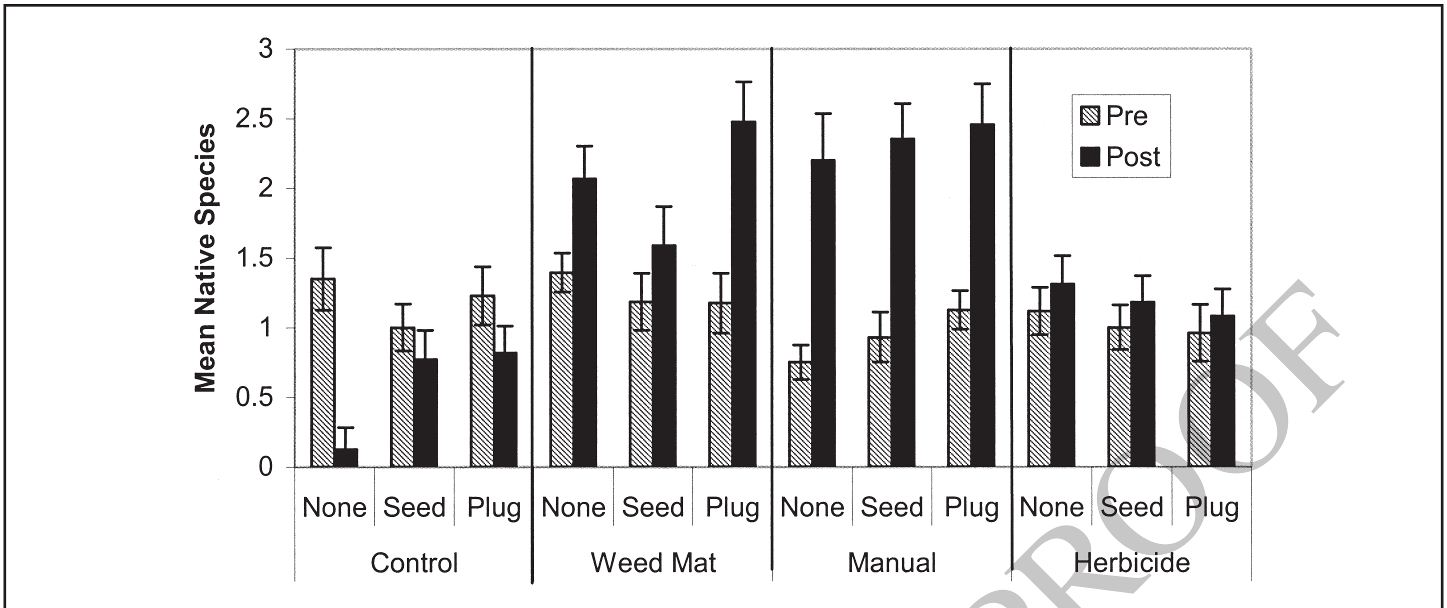

Figure 3. Native species richness pre- and post-removal treatments (Control, Weed Mat, Manual removal, or Herbicide) and recovery treatments (None, Seeding with natives, or Plugging). For each removal/recovery treatment, we sampled two 25 m^2 quadrats in 12 replicate plots. Means ± 1 SE are indicated.

have benefited the establishment of plugs and germination of seeds, but would not have reflected practical restoration strategies applied in the field. The recovery treatments may only influence the future composition of this plant community if the region experiences more rainfall or if the plots continue to be irrigated.

Eradication and Recovery Techniques

We demonstrated that *B. inermis* could be significantly reduced. However, with the exception of a few isolated plots, it is noteworthy that none of the removal or recovery treatments entirely eliminated *B. inermis*. Manual removal and weed barrier fabric were most effective in reducing *B. inermis,* while increasing species richness of natives 1-3 fold (Table 2, Figure 3). As seed and plugs mature, we would expect a diverse native plant community to develop. Increases in native abundance were similar in Manual Removal plots, where no seeding or plugging occurred, indicating that this restoration strategy may be worth the time and effort in reestablishing a native plant community. Our data showing that both cover and diversity of natives are reduced in the presence of smooth brome, but increase when brome is removed support Elliot's (1949) assertion that smooth brome can out compete native species.

If the primary goal of a restoration project is to rid the existing plant community of exotics, then consideration should be given to treatment by manual removal and weed barrier fabric, which reduced exotics > 50% and 15-30% respectively (Figure 1). Both were more effective for reducing exotics and increasing natives than the Quik Weed Killer Tm herbicide. The herbicide treatments had minimal impact on the abundance of smooth brome and other exotics. Manual removal and weed barrier fabric are more labor intensive, but they may prove to be the best investment.

Costs and Benefits

Time and cost considerations should be factored into the approach taken to eradicate *B. inermis.* Manual removal of smooth brome required around six hours per 300 m^2 to remove plants with the aid of a rototiller. Weekly monitoring and removal of exotics occurred as needed over a period of 90 days prior to seeding and planting. The disturbance associated with manual removal treatments opened a niche that was quickly filled by ruderal species.

Weed barrier fabric can be applied quickly, requiring about one hour for 300 m^2. However, the cost of $100 per 300 m^2 may make its use prohibitive for larger scale projects. In addition, the 90 days we used for covering the plots may be the bare minimum for effective control of *B. inermis*. A cost/benefit analysis on smaller projects could weigh in favor of using weed barrier fabric, particularly if time and physical labor constrained efforts in manual removal of exotics. In addition, weed barrier fabric can be reused for landscaping or future restoration projects.

The cost of the irrigation system and installation was approximately $1400 for a rudimentary quick-coupler system employing 12 Hunter sprinkler heads and 335 m of pipe over 1 ha of grassland. Applying potable water in times of drought to projects such as this calls into question a number of ethical considerations, and in the end may be unaffordable for larger scale applications.

Improvements in Methodology

Changing the timing of weed removal may improve the success of future projects. In Flagstaff, the frost-free growing season is very short, usually lasting about 90 days from mid-June through mid-September. Yet, many exotics precede natives and germinate from April to May. Early germination can be important in competitive

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interactions (Ross and Harper 1972); therefore, intervention during the months of April and May could reduce the competitive advantage and abundance of exotics, while simultaneously enhancing establishment of natives. This requires an ability to recognize exotics in a seedling stage, which requires experience and/or training.

Changing the type of herbicide used would probably also increase the success of eradicating *B. inermis*. Our results indicate that Monterey Quik Weed Killer herbicide Tm was ineffective for eliminating smooth brome. To our knowledge, this product had not been used previously in a large restoration context. It is likely that repeated sprayings of a glyphosate-based herbicide (e.g., Roundup R), which is a systemic herbicide that is translocated throughout the plant, would have achieved greater control of a rhizomatous plant like *B. inermis* (University of Wisconsin Extension 2003). Although some herbicides, such as those containing glyphosate that have low mammalian toxicity (Neal 1998), are approved for aerial application (U.S. Forest Service 1994) and are not included in public health risk reports by the Center for Disease Control (CDC 2003), many environmentally conscious communities (like Flagstaff) have negative feelings about chemical use. We saw first-hand evidence that any hesitancy on the part of participating students, teachers, and volunteers seemed to wane when they learned of our using an herbicide advertised as "organic." Trials of different herbicides for restoration work are warranted, as are educational programs to inform the public about risks and benefits of herbicide use.

Using pine needle mulch had benefits, but it may have also created problems. Mulch reduced desiccation by wind and sun, while enhancing the germination potential of seed sown or already present in the seed bank. However, mulch may have also contributed to new tiller formation and growth of smooth brome, as evidenced by the slight increase in smooth brome cover in mulched and seeded plots.

This project will require several years of monitoring and weed removal to demonstrate fully the effectiveness of the treatments for converting the area to a native grassland. Without additional intervention utilizing some of the effective treatments from this research, natives will have a difficult time displacing the existing monoculture of smooth brome. The competitive nature of *B. inermis* and contamination from other exotics may prohibit this grassland from becoming an established native seed resource bank.

Restoration Education

We benefited greatly from the contributions of students who participated in The Arboretum at Flagstaff's restoration education program. The project would have been difficult to achieve without widespread community support. The students who assisted in the restoration research gained a breadth of knowledge, from plant identification skills and greenhouse propagation techniques to creative problem solving and cooperative learning strategies. As was true of the research aspect of the project, the educational components had successes. During the course of the project, we made modifications to improve the educational components.

By cooperating in teams, students had incentive for doing the best possible job, which improved accuracy in data collection. Arboretum scientists monitored accuracy of data collection and found that less than 5% of the quadrats had to be revisited by Arboretum staff. We attributed this success rate to pre-service visits to participating classrooms, where we reinforced objectives prior to conducting the field tasks. Using volunteers to monitor vegetation and gather quality research data has a demonstrated success when reliable training methods precede fieldwork (Dietz et al., unpubl. data). Students had a sense of ownership in the research, because they saw how it was being used to solve problems in their own lives, their school, and their community.

Because research requires a great deal of repetitive work and some young students lack the attention, focus, and patience for data collection, we shifted younger students to different tasks after 30 minutes. Cooperative teamwork mediated many problems. However, poor handwriting and inaccuracies in simple math skills required our constant attention.

In the evaluation process, we returned to the schools to assess what the students had gained from this project. Follow-up evaluations conducted in Middle and High school classrooms elicited lively discussions on restoration issues and thoughtful written responses from the students. The students knew the names of many plants, understood the conceptual differences between native and exotic species, and recognized these plants on their school grounds. They were also able to define terms such as: restoration, conservation, preservation, invasive, and noxious. We concluded a couple of our visits with "weed pulls" on the school campus. Student enthusiasm was contagious and reinforced the successes we gained from our place-based educational research program. Students, who previously had no idea what an invasive plant was, could now take their knowledge back to their schools and homes and make a positive contribution to their community.

Synthesis and Conclusion

Completing the conversion of the Arboretum's grassland to a native plant community could be attained in three to four years if funding and additional students and volunteers assisted in restoration efforts. Goals for restoration projects should focus on desired characteristics for the system in the future (Hobbs and Harris 2001). Future goals of a sustainable seed resource comprised of natives from local ecotypes would serve as a seed bank for regional grassland and forest understory restoration projects. This could fill both an ecological and commercial niche for the Flagstaff area. While most ecologists agree that conservation is a more effective tool for protecting and maintaining biodiversity than restoration (Falk et al. 1996), restoration projects integrating the community concept with an educational component may undo ecological damage, (Murray 1993) while simultaneously cultivating a land ethic in future generations (Leopold 1966).

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