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Restoration Implications of *Bromus tectorum*- Infested Grasslands of the Great Basin

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Introduction

The devastating wildland fire seasons of 1999 and 2000 in the Great Basin region of the United States acted as a wake-up call to the critically degraded conditions of these natural grasslands. This area has been abused and degraded for over 100 years, with numerous components responsible for its deteriorating condition. These components include poor grazing management, ignorance or denial that the grasslands are deteriorating, and rapidly increasing infestations by invasive species. *Bromus tectorum* (cheatgrass) is only one of several invasive species that have invaded the Great Basin, but it has made the most devastating impact on the region by inducing the wildland fire/annual grass cycle. This cycle is so out of control that grassland fires are now occurring every 3 to 5 years in some areas, instead of the estimated normal 60 to 100 years for a native bunchgrass/sagebrush plant community (Whisenant 1989, Devine 1998, from Carpenter and Murray 2000). Intense immediate and long-term restoration of this region must be done to stop this downward spiral, or this whole region could eventually become a desert wasteland. Restoration will not happen, however, without millions of dollars from federal and regional agencies. This paper is not a step-by-step manual of how to restore the Great Basin grasslands, but describes the devastating situation and discusses numerous restoration techniques that are successful, unsuccessful, and that show promise for the future.

History of the Great Basin Region

The Great Basin region of the U.S. is massive, running about 900 miles long (1440 km) and 570 miles wide (912 km) (BLM, Oct 2000). It encompasses the SE corner of Oregon, the lower third of Idaho, the western half of Utah, most of Nevada, and a narrow strip of eastern California (BLM, Sept 2000; BLM, Oct 2000). More than 60% of this region is federally owned and managed by the Bureau of Land Management (BLM) and other federal and local agencies (BLM, Oct 2000). Much of this federally owned land in the Great Basin is available to the public for grazing cattle and for recreation (BLM, Oct 2000). This area is also home to approximately 100 bird, 70 mammal, and 23 amphibian and reptile species, which include wild herds of antelope, mountain sheep, mule deer, elk, and horses that roam across and graze on the land. Managing millions of acres to ensure the land is not being abused, and to protect the health of the land and the animals, is a daunting task (BLM, Oct 2000). Funds designated for land management is limited and much of what is available is spent on restoring the most critically degraded areas and fighting wildland fires (BLM, Sept 2000).

For several million years, the Great Basin has been dominated by three major plant communities: sagebrush, salt desert shrub, and pinyon-juniper woodlands (BLM, Sept 2000; BLM, Oct 2000). The most common and widespread community is the sagebrush, which is the area I will focus on in this paper. This plant community consists of a mixture of shrubs, perennial grasses, and forbs, of which the grasses are the most critical (BLM, Oct 2000). Two common shrubs are sagebrush (*Artemisia tridentata*), and antelope bitterbrush (*Purshia tridentata*), of which sagebrush is most common. Several of the major bunchgrasses are bluebunch wheatgrass (*Agropyron spicatum*), crested wheatgrass (*Agropyron cristatum*), western wheatgrass (*Agropyron smithii*), Sandberg bluegrass (*Poa sanbergii*), needle and thread grass (*Stipa comata*), and Thurber's needlegrass (*Stipa thurberiana*) (BLM, Sept 2000; BLM, Oct 2000; Carpenter and Murray 2000).

Another almost unseen, yet vital component of this ecosystem is the biological soil crust, a thin layer of cyanobacteria, mosses, and lichens that grows in the spaces between the bunchgrasses (BLM, Oct 2000; Herbert, Nov 2000). This biological crust consists of soil particles bound together by organic materials formed by living organisms and their byproducts (Herbert, Nov 2000). Soil crusts exist in the top 1 to 4 mm of soil and affect environmental processes that happen at the soil surface, such as atmospheric N-fixation, nutrient contributions, soil stability and /or erosion, infiltration, germination, and plant growth (Herbert, Nov 2000).

Located between the Rocky Mountains and the Sierra-Nevada and Cascade Ranges, this intermountain grassland receives limited precipitation that falls mainly in autumn and winter (Mack 1984). The native bunchgrasses survive the harsh climate by completing their growth and seed production by mid-July and going dormant during the arid summer months (Mack 1984).

For thousands of years, with arid summers and limited green forage in the basin, bison never became as abundant here as they did in the Great Plains. In the plains, rainfall during the summer supported lush growth of rhizomanous grasses that were tolerant of trampling by bison. In the Great Basin, however, elk, deer, and antelope existed, but their numbers were too small to affect the evolution of impact-tolerant grasses and shrubs. Thus, the bunchgrasses and the sagebrush that evolved in the basin never became tolerant of trampling (Mack 1984; Stylinski and Allen 1999). Also intolerant of trampling is the biological soil crust. This thin crust is easily shattered and destroyed by even light grazing. The destruction of this crust highly reduces the ability of the crust to influence environmental processes, such as soil stability and soil nutrients (Herbert, Nov 2000). Destruction of the crust also provides holes in the plant community where weeds can easily take root (Devine 1993; Herbert, Nov 2000).

Knowing how the vegetation of the Great Basin evolved, it is understandable that the native plant community quickly became stressed as European settlers moved into the region with their herds of grazing cattle (Mack 1984). Several decades of unrestrained grazing of cattle and sheep had seriously degraded the intermountain plant communities as early as the late 1800s. It was still many years later before much of this rangeland was supervised by the Bureau of Land Management and other governmental agencies (Devine 1993).

Bromus tectorum **Invades Great Basin**

The Great Basin continued to degrade as more and more settlers moved into the region to set up ranching. Early in this settlement process the degradation of the basin generally was not considered a critical problem. This began to change, however, as increased international sales and trade of animals and plants increased, and unfamiliar species from around the world started appearing all over the U.S. (Devine 1993). *Bromus tectorum*, commonly called cheatgrass (also known as downy brome, downy chess, bronco grass, Mormon oats, six-weeks grass, and Junegrass (Mack 1984; Devine 1993; Carpenter and Murray 2000; Northern Prairie 2000)), is one of the exotics that took advantage of the degraded Great Basin plant community. The original introduction of *B. tectorum* is unknown, though it is likely that numerous introductions happened around the same time. The first specimens were collected between 1889 and 1894 in British Columbia, Washington, and Utah (Mack 1984), but *B. tectorum* was also introduced to the Denver, Colorado area through packing material (Northern Prairie 2000). Well-intentioned research may have introduced *B. tectorum* seeds to the Pullman, Washington area also. A college experiment, where *B. tectorum* seeds were germinated and grown, was later abandoned when the plants died in the spring. More than likely, some of the seeds that were set in the spring germinated the following fall and introduced *B. tectorum* to the native plant community (Mack 1984; Carpenter and Murray 2000). In most locations that *B. tectorum* seed was produced, it was dispersed quickly and thoroughly across the Great Basin because it easily attached to livestock hair, socks and pants, and got mixed in with wheat seed shipments and cattle bedstraw (Devine 1993; Enserink 1999; Carpenter and Murray 2000). This repeated and widespread introduction of *B. tectorum* seed to the basin region probably boosted its chances of becoming invasive (Enserink 1999).

History and Description of *Bromus tectorum*

B. tectorum is a native of the arid steppes of Eurasia (Mack 1984; Devine 1993; Carpenter and Murray 2000) and the Mediterranean region (Carpenter and Murray 2000; Northern Prairie 2000). The climate in these areas pre-adapted *B. tectorum* for the climate in the Great Basin region (Mack 1984). The annual summer drought that the basin experiences is similar to Eurasia, and *B. tectorum* is able to survive this harsh condition by going dormant until the rains return in the fall (Mack 1984). Another characteristic that preadapted *B. tectorum* to the basin region is its ability to withstand repeated grazing. In Eurasia, *B. tectorum* was continually grazed by horses and camels and has a long history of agricultural and urban disturbances (Mack 1984; Stylinski 1999). Its ability to withstand constant cattle grazing in the Great Basin gave it an advantage over the native bunchgrasses (Mack 1984). The fact that *B. tectorum* is an annual grass also was advantageous. As long as it was able to set seed, there was no reason for it to survive any longer, unlike perennials' need to survive year after year (Mack 1984).

This invasive species will grow on most soils but prefers loose, sandy or gravely soils, which are common in the basin region. It does not flourish on heavy, clay soils, or soils high in salt (Emmerich et al. 1993; Upadhyaya et al. 1986, from Carpenter and Murray 2000; Northern Prairie 2000), and seems to grow especially well in soils with high levels of potassium (Northern Prairie 2000).

B. tectorum reproduces from seed. It is capable of producing over 300 seeds per plant (Northern Prairie 2000), and an acre of land infested with *B. tectorum* can produce millions of seeds annually (BLM, Sept 2000). Seeds are set and cast off by mid-June, after which the plants quickly dry up and die (West 1983; Carpenter and Murray 2000). Seed dispersal is accomplished by the wind and by attachment to things like animal hair and human's socks and clothing. The great number of seeds produced each year also ensures that some of these seeds will contaminate crop seed, hay, and straw (Devine 1993; Carpenter and Murray 2000; Northern Prairie 2000).

Research has demonstrated that *B. tectorum* seeds have adaptively significant variation in their germination rates (Meyer et al. 1997). Studies also support the hypothesis that these differences in seed germination are genetically based (Meyer and Allen 1995, from Meyer et al. 1997). Generally, *B. tectorum* seeds germinate in the fall or winter, but in particular conditions, germination may be staggered from August to May (Mack 1984; Carpenter and Murray 2000) and may occur in a series of "pulses" with each one occurring within a few days after a rainfall (Mack 1984). This ability to germinate at various times almost guarantees that some *B. tectorum* plants will survive until June to produce more seed (Mack 1984). *B. tectorum* seed requires moisture to germinate and contact with soil enhances the germination rate of the seeds, although it is not required (Northern Prairie 2000).

For successful establishment in the arid Great Basin region, as *B. tectorum* has accomplished, rapid germination, root penetration, and seedling growth at low temperatures are essential (Aguirre and Johnson 1991; Francis and Pyke 1996). *B. tectorum* also competes successfully with native bunchgrasses for soil moisture in this dry region (Melgoza et al. 1990; Aguirre and Johnson 1991; Devine 1993; Francis and Pyke 1996). Both native bunchgrass seeds and *B. tectorum* seeds germinate in the fall and quickly produce roots. The roots of a native bunchgrass, bluebunch wheatgrass (*Agropyron spictatum*) will grow to a depth of 15 cm before soil temperatures drop below 50° F (10 C)and growth virtually stops. New *B. tectorum* roots, however, can grow 1-1/2 times as fast as *Agropyron spictatum* roots and can grow in soil temperatures as low as 37° F (2.8 C)(Devine 1993). This enables them to reach a soil depth where they may continue to grow through the winter. This over-winter root development allows *B. tectorum* to exploit any available soil moisture (Emmerich et al. 1993; Francis and Pyke 1996). By the time temperatures rise enough in the spring for *Agropyron spicatum* to resume growing, *B. tectorum* roots may have grown up to three feet long with developed secondary roots. In the spring, young *Agropyron spicatum* roots will grow deeper, looking for available moisture, but will die if *B. tectorum* plants have already depleted the available supply (Devine 1993; Carpenter and Murray 2000).

Native bunchgrasses are perennials so mature, healthy plants have extensive roots systems that can compete successfully with *B. tectorum* for moisture. Also, during low precipitation years, *B. tectorum* production is poor and seedlings of native grasses may be favored (Emmerich et al. 1993). *B. tectorum* has a definite competitive advantage in areas where the native bunchgrasses and forbs are stressed and degraded. These areas may be excessively grazed, significantly infested with *B. tectorum*, recently burned from wildland fires, or receiving higher amounts of precipitation. Widespread abundance of *B. tectorum* after fire is common in some areas of the Great Basin (Melgoza et al. 1990; Emmerich et al. 1993; BLM, Sept 2000; BLM, Oct 2000). Research has shown that on burned sites, soil water content around native species may be significantly less when these species occur with *B. tectorum* than when *B. tectorum* is not present (Melgoza et al. 1990). The reduced productivity and water status of native species, caused by *B. tectorum's* competitive advantage, may be evident even 12 years after a fire (Melgoza et al. 1990). Thus, *B. tectorum's* competitive ability allows it to exploit soil resources after fire and enhance its status (Melgoza et al. 1990).

Impact of *Bromus tectorum* Invasion of the Great Basin Region

B. tectorum is one of numerous components in the continuing degradation of the Great Basin region. Other invasive species, poor grazing management, increase in frequency and intensity of wildland fires, and ignorance or denial that the grasslands are deteriorating have all contributed to the degradation of this region. *B. tectorum* is the one component, however, that has become the largest threat to the health of this region. 25 million acres (10 million ha) of public land have been consumed by exotic annual grasses, with *B. tectorum* by far the most common (BLM, Oct 2000). "A large part of the Great Basin lies on the brink of ecological collapse," (BLM, Oct 2000).

As early as the 1890s, some livestock owners in the Great Basin were fearful that native bunchgrasses would be completely lost because they seemed to be intolerant of livestock grazing (Mack 1984). Promoters to the region, however, pushed the idea that the new vegetation moving into the area (including *B. tectorum*) was an equally nutritious replacement (Mack 1984). Resistance by some ranchers to removing *B. tectorum* from grazeland continues because they use it to provide six to eight weeks of abundant forage in the spring for their cattle (Devine 1993; Emmerich et al. 1993). The devastating wildland fires of 1999 and 2000, however, brought international attention to the region and left little doubt that the degradation of the Great Basin is a critical issue that must be addressed immediately.

Although all of the components mentioned above have contributed to the degradation of the Great Basin native plant community, *B. tectorum* has made a devastating impact by inducing the wildland fire/annual grass cycle (Corliss 1992; BLM, Sept 2000; BLM, Oct 2000; Carpenter and Murray 2000). Rangeland covered with *B.* tectorum is 500 times more likely to burn than rangeland covered with native vegetation, according to to a study in Oregon (BLM, Oct 2000). *B. tectorum* sets seed and dies between mid-June and mid-July, after which it becomes dry, fine-textured straw that burns at a frightening speed (Corliss 1992; Devine 1993). This greatly increased potential for fire occurs two to four weeks before most native vegetation has matured and set seed (Devine 1993). It also occurs right during the Great Basin's active lightning storm season. Although fires have always been a natural occurrence in the Great Basin grasslands, they normally occurred no more than every 60 to 100 years (Whisenant 1989 from Carpenter and Murray 2000). In *B. tectorum* infested regions, fires are occurring as often as 3 to 5 years (Devine 1998, Whisenant 1989, from Carpenter and Murray 2000). Native plants cannot recover from such frequent burnings, and after a few cycles, a *B. tectorum* monoculture develops, which further induces the wildland fire/annual grass cycle (Devine 1993; BLM, Oct 2000; Carpenter and Murray 2000).

This loss of native plant species creates a domino effect which causes increased domination by noxious weeds, loss of wildlife species, increased soil erosion, loss of soil fertility, unstable watersheds and degraded water quality, reduced livestock grazing, fewer recreational opportunities, and more costly and dangerous wildland firefighting (Devine 1993; BLM, Sept 2000; BLM, Oct 2000).

Restoration and Management Goals

According to the Bureau of Land Management, the vision for the restoration of the Great Basin should be "to restore the land to its proper functioning condition" (BLM, Sept 2000). However, restoration will not return the Great Basin to its previous condition of 150 years ago (BLM, Oct 2000). The goal of "restoring both burned rangeland and other Great Basin areas at risk" includes restoring some areas of high resource values, reducing infestations of annual grasses and noxious weeds, and reversing the destructive cycle of wildland fires and annual grass infestations (BLM, Sept 2000; BLM, Oct 2000). Because there are millions of acres of land in the Great Basin that need attention, restoration plans must concentrate on "areas with the most critical resource values and highest potential for success through a common approach" (BLM, Oct 2000).

Numerous programs to help restore native habitat in the Great Basin have been in place for years. These include:

- emergency fire rehabilitation, which focuses on stabilizing soils immediately after a fire;
- the weed program, which becomes more ineffective every year because of increased costs and the huge annual increase of invasive species; and
- hazardous fuels treatments, which isolate native plant communities from *B. tectorum* invasion by creating fuel breaks, and use controlled burns in areas with degraded vegetation (BLM, Sept 2000).

Even with these programs, restoration efforts have been piecemeal, site specific, and short-term. Also, the amount of funds allocated to these control methods fall far short from slowing down the rapidly degrading native plant communities in the Great Basin (BLM, Sept 2000; BLM, Oct 2000). New restoration efforts must be long-term, must bring all the individual restoration goals together, and must receive millions of federal and local dollars to run it (BLM, Sept 2000; BLM, Oct 2000). Even if extensive funding can be attained to greatly increase restoration efforts, it will take time to reverse the current downward spiral which took more than 100 years to reach the point it is at today (BLM, Sept 2000).

Restoration Complications in the Great Basin

The Great Basin restoration strategy is to focus on the whole region, instead of treating small, individual areas (BLM, Oct 2000). This strategy came about because piecemeal treatments have not worked. This strategy is complicated, however, because the region is so large and no restoration project of this size has ever been undertaken (BLM, Oct 2000).

This paper focuses on the sagebrush plant community of the Great Basin. But this one plant community itself is huge and diverse, containing differing mixtures of sagebrush, perennial grasses, and forbs. The variation of native plants and grazing wildlife, the amount of infestation by invasive species, specifically *B. tectorum*, and the condition of the biological soil crust all have bearing on the specific restoration strategy developed for each particular area.

Restorationists are also discovering that what works in one area does not necessarily work in another, even though the native vegetation is similar.

Observation has shown that a stressed area of the Great Basin can be quickly invaded by *B. tectorum*. So, one of the first steps necessary in the battle to restore the Great Basin is to protect the native plant communities that are still reasonably healthy and to continue this practice simultaneously with restoration techniques (BLM, Oct 2000). This is a difficult task with an extremely large area of public land.

Land managers believe that overgrazing is a major cause of stress in the sagebrush plant community (Devine 1993). Herds of wild, grazing animals are usually not problematic, however, since most native vegetation is adapted to this infrequent grazing. Land managers do consider excessive overgrazing by livestock a problem. An enforced livestock grazing management program has helped to protect delicate plant communities from further stress, but grazing management is complicated and must be tailored to each specific site (Devine 1993).

Ranching is a huge industry in the Great Basin and adds much to the local economy in this region. Ranchers often own thousands of acres of land that they manage themselves. But, rangeland is seasonal and cattle must be moved to winter or summer locations, which can be hundreds of miles apart. Much of the land in between is federally owned land that ranchers are allowed to use, but is managed by the BLM or local agencies. Protecting native plant communities by eliminating grazing on this public land is not a feasible option. Land managers working with ranchers on new management techniques is a much better option (BLM, Oct 2000). Grazing management is extremely unpopular with some ranchers, however, even when the goal is protecting the natural plant community. They insist that their practices have greatly improved since years past, which they have, but grazeland is still being invaded by *B. tectorum* (Devine 1993). For years, invasion by *B. tectorum* has been considered a result of overgrazing or other disturbance to the land, but some ranchers say that the aggressive, adaptive characteristics of *B. tectorum* are the cause of invasions and not excessive overgrazing (Emmerich et al. 1993). Research by Svejcar and Tausch in 1991 does indicate that stable native plant communities never grazed by cattle can be invaded by *B. tectorum*, and that *B. tectorum* can successfully compete with established perennial plants (Emmerich et al. 1993). But years of observance and research have also shown that overgrazed areas of the Great Basin are more vulnerable to quick invasion of *B. tectorum*. Another hurdle land managers must negotiate is that some ranchers feel *B. tectorum* is a great benefit. They depend on the fresh, new growth of *B. tectorum* in the early spring, which provides nutritious forage for their cattle as they move to higher elevations for the summer (Emmerich et al. 1993).

Land management agencies have been reluctant to push the process for restricting grazing for a number of reasons. One is the enormous political influence of the ranching industry in the Great Basin; another is because the whole process is fraught with administrative procedures and can take years to finalize (Devine 1993). But, probably the most influential reason is the lack of funding available to cover the substantial costs for monitoring grazing on millions of acres.

Another major complication of restoration in the Great Basin is the extreme increase in the frequency of wildland fires. Millions of acres burned in 1999 and 2000. These wildland fires significantly perpetuate further invasion of *B. tectorum*, which in turn significantly increases the frequency of fire. During the dry summer seasons, after *B. tectorum* has matured, enormous amounts of resources are used fighting wildland fires instead of restoring or stabilizing grazeland. This seasonal annual grass/wildland fire cycle has made restoration efforts very difficult.

Restoration Techniques to Control *Bromus tectorum* Invasion

Spring is generally the best time to perform control techniques on areas invaded with *B. tectorum* because seedlings emerge from the soil earlier than native perennial seedlings. There are several useful techniques used to restore Great Basin grasslands, but restoration success of *B. tectorum* infested areas is only achieved if these techniques are done in combination and continued as a mangement tool. *B. tectorum* plants produce millions of seeds that are viable for up to five years, so the seed bank may allow plants to re-invade restored areas for several years after control (Wicks 1997, from Carpenter and Murray 2000). Additionally, as soon as a native plant community starts becoming stressed again from mismanagement, it becomes extremely vulnerable to re-invasion by *B. tectorum*.

Chemical Control

Chemical control of *B. tectorum* is used for restoration of Great Basin areas either alone, or in combination with other techniques. If an infestation is small, a backpack sprayer works well for spot treatments. Many *B. tectorum* infestations, however, are extensive and a large sprayer attached to a vehicle is needed (Carpenter and Murray 2000). Herbicide treatment of *B. tectorum* is usually done in the spring when native perennials are still dormant (Carpenter and Murray 2000) and is often done after fire to kill *B. tectorum* seedlings that quickly germinate. Treatment of *B. tectorum* is most effective when plants are less than four inches tall and vigorously growing (Wiese et al 1995, from Carpenter and Murray 2000). Tables 1 and 2 below list several spring and fall applied herbicides that may be used to treat *B. tectorum*.

Table 1: Spring Applied Herbicides:

Herbicide Name	Trade Name(s)	Properties/Application
Quizalofop	Assure II®	Quizalofop is a grass meristem destroyer and should be used post-emergence on seedlings before the seed head is detectable. Applied at 0.5 lb./acre (.56 kg/ha) controlled 100% of *B. tectorum*, but suppressed seed head production of perennial grasses. Applied at 0.02 lb./acre (.022 kg/ha) provided greater than 95% control of *B. tectorum* (Carpenter and Murray 2000).
Fluazifop-p-butyl	Fusilade® 2000, Fusiilade® DX	Fluazifop-p-butyl is a post-emergence herbicide that attacks the meristematic tissue of annual and perennial grasses. Fluazifop-p-butyl does not kill broadleaved

		plants, but will suppress seedhead development in *B. tectorum* when applied at sublethal rates. If applied at very low rates, Fluazifop-p-butyl only retards growth of *B. tectorum*. (Carpenter and Murray 2000).
Sethoxydim	Poast®, Poast Plus®	Sethoxydim is a post-emergence herbicide used to control annual and perennial grasses. It does not kill most broadleaved plants, but shows selectivity among grass species (Carpenter and Murray 2000).
Paraquat	Gramaxone®	Paraquat is a contact herbicide that kills only the tissue contacted, so only partial shoot kill will occur if plant is only partially covered with herbicide. Applied at 0.5 to 0.7 lb./acre (.56-.78 kg/ha) during late April or early May, may control greater than 97% of *B. tectorum*. Applied at 0.22 to 0.27 lb./acre (.25-.30 kg/ha), may control 80-90% (Carpenter and Murray 2000).
Glyphosate	Roundup®, Roundup Ultra®, Rodeo®, Accord®)	Glyphosate is a non-selective herbicide that damages or kills vegetation it contacts. It should be applied to *B. tectorum* foliage in the early spring before native perennial seedlings have emerged. Applied at 0.16 to 0.18 lb./acre (.18 to .2 kg/ha), may kill 80-90% of *B. tectorum*. However, another study applied Glyphosate at 0.37 to 0.5 lb./acre (.4-.56 kg/ha) and had only 80% reduction of *B. tectorum* within and between years (Carpenter and Murray 2000).

Table 2: Fall Applied Herbicides:

Herbicide Name	Trade Name(s)	Properties/Application
Sulfometuron Methyl	Oust®	Sulfometuron methyl is an extremely potent pre-emergence and post-emergence herbicide that may damage non-target vegetation if applied incorrectly. Application recommendation from Oust® is 0.2 to 0.3 lb./acre (.22-.34 kg/ha) to control *B. tectorum.* Sulfometuron will control many annual and perennial grasses and broadleaf weeds (Carpenter and Murray 2000).

Atrazine	Aatrex®	Atrazine is a pre-emergence and possibly early post-emergence herbicide sometimes used in rangelands. Atrazine will kill fall seedlings of *B. tectorum* that have emerged after perennial plants are dormant. Applying at 0.54 lb./acre (.61 kg/ha)was most effective for controlling *B. tectorum*, while not harming perennial grasses. Atrazine is extremely mobile in the soil and has a half-life of 60-100 days, so has a high potential for groundwater contamination (Carpenter and Murray 2000).

Reseeding

B. tectorum seedlings that survived a burn will germinate quickly, depending on the time of year. It is important that native vegetation is reseeded after a burn to compete with these *B. tectorum* seedlings. Reseeding is most effective when sufficient soil moisture is available to promote quick germination, or in late fall as a dormant seeding. A technique called seed matric priming has reduced the germination times of some native bunchgrasses (Corliss 1992). This procedure primes seeds by plumping them with moisture, which may allow them to germinate in almost half the normal time, thus competing more effectively with *B. tectorum* for available soil moisture (Corliss 1992). This procedure has not been tested on all native species and may not be feasible when large areas must be reseeded.

Idaho fescue (*Festuca idahoensis*) is a native bunchgrass that competes with high densities of *B. tectorum* on disturbed rangeland and may be a possible candidate for reseeding (Nasri and Doescher 1995, from Carpenter and Murray 2000; Carpenter and Murray 2000). Research of ‘Norden’ (*Agropyron desertorum*) and ‘Hycrest’ (*A. cristatum*) crested wheatgrass has indicated they are somewhat competitive with *B. tectorum* if planted in lower densities (Francis and Pyke 1996). *Agropyron cristatum* is, however, an exotic grass that can grow aggressively and tend toward monodominance.

Greenstripping

Protecting reasonably healthy native plant communities from *B. tectorum* invasion and from wildland fires is a desirable, but sometimes unattainable goal (Devine 1993; BLM, Sept 2000; BLM, Oct 2000). One technique that has been used, with limited success, is greenstripping. A greenstrip is a planted row or rows of vegatation that is resistant to both fire and to *B. tectorum* invasion (Devine 1993; BLM, Sept 2000). A greenstrip is difficult to establish, however, because developing effective plants is difficult, the plantings often fail during droughts, and the whole process is expensive (Devine 1993). In areas of the Great Basin where *Artemisia tridentata* or *Purshia tridentata* are common, greenstripping can break these large stands into small, isolated areas, resulting in habitat fragmentation, and decline in native plants and wildlife (BLM, Oct 2000).

Restoration Techniques Specific to Restoring Wildland Fire Damage

It is critical that soils are stabilized and restoration efforts are begun immediately following a wildland fire in a *B. tectorum* infested region. Many wildland fires burn very hot, which will kill many of the already struggling native sagebrush and herbaceous species (Melgoza et al. 1990; Devine 1993). Sometimes, a wildland fire is not severe enough to kill the mature native species, but will severely stress them. If this plant community is healthy, these native species may rebound. In a *B. tectorum* infested area, however, the additional stress from a fire will probably kill many of the native species, especially if this area has also been actively grazed. The more stressed the native plants become, the less competitive they are with *B. tectorum.* As *B. tectorum* proliferates, the odds are greater that this area will burn again (Devine 1993; Enserink 1999; BLM, Oct 2000; Carpenter and Murray 2000).

Restoration after a wildland fire varies greatly, depending on the intensity of the fire and the time of year it takes place. Most wildland fires, however, take place in the dry summers after *B. tectorum* plants have matured and dropped their seeds. Some of this seedbank may be destroyed by the fire, but seeds that survive will quickly germinate and fill in any spaces left by native perennials that did not survive (Wright and Klemmedson 1965, from Melgoza et al. 1990; Young et al. 1969, from Melgoza et al. 1990; Melgoza et al. 1990; Devine 1993). Surviving *B. tectorum* seeds from late season fires often develop into very prolific plants that produce large amounts of seed (Young and Evan 1978, from Northern Prairie 2000).

The *B. tectorum* seedlings, which start to grow soon after a fire, may be treated with herbicides, but care must be taken to use an herbicide that will have limited effect on the highly stressed, surviving native perennials. (See Table 2 in Chemical Control for a list of herbicides that can be applied in the fall.) When treatment of *B. tectorum* seedlings is completed, reseeding of native vegetation can be done. If a good percentage of the native shrubs have survived a fire, fast-growing native grasses may be aerially seeded to stabilize the soils between the shrubs, which will also help the shrubs to re-establish. If a fire is very intense, and many of the shrubs die, they may also need to be reseeded by drill or aerial seeding (BLM, Sept 2000). To give new seedlings the best possible chance for success, seeds are obtained from locally grown native plants.

Prescribed Burning

Since wildland fires are a tremendous problem in the Great Basin, it seems antiproductive to use prescribed burning as a control method for *B. tectorum*. The frequency and intensity of wildland fires were far fewer several years ago, however, so prescribed burning was used considerably in the past. Results vary greatly across the region, and is still a regular method of control in some areas, and dropped as a control in others.

If burning is used as a control method, it may be done at different times of the year in different areas, depending on the kind of native vegetation present, the percentage of *B. tectorum* coverage compared to the native vegetation, and the ability to control the fire. Sagebrush (*Artemisia* *tridentata*) may fail to recover after fire, while other perennial species may experience little or no mortality (Melgoza et al. 1990). Thus, restoration or maintenance regimes in areas dominated by *A. tridentata* may not include regular prescribed burning unless *A. tridentata* is too competitive with other native perennials. Areas dominated by native grasses, however, may regularly be burned to kill off *B. tectorum*. If burning is used to control *B. tectorum*, most programs will burn in the early spring, after *B. tectorum* seedlings have emerged, but before native perennials are growing. Burning at this time will kill *B. tectorum* seedlings and may help to reduce the surface seed bank, but will do limited damage to native vegetation (Carpenter and Murray 2000; Northern Prairie 2000). Burns may also be done in June, after *B. tectorum* plants have dried but have not released their seeds (Carpenter and Murray 2000). This would be effective if burn temperatures do not get high enough to severely damage native perennials, or if the area is mostly a *B. tectorum* monoculture. Burns may also be done in the late summer or fall, after native perennials have gone dormant. Some research has shown, however, that late season burns may actually promote re-establishment of *B. tectorum* because surviving seeds may produce very prolific plants that vigorously produce seeds (Young and Evans 1978, from Northern Prairie 2000).

Attempted, But not Recommended, Control Methods

Mowing is not usually considered a feasible control method for *B. tectorum*. If plants are mowed at an early stage, they just regenerate new culms and produce viable seeds (Carpenter and Murray 2000). Mowing every three weeks has shown to be an effective method for controlling seed production, but this method is extremely labor intensive and not a feasible choice for very large areas of restoration (Carpenter and Murray 2000).

Grazing is used successfully for some types of invasive grasses, but is an ineffective control method for *B. tectorum*, and it can be damaging to native vegetation (Carpenter and Murray 2000). Grazing in the spring is ineffective because it allows *B. tectorum* to regenerate new culms and produce viable seeds, as does mowing. *B. tectorum* that is grazed in the summer or fall is undamaged because plants have already produced seeds. *B. tectorum* at this stage is also very unpalatable and the dry, sharp awns may cut the mouths of livestock.

Current Research and Possible Future Control Methods

B. tectorum grows especially well in high-potassium soils. Research on ways to reduce potassium, which may reduce *B. tectorum's* vigor or abundance, may lead to a possible control method (Enserink 1999; Belnap personal communication, from Carpenter and Murray 2000).

There is limited information on the potential of biological control of *B. tectorum*. Rabbits, mice, and grasshoppers will feed on *B. tectorum* (Northern Prairie 2000). Research is needed in this area.

Soils high in soluble salts provide a natural defence against *B. tectorum*, since this plant has a low tolerance for soluble salts. Some of the salt desert shrub areas of the Great Basin contain soils with high soluble salts and so benefit from this natural defense of *B. tectorum* (Emmerich et al. 1993).

Studies of biological soil crust's role in soil nutrient budgets is a promising area of research. And, studies of how native vegetation can be made more competitive with *B. tectorum* is continually ongoing. This would include seed germination rates, planting densities, temperature sensitivities, and soil water exploitation, just to name a few.

Conclusion

The degradation of the Great Basin grasslands region is a huge environmental crisis that needs to be addressed immediately. This crisis is a national issue, because it affects more than just local citizens and economies. The loss of native plant species also creates the loss of wildlife species, the loss of soil fertility and increased soil erosion, unstable watersheds and degraded water quality, and huge costs in funds needed to fight ever-increasing wildland fires. These secondary losses affect all of us.

This situation is not hopeless, however, because individuals and experts in many fields, including ecologists, environmentalists, soil scientists, specialists in federal and regional agencies, and special interest groups have the expertise and abilities to successfully battle this environmental crisis. The piece that is absolutely necessary to establish an immediate and long-term restoration plan, however, is funding. With sufficient funding, all of these groups and individuals will be able to work together to design ongoing restoration techniques, research new methods and controls, and implement a successful restoration and maintenance program for the whole Great Basin region.

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