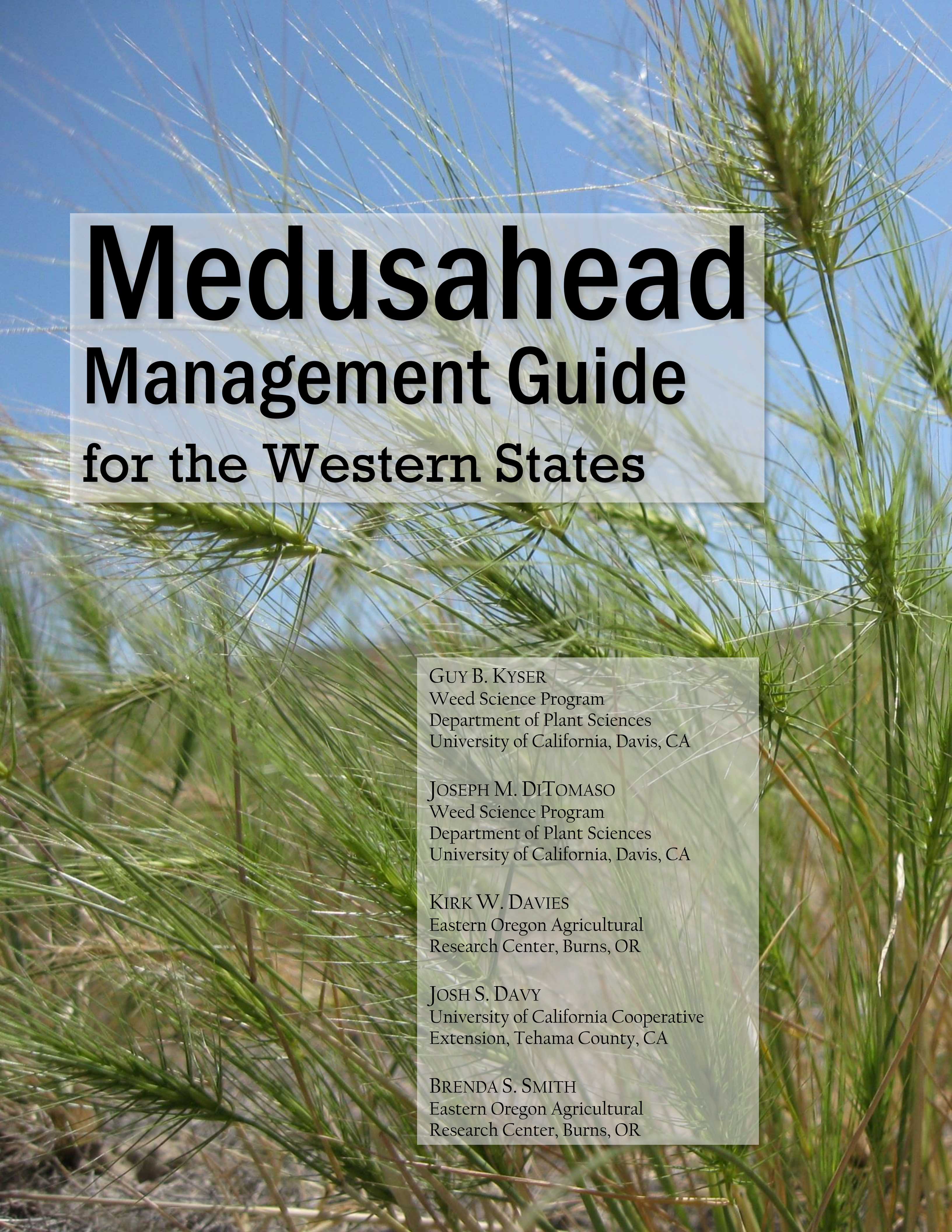

Medusahead Management Guide for the Western States

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Uncredited photographs are by J.M. DiTomaso.

Chapter 1: Introduction and Spread

Origins

Medusahead (*Taeniatherum caput-medusae*) is native to the Mediterranean region (Figure 1). Currently, three subspecies surround the Mediterranean from Spain to Morocco, and northeast into Eurasia (Frederiksen 1986; Major 1960).

Figure 1. Medusahead's center of origin

(Image: Google Earth)

Medusahead is a member of the Triticeae, a tribe of grasses which includes the important grain crops wheat (*Triticum* spp.), barley (*Hordeum* spp.), and cereal rye (*Secale* spp.), as well as wheatgrasses (*Agropyron* and *Thinopyron* spp.), wildryes (*Elymus* and *Leymus* spp.), and goatgrasses (*Aegilops* spp.). This grass tribe has its likely center of origin in the Middle East. There is evidence that some types were used for human food 23,000 years ago (Weiss et al. 2004); wheat, barley, and rye, of course, formed the basis for early agriculture and human settlement.

Like many weeds from this part of the world, it is likely that medusahead accompanied agriculture from the earliest days. Medusahead spikes have been found in 9,000-year old storage jars from the Neolithic town of Çatalhöyük, in central Turkey, alongside jars of primitive cultivars of wheat and barley (Fairbairn et al. 2007; Helbæk 1964). Helbæk commented, "What the ancient people wanted them for is impossible to guess."

Introduction to North America

Medusahead was first recorded in the United States near Roseburg, Oregon, in 1887 (Howell 1903). Herbarium records indicate that the plant spread concentrically – north into Washington, south into California, and east into the Great Basin, Idaho, and other western states (Figure 3) – but most rapidly in the direction of California (Major et al. 1960). Recent genetic analysis suggests that at least seven distinct genotypes of medusahead have been introduced over a timespan from 1887 to as recently as 1988, and that the plant has more genetic diversity here than previously thought (Novak and Sforza 2008).

It is not known how medusahead was introduced to the United States. It has been suggested that medusahead arrived as a contaminant in cereal grain seed, while others (George 1992; Hilken and Miller 1980) suggest it may have arrived clinging to the fur of imported livestock. Because medusahead seeds are smaller than most cereal grains, and because this plant goes to seed later than most domesticated cereals, the fur hypothesis seems most likely. In addition, during its subsequent spread from the point of introduction, medusahead has been strongly associated with areas of livestock production. For example, in the 1960s isolated populations were found in the eastern Sierra Nevada in areas used to corral sheep (Young 1992).

Spread and Distribution

Once introduced to the western US, medusahead spread rapidly in low-elevation annual grasslands, oak woodlands, and chaparral communities (Young 1992). These west coast communities have a Mediterranean-type climate comparable to medusahead's native region: hot and dry in summer, and cool and moist from late fall through spring. Mediterranean

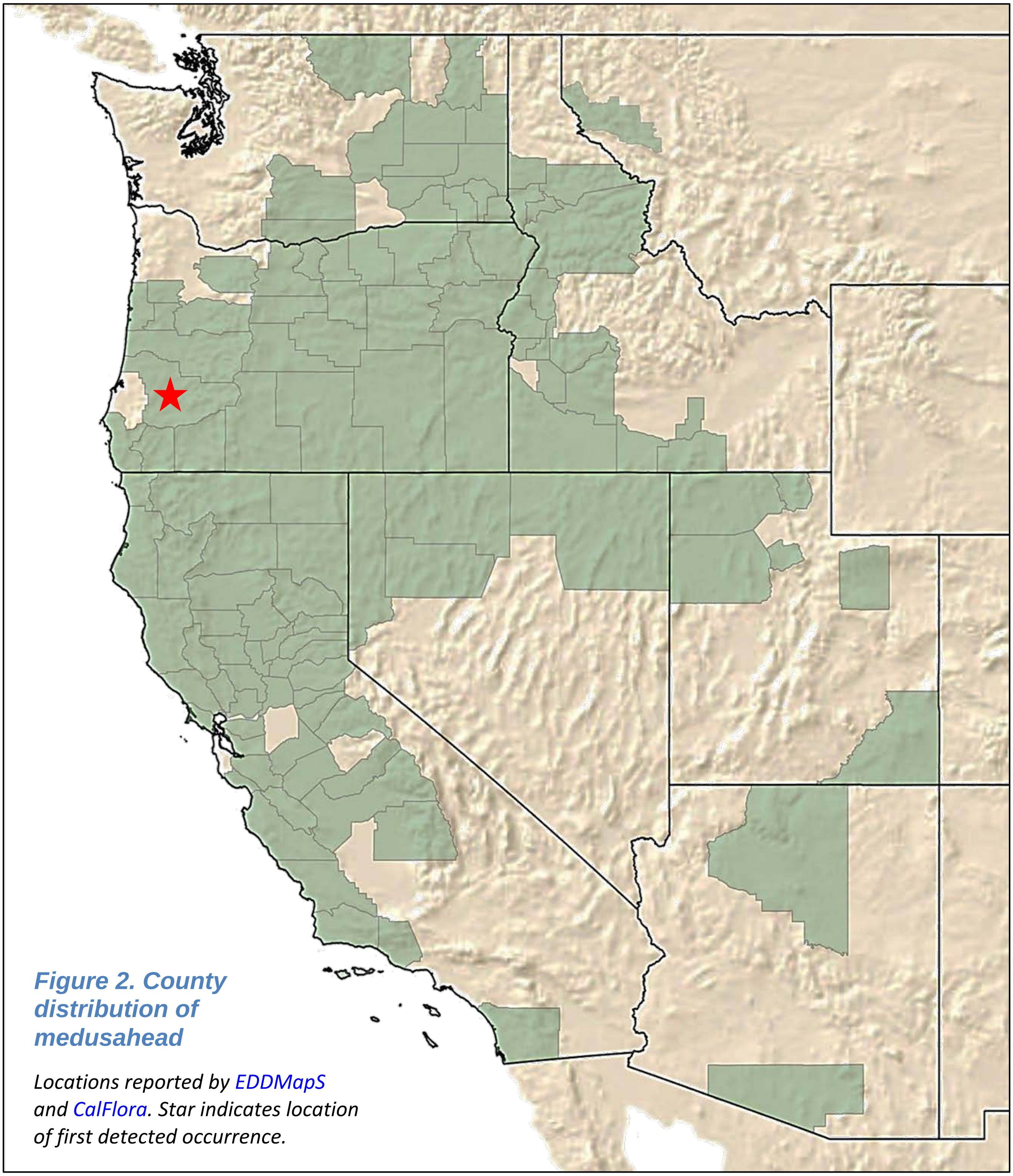

Figure 2. County distribution of medusahead

Locations reported by EDDMapS and CalFlora. Star indicates location of first detected occurrence.

winter annuals such as medusahead generally germinate in fall and flower and set seed in spring.

Medusahead invaded the intermountain region, east of the Sierra and Cascade ranges, at a much slower rate. It was first reported in this region at Verdi, Nevada, in the early 1960s (Young 1992). Medusahead is somewhat moisture-limited in the Great Basin and appears to favor clay soils (Dahl and Tisdale 1975). Where established, however, it has the potential to outcompete downy brome (*Bromus tectorum*, also called cheatgrass) (Hironaka 1994).

It continues to expand its range by about 12% per year and recently was estimated to infest over 2.4 million acres (950,000 ha) in the 17 western states (Rice 2005). In California, medusahead now occupies more than a million acres of annual-dominated grassland, oak woodland, and chaparral communities (Duncan et al. 2004). It is found almost statewide, except for the high Sierra and the southern deserts (Jepson eFlora 2014). In Idaho and Oregon, rangeland infested with medusahead approximately doubled in the last 40 years of the 20th century (Davies and Johnson 2008). This weed is now found in almost every Oregon county, in most of western and southern Idaho, eastern Washington, and northern Nevada. It occurs in patches in Utah and Arizona and has recently been reported in the eyebrow of Montana. Medusahead is a state-listed noxious weed in California, Colorado, Nevada, Oregon, and Utah.

Mechanisms of Spread

Hooks, barbs, and awns are common adaptations in seeds transported by animals (Shmida and Ellner 1983; Sorensen 1986). Medusahead seeds are small, with long awns barbed with silica scales. These seeds are well suited for attaching to animal fur, clothing, vehicles, and machinery. It is thought that medium-range dispersal of medusahead is primarily by travel in coats of livestock (Figure 3). The seeds do not appear to be stashed by rodents (Longland 1994) or used by birds (Goebel and Berry 1976).

Long-range dispersal – for example, the introduction of medusahead to North America, or movement from lowland pastures to the intermountain region – is probably always abetted by human activity. Dissemination might occur by seeds attaching to clothing or vehicles (Figure 4) or to livestock being trucked to seasonal grazing sites. In a survey of medusahead distribution in southeastern Oregon, Davies et al. (2013) found that infestations were concentrated along travel routes.

Figure 3. Seeds attach readily to cattle

(Photo: Erica Spotswood, UC Berkeley)

Figure 4. Seeds move with human activity

Medusahead and other awned invasives can attach to clothing. (Photo: Erica Spotswood, UC Berkeley)

Chapter 2: Impacts

In both lowland rangelands and in high-elevation semiarid systems, medusahead is considered to be an ecosystem transformer species (Richardson et al. 2000; Wells et al. 1986). This places it among the worst weeds: not only does medusahead compete for resources with more desirable species, but it changes ecosystem function to favor its own survival at the expense of the entire ecosystem.

Displacement of natural vegetation has substantial impacts on the structure, organization and functioning of ecosystems. Loss of native plant species can permanently change nutrient and hydrologic cycles and accelerate erosion (Olson 1999). The costs of lower productivity and the increased costs of managing medusahead can have effects far beyond the ranch gate, often having a negative impact on rural economies.

Forage and Habitat

Medusahead foliage has poor palatability owing to a high silica content (approximately 10% dry weight) (Bovey et al. 1961; Hironaka 1994) and a rough tex-

Figure 5. Medusahead on foothill rangeland

Medusahead can develop into monotypic stands that limit the establishment of desirable rangeland species.

Figure 6. Greater sage grouse
Centrocercus urophasianus. *(Photo: Pacific Southwest Region US Fish and Wildlife Service)*

ture (George 1992; Lusk et al. 1961). Due to the high silica content, particularly once seed is set (Murphy and Turner 1959), medusahead is of little value in livestock production and wildlife habitat. Furthermore, mature medusahead seeds have long, stiff, sharp, barbed awns, which discourage seed predation. As with downy brome, these spiny awns can injure mouth and throat tissues of grazing animals, causing reductions in feed intake and weight gain (Currie et al. 1987).

As forage, composition of medusahead is comparable to many desirable forage species in moisture content, crude protein, crude fat, crude fiber and lignin (Bovey et al. 1961). However, its palatability is limited, especially as it matures.

Because grazing animals selectively avoid this plant, and because medusahead thatch tends to suppress desirable forage species (see below), infestations often develop into near-monotypic stands (Figure 5). Dense medusahead infestations can reduce grazing capacity on rangelands by 75% to 80% (Hironaka 1961; George 1994).

Medusahead figures heavily in habitat degradation across the range of sage grouse (*Centrocercus* spp.) (Figure 6) in the intermountain region. Medusahead displaces sagebrush, forbs, and perennial bunchgrasses, and contributes to an altered fire regime (Knick and Connelly 2011). In undisturbed habitat, sage grouse feed on leaves of sagebrush and forbs, and find shelter under sagebrush and other shrubs. Invasive annual grasses such as medusahead are one of the main identified threats to the sagebrush steppe ecosystem. The medusahead threat to this iconic species has given impetus to regional management coalitions such as the USDA-funded Ecologically-Based Invasive Plant Management (EBIPM) program.

Medusahead seeds are less used by seed-eating birds than other grasses, even downy brome (Goebel and Berry 1976). Native seed-eating rodents also prefer seeds of other species, tending to avoid medusahead-infested areas (Longland 1994). Consequently, the effects of a medusahead infestation are felt throughout the faunal community.

Thatch

The high silica content in medusahead foliage not only discourages grazing but also retards decomposition of senesced plants (Bovey et al. 1961; Hironaka 1994). As a result, the old stalks and foliage of medusahead often build up into a thick, persistent thatch layer (George 1992; Young 1992) (Figure 7). Medu-

Figure 7. Medusahead thatch
This thick blanket of old medusahead material forms a mulch which prevents establishment of other plant species. (Photo: Gilbert DelRosario, Dow AgroSciences)

sahead is adapted to germinating and establishing through its own thatch.

At the same time, this thatch reduces light penetration to the soil surface, inhibiting germination of seeds of plant species which require light stimulation. Seeds of large-seeded species may be prevented from reaching the soil, e.g., blue oak in California (Borchet et al. 1989); smaller seeds may not contain sufficient resources to sustain growth of a shoot through the litter layer. The thatch delays soil warming in spring and ties up nutrients. Thus, a thick medusahead litter layer physically suppresses germination, establishment, and survival of other rangeland species (Bovey et al. 1961; Brannon 1972; Evans and Young 1970; Harris 1977; Young 1992; Young et al. 1971).

In Great Basin sagebrush steppe communities, medusahead infestations are correlated with reduced diversity, richness, abundance, and biomass of native plant species and functional groups (Davies 2011; Davies and Svejcar 2008; HilleRisLambers et al. 2010). Young (1992) hypothesized that medusahead litter accumulation was the greatest threat to plant biodiversity in the Great Basin (Figure 8).

Fire Cycles

In semiarid big sagebrush (*Artemisia tridentata*) steppe, medusahead acts as a fire promoter (Brooks

Figure 8. Medusahead at high elevations

This Oregon steppe habitat is at risk of conversion to exotic annual grassland. (Photo: David Bohnert, Eastern Oregon Agricultural Research Center, Burns, OR) et al. 2004) in a manner similar to downy brome in more arid parts of the Great Basin (Brooks and Pyke 2001; D'Antonio and Vitousek 1992; Torell et al. 1961). Like downy brome, medusahead fills in between the sagebrush, creating a continuous fuel corridor that accelerates the fire cycle. Areas in the Great Basin dominated by downy brome have an average fire return interval of 50 to 80 years, compared to fire return intervals of ~200 years on native sagebrush steppe (Balch et al. 2013). The persistent thatch accompanying medusahead infestations may pose a risk of fire in any season.

Unlike many low-elevation shrub species, many species of sagebrush are unable to regenerate from more frequent fires. This change in fire frequency rapidly degrades the ecosystem from a native shrub community to predominantly nonnative annual grassland. In addition, increased fuel accumulation from annual grass infestations increases the rate of fire-induced mortality of perennial grasses (Davies et al. 2009). As a secondary impact, this contributes to the decline of sagebrush-dependent wildlife species such as sage grouse (Davies and Johnson 2008).

Resource Consumption and Competition

Medusahead competes for water and nutrients with annual and perennial grasses, particularly while perennial grasses are establishing from seed (Clausnitzer et al. 1999; Harris 1977; Harris and Wilson 1970; Hilken and Miller 1980; Young and Mangold 2008). In the Great Basin, medusahead is even able to displace downy brome, an invasive early-season annual grass, on sites where there is still soil moisture available after downy brome matures, e.g., on clay soils (Hironaka 1961).

The buildup of persistent thatch ties up soil nutrients, making them unavailable to other plant species (Brannon 1972; Facelli and Pickett 1991). In addition, there is some evidence that this litter has allelopathic effects, i.e., leaches chemicals which suppress germination of other plant species (Zhang et al. 2010b).

In comparing soils from medusahead-infested sites in Lassen County, CA, with uninfested sites, Trent et al. (1994) found reduced nitrogen mineralization, reduced total nitrogen, and significantly increased soil pH in infested sites. However, they did not detect significant effects on soil microbiota.

Genetic Integrity

Medusahead has not been shown to impact the genetic integrity of native species. Although some classifications place medusahead in the genus *Elymus*, alongside a number of North American native grasses, there is no evidence that they hybridize.

Chapter 3: Biology and Ecology

Figure 9. The legend and the reality

In Greek mythology, Perseus defeated the snake-haired Medusa. Medusahead is named for its twisting awns.

Medusahead is a winter annual, native to the Mediterranean region of Europe, an area with a climate of wet winters and warm, dry summers. Thus, medusahead is well suited to the Mediterranean-type climate common in semiarid parts of the western United States. Such regions are characterized by annual grasslands, oak woodlands, and chaparral communities. In addition to Mediterranean climatic regions, medusahead also thrives in drier parts of the Intermountain West and the Great Basin, which are dominated by shrubs, perennial grasses, and downy brome.

Like most winter annual grasses, medusahead germinates in fall, grows slowly during winter, and grows rapidly in spring. However, in areas with a Mediterranean climate pattern, most other winter annual grasses complete their life cycle by mid-spring. Medusahead matures two to four weeks later, after other annual grasses have senesced (Harris 1977; Young 1992). During this late-season maturation period, medusahead can access soil moisture and sunlight without competition from other annual grasses.

Taxonomy and Identification

Medusahead's species name is most commonly given as *Taeniatherum caput-medusae* (L.) Nevski. It is a member of the tribe Triticeae in the Poaceae (grass family). Its taxonomy is complex across its native range (Peters 2013). As a result, its classification has also been difficult in its introduced range, primarily due to multiple, morphologically similar subspecies.

Carl Linnaeus, the father of modern taxonomy, originally classified medusahead in the genus *Elymus* (*Elymus caput-medusae* L.) in 1753, naming the species for the snake-haired Gorgon of Greek mythology (Figure 9). In 1772 Schreber described a second related species, which he called *Elymus crinitus* Schreb., and in 1827 Link described a third species of medusahead, which he named *Elymus platatherus* Link. (Frederiksen 1986). In 1934, Nevski (1934) proposed that the distinct genus *Taeniatherum* be used to classify these three species. He noted that *Taeniatherum* differed from *Elymus* in having one-flowered spikelets with connate, subulate glumes, as well as an annual life cycle. Interestingly, the most recent edition of *The Jepson Manual, Vascular Plants of California*, has lumped a number of related genera into *Elymus* and lists medusahead as *Elymus caput-medusae* L. (Baldwin et al. 2012), although the USDA Plants Database (USDA 2014) and the Biota of North America Program (BONAP 2014) continue to use the genus *Taeniatherum.*

Nevski and others classified three species of *Taeniatherum* in Eurasia, but today most taxonomists consider medusahead to be a single species, *T. caput-medusae* (L.) Nevski, with three subspecies: ssp. *caput-medusae*, ssp. *asperum* (Simk.) Melderis, and ssp. *crinitum* (Schreb.) Melderis (Frederiksen 1986). Of these subspecies, ssp. *caput-medusae* is found in the western Mediterranean, ssp. *crinitum* occurs from eastern Europe to Central Asia, and ssp. *asperum* is found across the geographic distribution of the species. In 1960, Major (1960) determined that the material introduced to the United States was *Taeniatherum caput-medusae* ssp. *asperum.* In a study of *Taeniatherum* using molecular genetic markers, Peters (2013) found that (1) ssp. *crinitum* is genetically differentiated from the other two, (2) some populations of ssp. *caput-medusae* and ssp. *asperum* co-occur within different clusters, and (3) ssp. *asperum* is the most variable. She confirmed that only ssp. *asperum* is believed to occur in the United States, where it is invasive in portions of California, Idaho, Nevada, Oregon, Utah, and Washington. For now, *Taeniatherum caput-medusae* is the most frequently used nomenclature for medusahead.

Major (1960) suggested that the limited variability within populations of medusahead indicated that there were very few introductions of the species, perhaps even a single introduction. More recently, however, genetic analysis has suggested that medusahead was introduced to the United States on at least seven separate occasions (Novak 2004; Novak and Sforza 2008). Similarly, Peters (2013) also showed that there were multiple introductions of medusahead to the western United States, likely from France, Sardinia, Greece, and Turkey. However, Great Basin populations of medusahead are less diverse, probably representing only a couple of introductions (Rector et al. 2013), presumably of arid-adapted biotypes.

Water Use Patterns and Soils

Medusahead can occur on sites with rainfall ranging from 10 to 40 inches (25 to 102 cm) per year, although it is more typically found on sites receiving 12 to 24 inches (30 to 61 cm) (George 1992; Major et al. 1960; Sharp et al. 1957; Torell et al. 1961). Because it matures late compared to other annual grasses, medusahead benefits more from spring rainfall than from earlier fall and winter rainfall (George 1992). This may help to explain why medusahead thrives in arid, high-elevation Great Basin sites: although precipitation is limited, much of it falls as snow which melts during the spring growing season, providing the moisture necessary for medusahead to survive into the early summer. It has also been shown that medusahead is better able to survive on infrequent precipitation events than are downy brome or ventenata (*Ventenata dubia*), two other invasive annual grasses found in the Great Basin (Bansal et al. 2014).

Medusahead is found on many soil types. At the upper end of its precipitation range, it can survive on sites with coarse, poorly developed soils. In general, though, it is less likely to occur on sandy, well-drained substrates (Dahl and Tisdale 1975). Under the right conditions, medusahead can invade areas of loamy soil (Miller 1996). In more arid areas, medusahead tends to require well-developed clay soils, which help retain soil moisture until later in the season (Dahl and Tisdale 1975; Young and Evans 1970) (Figure 10). The thick silica-rich thatch which often develops in infested areas favors medusahead in dry sites, perhaps by acting as a mulch that slows water loss from the soil (Cherr 2009). Soil disturbance increases the potential for medusahead invasion on all soil types (Miller 1996).

Soils with high nutrient levels are more susceptible to medusahead invasion and establishment. On such soils, medusahead also is more likely to inhibit native vegetation, because its seedlings acquire soil resources more efficiently than do native grass seedlings. Although medusahead can potentially outperform native species on either low or high nutrient soils, the difference in growth rates is exacerbated under high nutrient conditions (James 2008a, 2008b; Mangla et al. 2011; Monaco et al. 2003b; Young and Mangold 2008).

Figure 10. Shrink-swell clays favor medusahead

In drier areas, soils which retain water help this species to survive (Photo: Alex Boehm, USDA-ARS, Boise, ID)

In a reciprocal transplant experiment, Blank and Sforza (2007) found that medusahead seeds from both California and France produced larger plants in California soil compared to French soil, reflecting higher nutrient levels in the soils here. California plants also appeared to have evolved a greater ability to take up manganese from the soil.

It has been reported that soil biotic crusts are absent in parts of the Great Basin infested with medusahead (Kaltenecker 1997; Young 1992). Biotic crusts are microfloral communities of algae, bacteria, fungi, and lichens which grow on the soil surface in semiarid regions (Figure 11). These crusts stabilize soils, influence nutrient levels, and help to retain moisture (Belnap 1994; St. Clair and Johansen 1993). Biotic crusts can be broken up and damaged by trampling, as in areas of heavy grazing, and may take many years to recover (Cole 1990). Invasive annuals such as medusahead find it easier to establish on loose soil in the absence of biotic crusts (Kaltenecker 1997).

Figure 11. Biotic (cryptogamic) crust

Natural Bridges National Monument, UT. These crusts are found on arid-region soils worldwide. (Photo: Nihonjoe, Wikimedia Commons) →

It is hard to say whether preexisting damage to biotic crusts in the Great Basin facilitated medusahead invasion, or the biotic crusts began to fail as a result of invasion. However, it is also known that fire can injure biotic crusts, and thus increases in fire frequency with medusahead invasion are likely to have a negative impact.

Germination, Dormancy, and Seed Longevity

Like most other winter annual grasses, medusahead begins to germinate in fall with the first rains, and rapidly develops its root system during winter (Johnson et al. 2011; Sheley et al. 1993). However, seeds can continue to germinate through winter and spring in milder climates (Young 1992). In colder areas with winter snowfall, there can be a second large flush of germination in spring after the snow melts.

Most seeds have a minimal dormancy period and germinate in the first season after dropping from the parent plant (Hironaka 1961; Murphy and Turner 1959; Sharp et al. 1957; Young et al. 1968). When dormancy does occur it appears to be a temperature-related afterripening process, where germination will not occur except after exposure to cold temperatures for 90 to 120 days after maturity (Young et al. 1968). It has been suggested that this afterripening period is controlled by inhibitory substances in the awns of fresh seed (Nelson and Wilson 1969).

In laboratory studies optimal germination of medusahead occurs at 68 to 77 F (20 to 25 C). However, when seeds are in litter in the field, optimum germination temperatures appear to be lower (50 to 59 F; 10 to 15 C), comparable to typical fall temperatures following rainfall events (Young et al. 1971).

Heavy infestations of medusahead can produce dense stands of seedlings with 130 to 1,860 plants ft^{-2} (1,400 to 20,000 plants m^{-2}), depending on the site (Bartolome 1979; Johnson et al. 2011; Sharp et al. 1957). Because the germination rate is so high and seed dormancy is low, it appears that the majority of medusahead seeds persist in the soil for less than two years, with very few seeds surviving for three years or more (Young et al. 1970).

Figure 12. Medusahead can germinate in and under thatch

(Photo: Ryan Steineckert, Eastern Oregon Agricultural Research Center, Burns, OR)

Effects of Medusahead Thatch

Medusahead thatch acts as a barrier preventing the germination or establishment of desirable grasses and forbs (Harris 1977; Young et al. 1971). In contrast to many other species, medusahead establishes well in the presence of its own thatch (Harris 1977; Young et al. 1971). In one study, medusahead seedling establishment was 47 times greater under litter than on bare ground (Evans and Young 1970). The architecture of the caryopsis (seed) is ideal for moving through the litter layer. The caryopsis is narrow and pointed (<1 mm wide) with a very sharp callus tip and an elongated, non-geniculated (bent) awn. The small barbed silica hairs on the caryopsis point backward, allowing the narrow seed to move unidirectionally down through the litter (Young 1992).

Few desirable species have seeds adapted for germination in a thick thatch layer. Many species are forced to germinate in or on top of the litter rather than in contact with the soil (Young et al. 1971). We speculate that small-seeded species which do reach the soil surface have trouble generating shoots long enough to reach above the litter. Thus, the establishment of desirable rangeland species is restricted when a thick medusahead litter layer is present (Davies and Svejcar 2008; Evans and Young 1970; Harris 1977; Young et al. 1971; Young and Mangold 2008).

Unlike most other rangeland species, medusahead seeds are adapted to germinate in and under thatch (Figure 12). Germination is controlled by the relative humidity within the litter. Each seed sends out an aerial root which is more resistant to drying than initial roots of competing species (Young et al. 1971). In addition, should the primary root dry and die, the seed can produce multiple new adventitious roots following remoistening (Young 1992). This affords medusahead a big advantage, as a caryopsis has multiple opportunities to root even under drying events that kill most competing seedlings.

Growth and Establishment

Following germination in fall or winter, medusahead grows slowly during the cool months. In the cooler parts of its range, leaf development in fall-germinating plants can reach a few inches before cold weather slows the process (Young 1992). However, growth can continue, even under a layer of snow (Harris and Wilson 1970; Hironaka 1961). In fact, in cold temperatures medusahead roots grow faster than do the roots of perennial grasses (Harris and Goebel 1976). This investment allows medusahead to make a rapid start in spring.

When the weather warms in spring, medusahead begins a period of rapid aboveground growth. The youngest leaves are very narrow, bright green, in a flattened clump. As growth continues the plants develop longer leaves and often take on a grey-green hue. Eventually the plants develop tillers, which may be more-or-less prostrate in open areas but erect in dense grassland. Two to three months after spring growth begins, the plants develop flowering stems (culms) and heads. Initiation of flowering often occurs in mid- to late April in milder climates at lower elevations, and from late May to early June in cooler climates at higher elevations (Kyser et al. 2012a; Lusk et al. 1961; Sweet et al. 2008). Medusahead appears to require hot summer temperatures – and may have a day-length trigger – for reaching maturity (George 1992).

At maturity, medusahead populations can exceed 930 plants ft^{-2} (10,000 plants m^{-2}) (Young 1992). (Figure 13 shows an example of the kind of spacing this plant density represents.) However, individual plants are phenotypically plastic enough that a population of 1 plant ft^{-2} (10 plants m^{-2}) has the potential to produce more seed than plants at a thousand times greater density (Young 1992). In areas where control efforts reduce the density of medusahead the following season, surviving individual plants grow larger and may reach similar values for total cover and seedhead production (Kyser et al. 2013). In addition, low-density populations of medusahead may remain green and productive longer into the growing season because there are more resources available to individual plants, particularly soil moisture.

Reproduction and Seed Dispersal

Studies of both native and invasive populations of medusahead have determined that this species is almost entirely self-pollinated (Prior et al. 2013). Flowering generally occurs from late spring to early summer (Sweet et al. 2008), with most seedheads maturing by July (Sharp et al. 1957). In contrast, most other annual grasses have completed their life cycle and their seeds have senesced before medusahead seeds have matured. For example, downy brome in the Great Basin flowers two to four weeks earlier than medusahead (Dahl and Tisdale 1975; McKell et al. 1962a; Young et al. 1970). Similarly, at lower elevations, annual forage grasses such as slender oat and wild oat (*Avena barbata* and *A. fatua*), soft chess (*Bromus hordeaceus*), and rye grass (*Lolium perenne* ssp. *multiflorum*, also called Italian ryegrass) flower two to four weeks earlier than medusahead. For this reason, medusahead is often referred to as a 'late-season grass' (Figure 14).

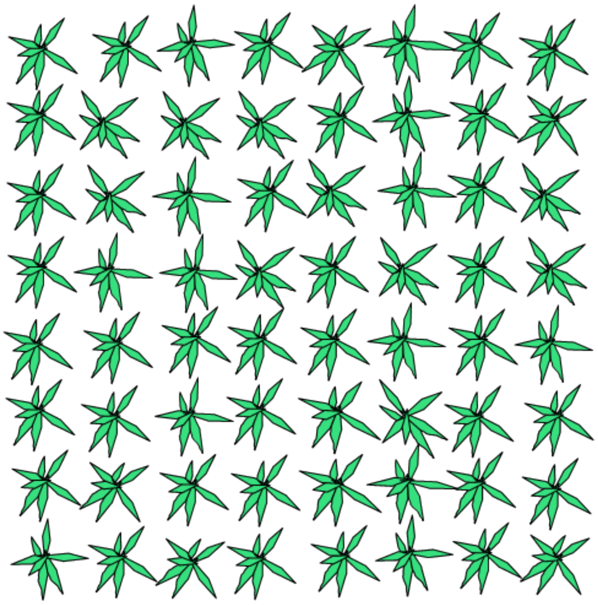

Figure 13. Density of 10,000 plants m^{-2}
Actual size portrayal.

Figure 14. Medusahead is still green
when most other annuals have senesced.

Figure 15. Medusahead seedheads

Seedheads ripen from green to reddish, then finally to straw-colored.

Figure 16. Seeds from a single head

Medusahead seeds twist as they dry out. This may help them catch onto animal fur.

The flowering heads of medusahead are green when they first appear, taking on a reddish tinge as they mature, and finally drying to a straw color at senescence and seed dispersal (Figure 15). Seedheads take about one month to go from green to senescent (Sweet et al. 2008). Once the seeds are filled, it appears that most seeds are viable even in the green stage (Sweet et al. 2008).

An average medusahead plant produces three to five seedheads, with a mean of 5.6 seeds per head in drier areas and 8.7 seeds per head in wetter sites (Sharp et al. 1957) (Figure 16). In richer soils, or in areas where competition is limited, medusahead may produce many more heads and more seeds per head (Miller et al. 1999) (Figure 17). Like most annual species, medusahead produces high numbers of seeds per unit area per year, with measurements ranging

Figure 17. A single green medusahead plant

Under the right conditions, a single plant can produce dozens of seedheads and hundreds of seeds. (Photo: Ryan Steineckert, Eastern Oregon Agricultural Research Center, Burns, OR)

from 130 to 5,574 seeds ft^{-1} (1,400 to 60,000 seeds m^{-2}) (Clausnitzer et al. 1999; Major et al. 1960; Young 1992). This equates to 5.7 to 243 million seed ac^{-1} (14 to 600 million seed ha^{-1}).

Medusahead maturation and seed disarticulation generally continue through most of summer (DiTomaso et al. 2008; Laca 2009). A few seeds will continue to disperse from the parent plants into fall (Davies 2008). At maturity, the seedheads disarticulate easily, and seed usually drops close to the parent plant. Studies have shown that 75% of seeds land less than 1.6 ft (0.5 m) from the invasion front, and most of the remaining seeds disperse no further than 6.6 ft (2 m) (Davies 2008).

Although most seed remains in, or near, the infestation, long-distance movement of seeds can occur through a variety of vectors, including animals, human activity, wind, and water (Nafus and Davies 2014).

Medusahead seeds have long awns covered in small barbs that facilitate dispersal by adhesion to the fur of animals, especially sheep (Davies 2008; Davies and Sheley 2007a; Furbush 1953; Miller 1996). Medusahead seeds also can be transported through human activity. Seed caught in clothing, equipment, the fur of pets, or mud adhering to a vehicle can move long distances and infest new areas (Davies 2008; Davies et al. 2013; Nafus and Davies 2014)

Wind has also been shown to be a vector for the short-distance movement of medusahead seed, though usually indirectly (Davies and Sheley 2007b; Furbush 1953). For example, medusahead seed can be moved short distances [typically less than 3.9 inches (10 cm)] when the disarticulated seeds get caught on other plants whose main mode of dispersal is wind, including tumble mustard (*Sisymbrium*

Figure 18. Medusahead in a riparian zone

In this scenario, a river running through high desert steppe has the potential to move medusahead seed. Note that downy brome is ready to drop seed although medusahead is still green. (Photo: Ryan Steineckert, Eastern Oregon Agricultural Research Center, Burns, OR) *altissimum*) and Russian-thistle (*Salsola tragus*) (Davies and Sheley 2007b). In some cases whole medusahead inflorescences may break off and tumble with the wind (Turner et al. 1963).

Local dispersal can also occur through water when medusahead is growing near riparian areas, though this is unusual (Figure 18).

Medusahead probably is not widely distributed by granivores (grain feeders). Most mammalian granivores don't appear to stash the seed, with the exception of deer mice (*Peromyscus maniculatus*) (Longland 1994). The seeds are not liked by birds (Goebel and Berry 1976) and in fact appear to be more-or-less indigestible (Savage et al. 1969).

Following seed drop, the empty seedheads with long bracts still attached may remain standing on the dead stalks through fall and into winter (Figure 19), eventually turning ash-grey in color. These medusahead skeletons can help the land manager to determine where to focus control efforts even in the off-season (Figure 20).

Figure 19. Mature seedheads
before and after dropping seed

Figure 20. Medusahead skeletons
often remain standing after seed drop.

Chapter 4: Management

It can be difficult to selectively remove an invasive grass such as medusahead from a grassland community. Many treatments that might be effective in controlling medusahead are likely to have negative effects on other plant species that are desirable components of forage and habitat. For example, some herbicides that control medusahead can also severely impact other desirable vegetation, particularly other annual grasses (Kyser et al. 2007; Shinn and Thill 2004).

A number of different management options are available, broadly grouped as mechanical, cultural, and chemical control methods (Figure 21). Regardless of the management technique used, medusahead must be prevented from producing new seed for two to three years in order to deplete the soil seedbank. In some cases, combining multiple management techniques will allow prevention of two years' seed production with a single year of activity: for example, prescribed burning in summer (prevents seed production in the first year) followed by application of preemergence herbicide in fall (prevents seed production in the following year). Two years of control may reduce the population to the point where less intensive management methods can be used, e.g., lower rates of herbicide or localized use of mechanical treatments or high-density grazing.

Figure 21. Management techniques

Mechanical treatments, grazing management, prescribed burning, revegetation, biocontrol, and chemical treatments are discussed below. (Mower, G. Kyser; cattle, J. Davy; burn, K. Davies; wheatgrass, M. Lavin; smut fungus, R. Sforza; aerial application, R. Wilson. For full credits see following sections.)

The scientific literature reports many inconsistencies in the control of medusahead. Some control techniques which appear to work well in one area may not provide sufficient control in another area. This reflects the wide scope of environments that medusahead occupies, over a diverse range of climates, soil types, and plant communities. When considering control techniques, the most important distinction to make is between low-elevation sites (e.g., the foothills, grasslands, and coastal ranges of California, Oregon, and Washington) and high-elevation sites (cold-winter steppe communities in the Great Basin). Medusahead management on low-elevation foothill rangeland is very different than management on high-elevation rangeland in the intermountain region.

Management on Low-Elevation Rangeland

Low-elevation rangeland, in the foothills, coastal ranges, and large valleys, consists primarily of annual grassland. Under proper grazing management, the annual grasses here are very competitive with medusahead. However, medusahead thatch is a much greater problem on these highly productive sites.

One of the ways medusahead successfully competes with other rangeland plants, particularly at low elevations, is its late flowering time. Medusahead flowers and goes to seed in late spring, when soil moisture reserves are nearly depleted and after most other plants have senesced. This allows medusahead to use the remaining soil moisture without competition from other species. However, this also leaves a window of two to four weeks during which medusahead can be controlled with minimal damage to desirable forage species. If medusahead foliage and seedheads are removed or killed in late spring before seeds mature – by mechanical means, fire, grazing, or chemicals – the plants usually do not have the resources to recover and produce new seedheads. As an additional benefit, desirable plants have usually dropped their seed by this time and are thus less vulnerable to control methods used for medusahead.

A second way that medusahead competes with other plants, especially on low-elevation, high productivity sites, is by building up a persistent thatch which suppresses germination and establishment of desirable species. Control techniques that remove the thatch, e.g., some mechanical treatments, fire, and intensive grazing, can help to reduce medusahead's competitiveness compared to other species, resulting in some suppression of the weed (Evans and Young 1970; Kyser et al. 2007).

Management on Intermountain Rangeland

Options for managing medusahead on high-elevation rangeland are somewhat limited compared to low-elevation sites. Because winter is longer and the growing season is shorter, most plant species flower at about the same time, as soon as the weather warms in spring. Unlike low-elevation infestations, there isn't much of a control window between the flowering times for desirable species and medusahead. Prescribed burning and some mechanical control techniques are less effective at high elevations and may cause more injury to native species than to medusahead.

On the other hand, some fall-applied preemergence herbicides appear to be more effective on high-elevation sites. This may be because these chemicals degrade more slowly during the colder winters. Fall-applied preemergence herbicides are also more widely used in the intermountain region because most desirable vegetation is perennial, thus allowing the use of preemergence chemicals for selective control of exotic annuals such as medusahead.

Economics of Medusahead Control

Private land grazing fees during 2005-2010 averaged \$16 to \$18 per animal unit month (AUM) in California and \$14 to \$15 per AUM in other western states (Stechman 2011). An animal unit is commonly referenced as a lactating cow weighing 1,200 lb (544 kg) with a small calf weighing less than 300 lb (136 kg). At peak milk production of 20 lb (9 kg) day^{-1}, two to three months after calving, the NRC estimates dry matter consumption of approximately 28 lb (13 kg) day^{-1} (National Research Council 2000). Thus an AUM is approximately 840 lb (381 kg) of forage.

One site in the Sierra Nevada foothills provides an example of forage production capability in the annual rangeland type (George et al. 2001). Over 16 years, this site produced an average 2,800 lb acre^{-1} (3,138 kg ha^{-1}) of dry matter during each six-month growing season. (This is considered a very productive site, comparable to many parts of the northern Central Valley and the California coastal prairie.) On topography with 0 to 10% slopes, as at this site, cattle are able to harvest about 50% of forage production. Thus, this foothill site provided average forage of 1,400 lb acre^{-1} (1,570 kg ha^{-1}), or 1.7 AUM acre^{-1} (4.2 AUM ha^{-1}).

Table 1. Typical forage production in regions of the western states

Estimated production values are from the National Resources Conservation Service Web Soil Survey. Rental values are from American Society of Farm Managers and Rural Appraisers (2013).

Region	Est. grazeable forage (50% of production on 0 to 10% slopes)	Est. AUM (animal unit months)	Est. forage value at \$16 AUM^{-1}	2013 rental values (per acre)
Northern valleys, foothills, & coast range (CA)	1,000 to 2,000 lb acre^{-1} (1,120 to 2,240 kg ha^{-1})	1.2 to 2.4 acre^{-1} (2.9 to 5.9 ha^{-1})	\$19 to \$38 acre^{-1} (\$47 to \$94 ha^{-1})	\$10 to \$30
Southern Central Valley & coast range (CA)	500 to 1,250 lb acre^{-1} (560 to 1,400 kg ha^{-1})	0.6 to 1.5 acre^{-1} (1.5 to 3.7 ha^{-1})	\$10 to \$24 acre^{-1} (\$24 to \$59 ha^{-1})	\$6 to \$20 (west side) \$12 to \$35 (east side)
Intermountain region	200 to 900 lb acre^{-1} (224 to 1,008 kg ha^{-1})	0.2 to 1.1 acre^{-1} (0.6 to 2.6 ha^{-1})	\$4 to \$17 acre^{-1} (\$9 to \$42 ha^{-1})	\$12 to \$18 (northern NV)

Table 1 presents typical forage production for several regions in the western states. It should be noted that foraging efficiency decreases drastically with increasing slopes (Becchetti et al. 2011). There are also requirements for a minimum amount of residual dry matter (RDM) to be left on site following grazing, to provide for erosion control, rainfall infiltration, and ecosystem recovery; these requirements vary by site (Bechetti et al. 2011).

At \$16 to \$18 per AUM, rangeland with grazeable production of 1.7 AUM acre^{-1} (4.2 AUM ha^{-1}) has a theoretical lease value of \$27 to \$31 acre^{-1} (\$67 to \$77 ha^{-1}). This value assumes that all forage produced is grazed by livestock. However, dense infestations of medusahead can reduce carrying capacities by up to 70% (Major et al. 1960; Hironaka 1961; George 1992). A 70% reduction would reduce the theoretical harvest to 0.5 AUM acre^{-1} (1.3 AUM ha^{-1}), decreasing the value to \$8 to \$9 acre^{-1} (\$20 to \$23 ha^{-1}).

In this example of a heavy infestation of medusahead on a highly productive site, a single year of medusahead control would justify an investment of \$19 to \$22 acre^{-1} (\$47 to \$54 ha^{-1}). A more moderate infestation that reduces carrying capacity by 40% would justify an investment of \$11 to \$13 acre^{-1} (\$27 to \$32 ha^{-1}).

This example makes many assumptions that may prove unrealistic. For example, it assumes that medusahead is completely controlled, that forage will return to full carrying capacity in the year of treatment, and that all forage that replaces medusahead is good for grazing. In reality, many treatments for controlling medusahead will result in temporary reductions in forage, and medusahead management is usually a multi-year project. Thus, even in this "best case" example, it will take several years to realize a return on the investment in controlling medusahead.

Investments in medusahead control will realize the fastest return on highly productive rangelands with mild topography that is highly accessible to grazing. However, at any site, the benefits of controlling medusahead will accumulate over many years. In addition, controlling medusahead at one site reduces the risk of the infestation spreading to surrounding areas.

Chapter 5: Mechanical Control Methods

"Mechanical control" of medusahead refers to any technique used to remove or physically damage the plants. Mechanical control on a large scale requires the use of power equipment.

Hand Pulling or Hoeing

Pulling or hoeing individual medusahead plants may be effective on a small scale. This should be done when medusahead plants are large enough to distinguish from other grasses, but before medusahead sets seed. Most medusahead infestations are too dense and on too broad a scale for this to be a practical option. However, removal of individual plants may be useful in newly established, small populations or as maintenance on sites following large-scale control efforts. One advantage to this technique, where practical, is that it is very selective and causes minimal disturbance to desirable species.

Mowing

Mowing in late spring when medusahead is in the early flowering stage can suppress seed production and reduce the medusahead population in the following year. For effective control, mowing must be completed late in the plant's development but before medusahead produces viable seed. On low-elevation rangeland, desirable forage grasses are usually finished producing seed by late spring, so mowing won't impede their reproduction.

Mowing too early, when medusahead is still small, will miss low-growing plants. In addition, an early mowing is likely to cut off desirable plant species before they can set seed. Mowing in mid-spring, when medusahead is larger but has not yet begun to send up flowering stems, may remove some medusahead foliage but still gives medusahead enough time to recover and go to flowering. For example, one study found that April mowing did not control medusahead, but May mowing was effective (Turner 1968). In clipping studies, it has been found that clipping at 1.2 to 2.4 inches (3 to 6 cm) during early flowering (from emergence of awns to emergence of anthers) nearly eliminated seed production (Zhang et al. 2010a).

One drawback to mowing is that it limits the availability of late-season forage. Although mowing doesn't remove forageable material from the site, it does break up the material and lay it on the ground where it may be of less interest to grazers. Mowing may also limit seed production in late-flowering desirable grasses such as rye grass. It may not be possible to mow in steep or rocky terrain. When rocks are present, mower blades may strike sparks and can start fires. And even in the best circumstances, mowers travel slowly, so there are practical limits to the total area which can be managed in this way.

Mowing is less advisable for medusahead infestations in high-elevation sagebrush communities. Studies have shown that mowing in these sites tends to favor exotic annual species, such as medusahead, over native perennials such as sagebrush and bunchgrasses (Davies et al. 2011, 2012). In addition, fuel costs and rocky, rugged terrain often make mowing such areas impractical.

Rangeland is usually mowed at a height of roughly 4 inches (10 cm). Mowers used in rangeland include flail and rotary (deck) mowers. Both types are pulled by tractors and powered by the tractors' power takeoff. Rotary mowers have fixed blades on a vertical shaft, like a large lawnmower. Flails have a

Figure 22. Flail mower
(Photo: Guy Kyser)

row of swinging metal rods or chains on a horizontal shaft (Figure 22). Flails are more widely used in rangeland, because the rods or chains are less likely to be damaged if they hit rocks. If the terrain is even and relatively free of rocks, a flail mower also gives the option of lowering the mow height to almost ground level, where it can break up the medusahead thatch. Thatch removal can give desirable forage species a competitive advantage, helping to suppress medusahead in the next season.

Tillage

Deep tillage (i.e., disking) is not a realistic option in many medusahead-infested areas owing to slopes, rocky soils, and the presence of desirable shrubs and trees (Figure 23). Tillage also increases the potential for erosion, loss of soil moisture, loss of organic matter, and loss of microbiotic crusts (Kaltenecker 1997; Young 1992). However, where possible, tillage can control existing medusahead plants, bury seed, and break up thatch. Compared to other grass species, medusahead seeds emerge poorly from depths greater than 2 inches (5 cm) (Young et al. 1969a), so tillage can favor desirable species. Thatch removal by tillage decreases medusahead's competitiveness and exposes the soil for more effective application of preemergence herbicides. Tillage should be done before medusahead produces seed. Tillage is a good way to prepare a site for reseeding (Young et al. 1969b); and in fact, owing to the potential drawbacks to tilling on rangeland, it is highly recommended that reseeding be included as a followup to tillage operations.

Because sagebrush and other native species in sagebrush steppe are not well adapted to disturbance, deep tillage is not recommended for medusahead control in intermountain rangeland. It is expected that this would have negative effects on the plant community, similar to mowing (see above). However, tillage may be a useful option in high-country pasture or other managed areas.

Shallow tillage, or harrowing, can help with medusahead management in some situations. Harrowing can be used to remove medusahead thatch and to incorporate seed during revegetation. However, harrowing does not control existing medusahead plants.

Harrowing causes less soil disturbance than deep tillage and can be used on rockier terrain. Some types are flexible (e.g., chain harrow, Figure 24) or 'springy' (e.g., spring tine harrow) and will slide over obstacles without breaking. Harrows also tend to weigh less than disks and can be pulled by smaller equipment; some can be pulled by ATVs or horses.

In one study, harrowing in fall with a spike harrow (at a high-elevation site in Lassen County, CA) or raking by hand (at a low-elevation site in Yolo County, CA) reduced medusahead cover by about 50% the following year (Kyser et al. 2007). This was presumably a result of removing the medusahead thatch, giving a greater competitive advantage to other grass species. Thatch removal also improved the efficacy of applications of the preemergence herbicide imazapic, which can be tied up in litter.

Figure 23. Disk (disk harrow)
(Photo: Josh Davy)

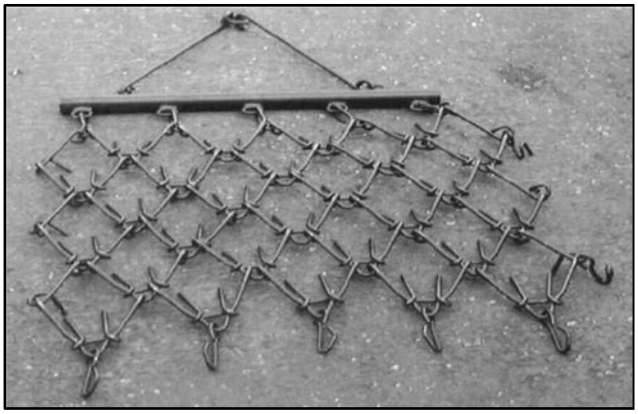

Figure 24. Chain harrow
(Photo: BSG Tractors and Machinery, UK)

Chapter 6: Cultural Control Methods

Grazing Management

Grazing is a natural process in grasslands. Properly managed livestock grazing can help to remove litter, recycle nutrients, stimulate tillering of perennial grasses, and reduce seedbanks of invasive plants (DiTomaso and Smith 2012). Furthermore, proper livestock grazing can restore rangeland services and increase resistance to invasion (Krueger-Mangold et al. 2006). Under light to moderate levels of grazing, many native forbs can increase in cover and frequency (Hayes and Holl 2003). In contrast, grazing exclusion during the growing season in California grasslands can lead to grass dominance and reductions in native and exotic legumes (*Trifolium* spp. and *Medicago* spp.) and filaree (*Erodium* spp.) (Bentley and Talbot 1951; Biswell 1956; Jones and Evans 1960). Another advantage of grazing as a management tool is that it can generate revenue while improving rangelands (DiTomaso and Smith 2012).

Prevention of overgrazing is one of the most important aspects of grazing management. Grazing too heavily in early spring can inhibit or remove competitive forage species, leaving more resources for medusahead as it comes into flower. In the intermountain region, overgrazing of perennial grasses in the intermountain region has assisted the invasion of downy brome (Knapp 1996) and is likely to favor medusahead (Sheley et al. 2008). Continuous grazing on perennial plants weakens the root systems as the plants sacrifice roots to regenerate shoot growth for photosynthesis. As the perennial grasses lose root mass, more water and nutrients become available to medusahead (DiTomaso and Smith 2012).

Although overgrazing can damage desirable plant populations, grazing too lightly can allow animals to select only the most desirable forage, leaving the less palatable species. This is often the case with spiny thistle species. At early stages of development, medusahead is palatable and its protein content is reportedly comparable to many other annual grass species (Bovey et al. 1961; Lusk et al. 1961; Torell et al. 1961). However, as medusahead matures it accumulates silica in the seedheads and foliage and becomes less palatable. At later stages, animals will avoid foraging on medusahead, which can lead to high seed production and larger infestations in subsequent years. Furthermore, once medusahead has flowered, the long sharp awns on the mature reproductive structures pose a risk of damage to flesh and fleece and can injure the eyes, nose, and mouth parts of grazing animals. In severe cases, these grass awns can penetrate the gums and jaw, causing irritation and infection in a condition called lump jaw (Mosley and Roselle 2006).

There are two key principles in using grazing to manage medusahead (DiTomaso and Smith 2012). First, medusahead is an annual grass and must produce seeds to survive. Therefore, it is critical to prevent medusahead plants from reproducing. By reducing the number of seeds produced, seed banks will eventually be depleted. Although grazing is not likely to prevent all seed production, even partial reduction in seed production by grazing can be helpful.

Second, it is important to maintain vigorous and healthy desirable vegetation. In the rangelands and grasslands of California, this may be other annual grasses, but in other regions of the west, it may be primarily perennial grasses. Grazing should be conducted at times and stocking rates which minimize the impact on desired species but maximize the effect on medusahead. Proper grazing can help shift the competitive advantage to favor desired species.

Regardless of management some sites are more susceptible to invasion than others, and even the best stewardship, including grazing management, may not prevent medusahead invasion. For example, on a sagebrush site with deep clay soil in northeastern California the level of medusahead infestation was similar regardless of whether the area was grazed or protected from grazing for over 30 years (Wagner et al. 2001). However, in many other areas grazing management can be an effective tool to reduce medusahead cover and seed production, as well as increase the cover of native forb species (DiTomaso et al. 2008; Griggs 2000; Reiner and Craig 2011).

Timing and Intensity of Grazing

Using grazing treatments at the correct timing and intensity is important in all areas of the western

United States (DiTomaso et al. 2008; Sheley et al. 2008; Sheley and Svejcar 2009). When medusahead is grazed at the proper timing, livestock can dramatically reduce seed production by foraging on the top portion of the plant. Such grazing, often referred to as precision grazing, can eventually reduce the medusahead seedbank (DiTomaso and Smith 2012). Studies have shown that the optimal timing is in late spring after medusahead stems begin to elongate and before the seed milk stage (DiTomaso et al. 2008; Emilio Laca, pers. comm.).

The proper intensity of grazing treatments is also critical to successful control of medusahead. The most effective results occur when grazing is high intensity and short duration (DiTomaso and Smith 2012). However, precision grazing of medusahead might be limited if high stocking densities have a negative impact on individual animal performance.

Figure 25. Intensive grazing with sheep
Late May grazing (at early flowering) controlled most medusahead in this plot.

Effect of Sheep and Cattle Grazing on Medusahead

Although medusahead palatability to livestock is relatively low, sheep will graze medusahead in the vegetative stage. As plants mature, sheep begin to selectively avoid medusahead, and it has been noted that sheep avoid areas with heavy medusahead thatch (Lusk et al. 1961). However, at high stocking rates sheep uniformly graze medusahead-infested grasslands in all vegetative stages.

In early studies using sheep, it was shown that heavy grazing in late spring reduced medusahead stands in summer (Lusk et al. 1961; Turner 1968). By contrast, grazing in early spring (March) or fall (October to November), alone or in combination, did not reduce medusahead cover (DiTomaso et al. 2008), and year-round grazing was associated with greater medusahead frequency (Harrison et al. 2003).

High density, short duration, mid-spring grazing in late April to early May gave excellent control of medusahead on California grassland in the Central Valley (DiTomaso et al. 2008) (Figure 25). At this timing, plants were in the "boot" stage or stem elongation phase, which is just prior to exposure of the inflorescences. At a high stocking rate (Table 2), sheep feed less selectively. The high density increased the grazing pressure on medusahead while avoiding detrimental impacts on more desirable species, which can occur with selective feeding behavior. As a benefit, this high intensity grazing did not cause detectable persistent effects on the productivity of the grassland (DiTomaso et al. 2008).

Summer evaluations of the April/May grazing studies showed a reduction in medusahead cover of 86% to 100% relative to ungrazed plots, regardless of whether it was used in combination with early spring or fall grazing (DiTomaso et al. 2008) (Figure

Table 2. Intensive grazing on one acre
Equivalents for rates used in DiTomaso et al. 2008

Number of sheep	Number of cattle	Time (days)	Stocking rate (AUD/acre)
400	80	1	80
100	20	4	80
57	11.4	7	80
40	8	10	80
28.5	5.7	14	80

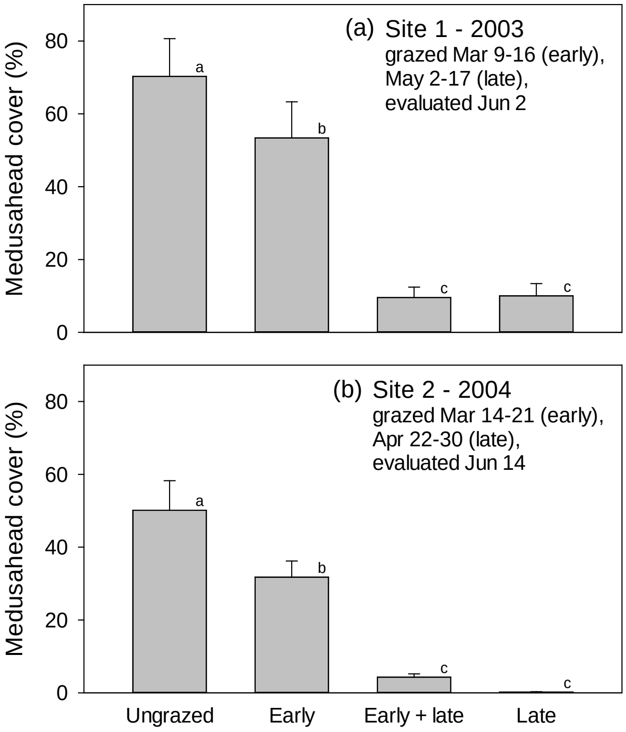

Figure 26. Timing of grazing

In intensive grazing trials with sheep in Yolo County, grazing too early (in March, around the time of tillering) was much less effective than grazing in May, at early heading (DiTomaso et al. 2008).

Figure 27. Prescribed grazing with yearling cattle

Central Valley foothills near Willows, CA. (Photo: Josh Davy)

26). Furthermore, mid-spring grazing just before flowering increased broadleaf cover, native species richness and abundance, and plant diversity.

Despite the success demonstrated with sheep grazing in managing medusahead, there are some logistical obstacles to precision grazing. Because the timing window is fairly narrow and the animal stocking rates are high, sheep grazing is unlikely to be a practical solution for management of large medusahead infestations (DiTomaso et al. 2008). In California grasslands, the sheep stocking rate that gave the most effective control of medusahead was equivalent to at least 1.6 animal units (AU) ac^{-1} (4 AU ha^{-1}) over 2 weeks (Cherr 2009). If a rancher owns a 247-acre (100-hectare) ranch and grazes year-round with a constant stocking rate, the area could support 15 to 30 sheep (0.37 to 0.75 AU ac^{-1}; 0.15 to 0.30 AU ha^{-1}), depending on local forage productivity. These animals could be used to apply precision medusahead grazing at the proper timing on only 5 to 12.4 ac (2 to 5 ha) (DiTomaso et al. 2008).

Because of the limitations of grazing as a management tool, it is most likely that control of medusahead with sheep grazing will be primarily used for small infestations, such as patches. In cases where medusahead control is of high value, custom grazing with hired animals can overcome the limitation of animal availability. It may also be possible to achieve control at lower stocking rates by extending the grazing period.

In a study of the effects of grazing on beef production in Tehama County, California, George et al. (1989) found that 2 years of intensive grazing [2.5 to 3 acres per 500 lb (2.2 to 2.6 ha per 500 kg) calf, for approximately 3 months total during each winter-to-spring growing season] reduced medusahead from 45% of relative vegetative cover to only 10%, and reduced medusahead thatch cover. The timing was the same as that described for sheep grazing. To achieve satisfactory control, however, cattle grazing required a stocking rate greater than one AUM [animal unit month] ac^{-1} (2.5 AUM ha^{-1}) within the 2 to 3 weeks when medusahead was susceptible to defoliation.

In a recent large-scale study over six years in Colusa County, CA, prescribed grazing using cattle was successful in reducing medusahead cover in years when late spring rains did not occur (Davy et al. 2014) (Figure 27). In this study, constraints on available drinking water and a decline in forage quality made it necessary to remove cattle from the grazing area at a relatively consistent timing in late spring each year. In years with late spring rain, sufficient soil moisture was available to allow medusahead to recover from grazing after cattle were removed. However, medusahead cover and seed production were reduced in years with dry spring weather. This suggests that prescribed grazing for medusahead management on a large scale may need to be used as part of a long-term strategy, because weather variations in some years may limit the impact of grazing on medusahead.

In addition to directly foraging on medusahead, intensive grazing by livestock can also trample the thatch layer, which can help to suppress the weed. For example, part of the reduction in medusahead reported by George et al. (1989) is attributed to thatch depletion after two years of heavy grazing during winter and spring. Because thatch reduction allows competing species to increase, heavy grazing often results in increased forb cover and decreased grass cover (McDougald et al. 1991).

On low-elevation annual rangeland, it has also been shown with both cattle (Davy et al., unpublished data) and sheep (Lusk et al. 1961) that range fertilization, especially with nitrogen, improves the palatability and forage attractiveness of medusahead. This reduces grazing selectivity and encourages grazers to concentrate their foraging in fertilized areas. These studies show some promise for the management of medusahead by combining fertilization with grazing, particularly when medusahead occurs in discrete patches.

Prescribed Burning

Medusahead matures a couple of weeks to more than a month later than most other annual species, including grasses (Dahl and Tisdale 1975; Young et al. 1970). In addition, medusahead and other long-awned invasive grasses [e.g., ripgut brome (*Bromus diandrus*), barb goatgrass (*Aegilops triuncialis*)] rely, in part, on animal dispersal for long-distance seed dissemination. Consequently, the seeds remain attached in the inflorescence longer than most desirable grasses. By late spring to early summer, most annual plant species have senesced and dropped their seed. However, the immature seedheads of late-season grasses such as

Figure 28. Prescribed control burn

At the ideal time for burning, medusahead plants are still green but other grasses have senesced.

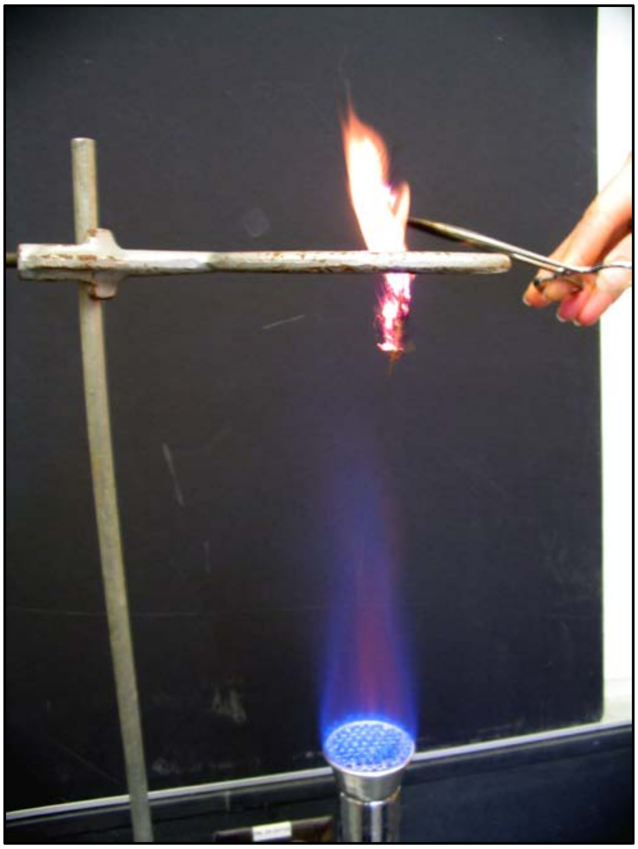

Figure 29. Testing seed tolerance to heat

Laboratory tests found that medusahead seeds are vulnerable to fire at all stages of ripeness.

medusahead are still ripening in the grassland canopy (Figure 28).

In grasslands, temperatures at the soil surface during a burn typically reach a range of ~482 F (~250 C) for a few seconds, not usually hot enough or long enough to kill seeds (DiTomaso et al. 1999; Sweet et al. 2008). Thus, seeds of forage plants on the ground usually escape the effects of fire. However, seeds held in the upper part of the grassland canopy during a burn may experience temperatures of 842 F to 1202 F(450 C to 650 C), hot enough to cause seed mortality (Figure 29). If burning can be applied during the time in late spring when most desirable species have dropped their seeds but medusahead seeds are still on the plants, then medusahead can be selectively controlled by fire. Although burning may not always consume the seedheads, the seeds inside are killed by the high temperatures (Figure 30). Burning also removes thatch, thus eliminating one of medusahead's competitive advantages (Figure 31).

Figure 30. Seedheads after a burn

During a prescribed burn, all thatch was burned off and these medusahead florets fell to the ground. They appear intact, but all the seeds are dead.

Figure 31. Burning removes medusahead thatch

(Photo: Kirk Davies, Eastern Oregon Agricultural Research Center, Burns, OR)

Because burning reduces the medusahead population and removes thatch, even an accidental burn presents an opportunity. Following a burn, other control techniques such as grazing, revegetation, and preemergence herbicides may be more effective. Whether a burn is prescribed or accidental, a land manager should use this opportunity to further manage medusahead.

Site differences in prescribed burn results

Many factors can influence the success of fire, including burn timing, fuel load and moisture, weather conditions, stage of seed maturity, and fire characteristics such as flame temperature and heat exposure time (Harrison et al. 2003; Kyser et al. 2008). While some early studies reported successful control of medusahead using prescribed burning (Furbush 1953; Murphy and Lusk 1961), others reported that burning was unsuccessful (Young et al. 1972) or inconsistent (McKell et al. 1962b). In northeastern California, for example, Young et al. (1972) found that repeated annual burning in mid-summer increased medusahead infestations while decreasing the population of more desirable annual grasses. Similarly, Youtie et al. (1998) conducted summer burns for medusahead control in north-central Oregon. While they showed some initial reduction in medusahead, it and other invasive annual grasses returned to pretreatment levels within two years of the burn.

In contrast to these reports, several studies at lower elevations in California demonstrated good control of medusahead with a single early summer burn (Furbush 1953; McKell et al. 1962b; Pollak and Kan 1998). Although some researchers have speculated that the inconsistent results among these studies might be due to differences in burn time, nearly all burns were conducted at the optimal timing, before seed dispersal but at a time when sufficient fuel load was available to carry a fire.

In a study on medusahead control using prescribed burning, trials were conducted in four regions of California, ranging from Fresno to near the Oregon border in Modoc County (Kyser et al. 2008). On low-elevation, warm-winter rangeland in Central Valley foothills (Fresno and Yolo counties), medusahead control was greater than 95% in the third season following 2 consecutive years of burning, and even a single burn gave significant control. Other annual grasses were slightly reduced and broadleaf species, including legumes, tended to increase. In contrast, in high-elevation, cold-winter Great Basin steppe (Modoc County), 2 years of burning gave no control. This was similar to results from an earlier study (Young et al. 1972) in a nearby location. Successful prescribed burning in warm-winter areas was correlated with the biomass of other annual grasses, besides medusahead, present at the site preceding a burn treatment. Greater production of combustible forage resulted in a slower and more intense burn (Kyser et al. 2008), killing more seed in the exposed inflorescences.

This study indicates that prescribed burning can be an effective control strategy for medusahead in low elevation, warm-winter areas with high annual grass biomass production, but may not be successful in semiarid cool winter areas. In the intermountain region, limited precipitation and a short growing season result in lower annual forage production; in addition, few winter annuals other than medusahead are usually present at such sites. This reduces the fuel load and results in lower intensity fires. Furthermore, in areas where a significant proportion of winter precipitation occurs as snow, the thatch layer from previous years' production tends to be compressed, contributing minimally to the fuel load (Kyser et al. 2008). Burns that occur late in the season, when even perennials are dry enough to carry a fire, are too late to control medusahead seed production. Thus, the effects of burning are less selective, having a greater impact on other species and a reduced impact on medusahead. As a result, high-elevation sagebrush ecosystems are vulnerable to fire, and burning tends to reduce cover of sagebrush and other native species (Young and Evans 1978).

Based on the sites in the burn study described here, we developed a table showing the average number of degree-days above 0 C between October and June, the typical number of annual frost-free days, and the corresponding value for estimated average annual dry-weight production (Table 3). These values give an indication of the type of fuel load which might be expected at each of the four sites. We also include the site for the unsuccessful burn

Table 3. Medusahead control with prescribed burning

Comparison of climatic parameters and medusahead control with prescribed burns in various locations in California (Kyser et al. 2008). Weather and production values are from the National Resources Conservation Service Web Soil Survey. XL Ranch data are from Young et al. (1972).

Study site county	Elevation, ft (m)	Degree-days > 0 C, mean for Oct-Jun	Expected frost-free days	Normal year dry-weight production, lb acre^{-1} (kg ha^{-1})	% control in late spring (summer when available)	
					One year after 1st burn	One year after 2nd burn
Low-elevation sites						
Fresno	558 (170)	3,871	238	1,345 (1,507)	100 (98)	100 (99)
Yolo	295 (90)	4,193	265	1,530 (1,715)	99 (85)	99 (96)
Intermediate site						
Siskiyou	2560 (780)	2,365	125	425 (476)	77 (70)	93
High-elevation sites						
Modoc	5184 (1580)	1,992	90	432 (485)	63	+55
Modoc ***(XL Ranch)***	5000 (1520)	1,791	75	556 (623)	+48	+21

+ indicates a percentage increase in medusahead

conducted by Young et al. (1972). These site characteristics are compared with the level of medusahead control after one and two consecutive years of burning at each site. At warm sites (typical winter through spring degree-day totals of roughly 3,000 or more, and more than 200 expected annual frost-free days), two consecutive years of burning achieved satisfactory control of medusahead. At cool sites (<2,000 degree days and 90 or fewer frost-free days), medusahead actually increased following two years of burning. It should be noted that the Siskiyou site was intermediate in its climatic characteristics; control at this site was somewhat less than in the low-elevation sites, and the medusahead population at this site rebounded significantly by two years after the final treatment.

Risks

Despite the potential usefulness of burning, it is often difficult to obtain permits because of air quality and liability issues. These are exacerbated by residential construction in rural areas. When prescribed burning is possible, it can be a successful management tool for a number of late-season invasive annuals in low-elevation sites, including medusahead (Kyser et al. 2008), barb goatgrass (DiTomaso et al. 2001), yellow starthistle (*Centaurea solstitialis*) (DiTomaso et al. 1999, 2006), and ripgut brome (DiTomaso et al. 2006; Kyser and DiTomaso 2002).

The potential impact on air quality is one of the risks associated with prescribed burning. Air quality issues and related requirements, including PM10 emissions, can be a significant problem when burns are conducted adjacent to urban areas (Campbell and Cahill 1996) (Figure 32). This potential problem can be avoided by conducting burns only in more isolated regions. Public relations problems can be minimized by educating residents of the intended goals of the project prior to the burn.

Another major risk of prescribed burning is the possibility of fire escapes. This is particularly true when burns are conducted during the summer months. This can be minimized by proper preparation and through involvement of local, state, and federal fire departments.

Because of these air quality and fire escape concerns, public agencies restrict prescribed burns to periods of proper wind, humidity, and temperature conditions. Burns are usually regulated by county air pollution control districts, which can allow or deny burn permits depending on climatic conditions. Given these restrictions, plus the ever-present possibility of variable weather during desired burn periods, it can be problematic to achieve a burn within the time period required for weed control.

County agencies should be the first point of contact when planning for a burn. These agencies also coordinate with state and federal fire protection agencies, which can sometimes provide personnel to conduct prescribed burns for training exercises.

Another potential risk is that too-frequent burning may increase soil erosion and impact the plant composition within a site. Species that complete their life cycle before the burn will be selected for, while those with later flowering times will be

Figure 32. Prescribed burn at the urban interface

This prescribed burn in the Boise foothills was carefully monitored to minimize the risks of smoke exposure and fire escape. (Photo: Ryan Steineckert, Eastern Oregon Agricultural Research Center, Burns, OR) selected against. In some areas, burning can lead to rapid invasion by other undesirable species with wind-dispersed seeds, particularly members of the Asteraceae (sunflower family). Although this is a potential concern, and a few desirable plant species are negatively affected by repeated burning, populations of most native species on low-elevation sites are enhanced by burns (DiTomaso et al. 1999).

Burning has a more negative impact on native species of high-elevation sagebrush rangeland. Great Basin ecosystems are adapted to a regime of infrequent fires – on the order of one burn per 100 to 200 years – and sagebrush and other shrubs in these areas do not recover quickly after a burn. Native bunchgrasses are also growing during the optimum timing for burning to control medusahead, and these species are much more sensitive to fire during the growing season than after senescence. Thus, introduction of burning at too-frequent intervals can result in the conversion of shrubland into land dominated by invasive annual grasses such as medusahead and downy brome (Figure 33). In addition, as discussed above, burning is less effective for medusahead control in these areas.

One other aspect of burning to consider is the short-term loss of grazeable forage. Ranchers who normally graze their stock on the dry residual forage during late spring to early fall may be reluctant to use prescribed burning for medusahead control because of the economic costs of burning off the dry forage. Forage production in the following year may also be reduced by 50% to 70% (Bechetti et al. 2011).

Figure 33. High-elevation shrubland *is poorly adapted to fire. Too-frequent burning in these ecosystems can allow medusahead to replace shrubs, as on this rangeland in eastern Oregon. (Photo: Bonnie Rasmussen, Oregon Department of Agriculture)*

Revegetation

The goals of a revegetation program are (1) to restore ecosystem services (such as forage, habitat, etc.) that have been lost due to declines in desirable plant species, and (2) to competitively exclude invasive plants from invading or reinvading the site. On rangelands infested with medusahead, ranchers would most likely initiate a revegetation program to increase more productive and desirable forage. Revegetation programs, however, are generally expensive and are not often conducted in areas where the economic return on the land is low.

In successful revegetation programs where medusahead is a problem the seeded species are typically perennial grasses. These species should be functionally similar to medusahead in the ways they acquire various resources, in order to limit the resources available to medusahead (Davies 2008; James et al. 2008; Nafus and Davies 2014). While this can reduce the population of medusahead by shifting the competitive advantage to more desirable species, particularly perennial grasses, it is unlikely to eliminate medusahead (Clausnitzer et al. 1999; Mangla et al. 2011; Young et al. 1999). In addition, some studies have shown that invasive annual grasses, such as medusahead, are more competitive than native perennial grasses even under low resource availability (James 2008a, 2008b; Monaco et al. 2003a), especially at the seedling stage (James et al. 2011a). However, depending on the species, low resource availability can also reduce the competitiveness of medusahead with perennial grasses. For example, while drought limited the successful establishment of native perennial bunchgrasses (Clausnitzer et al. 1999), it had an even greater effect on the establishment and competitiveness of medusahead (Mangla et al. 2011).

Nitrogen (N) availability can also greatly influence the competitive interaction between medusahead and perennial grasses. Many native perennial grasses are adapted to low soil N. While natives may not grow as vigorously under low N conditions, they can do better than medusahead. Low N levels limit medusahead growth to a level where perennial grasses compete more successfully (James et al. 2011a;

Monaco et al. 2003a). In support of this, Brunson et al. (2010) showed that biomass and seed production of medusahead were reduced at low N levels. Although it is possible to reduce N availability in the soil by applying barley straw, sucrose, or sawdust (Alpert and Maron 2000; Brunson et al. 2010; Monaco et al. 2003a), these practices are only temporary and are too expensive to conduct on a large scale (Nafus and Davies 2014).

In nearly all cases, revegetating with more desirable species will require pretreatment or concurrent treatment with some weed management practice. This can include the use of herbicides (Monaco et al. 2005), prescribed burning (Kyser et al. 2008), or a combination of control options, including burning followed by herbicide treatment (Sheley et al. 2012b). Weed control practices which also remove medusahead thatch (i.e., burning, tillage, and sometimes mowing or grazing) are most likely to result in successful establishment of revegetation plantings.

Even with adequate control, revegetation programs in rangelands often fail due to a number of factors (James et al. 2011b; Young 1992). For example, sites with high clay content and shrink-swell potential favor medusahead over perennial grasses, and thus reinvasion over time is inevitable even after the use of successful control methods (Sheley et al. 2008; Stromberg and Griffin 1996). More often, however, climatic conditions such as dry summers or unpredictable winter and spring rainfall can impact the success of establishing desirable perennial grasses (Young et al. 1999).

Plant selection

Another aspect of revegetation is selecting the proper plant species to include in the mix. While many restorationists would prefer to revegetate with native species, they can be expensive, more difficult to obtain and establish, and often less resistant to reinvasion (Arredondo et al. 1998; James et al. 2011b; Nafus and Davies 2014). Thus, the risk of failure is generally greater with native species. Success of revegetation with natives can vary with location. For example, in the Intermountain West, the likelihood of successfully establishing native species increases as sites become cooler and wetter (Nafus and Davies 2014).

Some native species have a better probability of establishment than others. For example, squirreltail species, including *Elymus multisetus* and *E. elymoides*, have considerable ecotypic variability and have been relatively easy to establish in many areas of the western US (Arredondo et al. 1998; Hironaka and Sindelar 1975; Hironaka and Tisdale 1963; Leger 2008; Young 1992; Young and Mangold 2008). Although squirreltail establishes well in the absence of medusahead, it is not a strong competitor with medusahead, especially in the seedling stage (Harris and Wilson 1970; Young and Mangold 2008). As a side note, the squirreltail inflorescence somewhat resembles that of medusahead and can be hard to distinguish without practice (Figure 34).

Bluebunch wheatgrass (*Elymus spicatus*) is another native bunchgrass which establishes well and can be used to revegetate sites after medusahead has been controlled (Figure 35). Like squirreltail, however, bluebunch wheatgrass is a relatively weak competitor with medusahead (Goebel et al. 1988; Harris 1977), particularly under grazing (Sheley and Svejcar 2009). Other native perennial grasses sometimes used in restoration projects include thickspike wheatgrass (*E. lanceolatus*), slender wheatgrass (*E.*

Figure 34. Squirreltail

(Photo: Matt Lavin, Montana State University) →

Figure 35. Bluebunch wheatgrass

(Photo: Matt Lavin, Montana State University) →

trachycaulus), basin wildrye (*Leymus cinerus*), beardless wildrye (*L. triticoides*), and western wheatgrass (*Pascopyrum smithii*).

Introduced perennial grasses such as crested wheatgrass (*Agropyron cristatum*) (Figure 36) are commonly used in revegetation programs in the Intermountain West. Though not native, crested wheatgrass has several benefits compared to native species. It is less expensive, germinates readily, establishes with a higher level of success, and is more competitive with medusahead compared to most native species (Boyd and Davies 2010; Davies et al. 2010; Eisworth et al. 2009; James et al. 2011b). This is one of very few perennial grasses able to establish even in an uncontrolled medusahead infestation (Wilson et al. 2010). In addition, crested wheatgrass can provide similar ecosystem function as more desirable native species (Davies et al. 2011).

Revegetating with crested wheatgrass poses some problems, however. In addition to competing with medusahead, it can be competitive with native plants and can reduce plant diversity in areas where it establishes successfully (Asay et al. 2001; Hull and Klomp 1967). In some parts of the northern Great Plains, crested wheatgrass is considered to be invasive in mixed-grass prairie (e.g., Henderson and Naeth 2005). In some areas, crested wheatgrass has also been found to reduce wildlife habitat (McAdoo et al. 1989; Reynolds and Trost 1981; Sutter and Brigham 1998).

Other nonnative perennial grasses, including desert wheatgrass (*Agropyron desertorum*), smooth brome (*Bromus inermis*), hybrid wheatgrass (*Elymus hoffmannii*), Russian wildrye (*Psathyrostachys juncea*), intermediate or pubescent wheatgrass (*Thinopyrum intermedium*; = *Elymus hispidus*), and tall wheatgrass (*Thinopyrum ponticum*), have also been used in revegetation programs to suppress medusahead. These species generally don't attract the same degree of criticism as crested wheatgrass (although some consider desert and crested wheatgrass to be variants in the same species). Young et al. (1969b) was successful in establishing intermediate wheatgrass in a medusahead-infested area of the Great Basin. This required a summer fallow followed by disk harrowing. However, even this successful treatment did not completely exclude medusahead.

Recent research suggests that early successional ("ruderal") species, such as native annual forbs and grasses, may establish more successfully than the late-successional perennial grasses typically used in Great Basin revegetation projects (Uselman et al. 2014) (Figure 37). These species are also very competitive with medusahead. This appears to be a promising area for future research.

Figure 36. Crested wheatgrass

(Photo: Matt Lavin, Montana State University) →

Figure 37. Native annual species
*may be useful in revegetation. Early successional species like bristly fiddleneck (*Amsinckia tessellata*) are competitive with medusahead and can be easier to establish than perennial grasses. (Photo: Brent Miller, CalPhotos)* →

If early successional natives can be established on medusahead-infested sites, they may serve as a bridge community which improves the viability of later revegetation efforts.

Unlike the Intermountain West and Great Basin areas of the western US, low-elevation California rangelands are dominated by nonnative winter annual grasses. Many of these grasses, particularly soft chess (Figure 38), slender oat and wild oat, and rye grass (Figure 39), are considered excellent forage grasses and desirable species for ranchers. Seed of soft chess (cultivar 'Blando Brome') and rye grass are almost always commercially available and inexpensive. Slender and wild oat seeds are not generally available for purchase because the seedheads shatter quickly in the field. These species, which occupy the

Figure 38. Soft chess
This is a palatable annual grass adapted for drought and grazing conditions. (Photo: Josh Davy)

Figure 39. Rye grass
Another useful annual grass.

Figure 40. Orchardgrass

A cool-season perennial which is competitive on low-elevation rangeland. (Photo: Josh Davy)

same root zone as medusahead, are very competitive with noxious annual grasses (Kyser et al. 2008).

Warm-season perennial grasses such as wheatgrasses, which are dormant during winter, have not been found to compete successfully with invasive annual grasses on low-elevation rangeland. At low elevations, winter annual species – including invasive grasses such as medusahead – are well-established by the time warm-season grasses begin to grow, and most low-elevation rangelands don't retain enough soil moisture to support grasses during the hot, dry summers. However, Borman et al. (1991) demonstrated successful competition against annual grasses using cool-season perennial grasses that initiate growth in fall and continue through winter. One example was the introduced species orchardgrass (*Dactylis glomerata* var. 'Berber') (Figure 40). Orchardgrass, like many of the perennial grasses native to lower elevations, has strong summer dormancy to help survive the dry season.

Economics

The primary limitation to the use of native species in revegetation programs is their high cost. Few producers are available and the demand for seed is low. This increases the cost of seed and reduces availability of genetically endemic biotypes of native species. Genetic races of native grasses have been found to be very different in their performance and phenology, making it important to select the appropriate plant material for the selected site (Adams et al. 1999). This is difficult to achieve given the limited number of native seed producers.

In many cases, the cost of using native seed can be in the hundreds to even thousands of dollars per acre. Access to seeding equipment can also be a major limitation. Drill seeders are expensive, specialized equipment, often unavailable, and cannot be used in steep terrain. Broadcast seeding reduces the chances of successful establishment.

In one example of the costs of revegetation, native legumes and perennial grasses were planted at Fort Hunter Liggett, CA. In this project, seed cost between \$500 and \$2,000 per acre (\$1,235 to \$4,940 ha^{-1}) (A. Hazebrook, Fort Hunter Liggett, pers. comm.). Native species comprised 5 to 30% of total vegetative cover two years after seeding.

Revegetation methods and timing

Revegetation can be accomplished by broadcast seeding into existing communities, or by drill seeding into disked, herbicide-treated, or no-till rangeland. Drill seeding programs are considerably more successful than those utilizing broadcast seeding techniques. Rangeland drill seeders (Figure 41) are designed to deal with uneven terrain and long-awned seed species.

Broadcast seeding disperses seeds on the top of the soil, so the seeds are more susceptible to predation or decay. In addition, if the seeds germinate on the soil surface they have a higher probability of desiccating under subsequent dry conditions. In addi-

Figure 41. Rangeland drill seeder

tion, medusahead thatch can limit the amount of broadcast seed that reach the soil. Broadcast seeding is more successful if seeds can be lightly incorporated by harrowing.

On low-elevation rangeland, weed control is the primary factor to consider before seeding, especially with perennial grasses. Seeding in early fall can result in the best establishment if there is autumn rainfall to initiate germination before winter. However, if the weather turns cold before enough rainfall occurs, perennial grasses may not germinate until late winter or early spring. This is not as great a problem when seeding with annual grasses, which are better able to establish in cold temperatures. Another risk with fall seeding is the event of an early autumn rainfall followed by a period of dry weather. Seeded species may germinate with the first rains, then dry out before they can establish. However, many perennial grasses have delayed or staggered germination, which may help to ameliorate episodic rainfall events.

If it is possible to access the site in January or February, this planting time can be successful if followed by sufficient spring rainfall. The gamble with a late winter seeding is that cold conditions may suppress germination until early spring, making the success of the planting entirely dependent on spring rainfall. The advantage of late winter seeding is that it allows additional time for weed control prior to planting. In addition, if spring rainfall continues while the weather is warming up, plants can establish quickly.

On Great Basin rangeland, reseeding in spring (February to early April) generally gives better results than seeding in fall (R.G. Wilson, pers. comm.). If seeded in fall, most species grow slowly during the cold months and often undergo high winter mortality (Boyd and James 2013). (Nevertheless, fall seeding is often quite successful with crested wheatgrass.) However, seeding is most often done in fall because it is logistically easier. In the Great Basin it may be too muddy to seed at the optimal time in spring, and seeding may be delayed until too little moisture is left for establishment. Alternatively, less successful methods such as broadcast seeding may be used.

Biological Control

In their native range, most species are kept in check by a variety of co-evolved organisms, including pathogens, insects, and predators (or herbivores). Once introduced to a new region, a species may leave behind many of its natural enemies. In the absence of natural controls, a new species may become invasive. In classic biological control, natural enemies in the native range are identified, collected, and tested for host specificity and effectiveness. The Biological Control of Pests Research Unit of USDA, which usually conducts biological control search-and-release programs, performs extensive testing to make sure that these potential biocontrol agents are host-specific. Those that prove very host-selective and that cause significant damage to pests under controlled conditions are then considered for release in the invasive species' new domain. Most such biocontrol agents are insects.

There are currently no successful biological control agents available for managing medusahead. Because of its close taxonomic relationship to wheat, barley, and rye, biological control of medusahead faces intense scrutiny, and finding a safe and reliable biocontrol organism may not be possible (Sforza et al. 2004). Nevertheless, the large-scale economic and ecological impacts attributed to medusahead have led to several attempts to identify potential biocontrol organisms. All of these have focused on pathogens rather than insects. Many of these are fungi that cause crown and root rot or infect the leaves of medusahead (Chagorova 1960; Holubec et al. 1997). While they have been successful in reducing medusahead seed production, most have not proven to be host specific and several have, to some degree, damaged some desirable native grasses and important cereal grain crops (Berner et al. 2007; Grey et al. 1995; Siegwart et al. 2003).

One species evaluated as a potential biological control agent against medusahead was the fungus *Fusarium arthrosporioides* (syn. *F. roseum* var. *arthrosporioides*), first isolated from the leaf collar of medusahead in Greece (Siegwart et al. 2003). In laboratory studies, it was found to inhibit normal root development and cause leaf discoloration (Siegwart et al. 2003). However, the fungus was also found to infect wheat, barley, oat and other desirable grasses and is no longer being considered as a potential biocontrol agent. Another crown rot fungus, *F. culmorum*, had a significant impact on drought-stressed medusahead, but it also was not host specific (Grey et al. 1995).

Among the more promising organisms is the systemic ovary-smut fungus *Ustilago phrygica*, collected from Turkey, Cyprus and Bulgaria. It exhibits typical smut symptoms on medusahead under both greenhouse and field conditions (Figure 42) and has not been observed to infect cultivated cereals (Sforza et al. 2004). However, it has not been widely tested on other grass species and it is not available for use.

Ongoing work continues to focus on a rhizobacterium, *Pseudomonas fluorescens* strain D7 (*Pf*D7). This organism has been effective on medusahead in laboratory studies (Kennedy et al. 2001) and is currently being tested in the field with some promising results. Because it is native to the western US, the time-consuming and costly permitting process is not necessary. *Pseudomonas fluorescens* has also provided some suppression of downy brome and jointed goatgrass, two other important grass weeds, while impacting only a few other monocots and no dicots.

Figure 42. Smut fungus on medusahead

The potential biocontrol agent Ustilago phryigica *attacks the medusahead inflorescence. (Photo: Rene Sforza, USDA-ARS, European Biological Control Laboratory)*

Chapter 7: Chemical Control Methods

Herbicides are widely used for controlling weeds, though less often in rangeland and wildland settings than in conventional agriculture. The particular problems in using herbicides to control medusahead include (1) the difficulty in selectively controlling medusahead without causing damage to desirable forage grasses or other plant species; and (2) the economic costs of large-scale application on land with a relatively low rate of return.

Herbicide Application Techniques

Herbicides can be applied on rangeland and grassland by a number of methods, including aerial applications (using fixed-wing aircraft or helicopters), ground vehicle applications, and backpack sprayers. Whatever application method is used, the operator will achieve the best selectivity and the most cost-effective results by using equipment which is properly calibrated to deliver known, consistent rates.

Figure 44. ATV application

Aerial broadcast applications can cover the greatest area in the shortest time, but they are susceptible to drift and have limited targeting ability. Under good weather conditions, and using GPS to leave buffers around sensitive areas, aerial applications can be performed safely and are the most efficient means of treating large areas (Figure 43).

Ground vehicle applications are made using ATVs or truck sprayers (Figure 44). These are appropriate for smaller infestations, where terrain permits. Ground applications have a lower risk of drift than aerial applications and can be applied in a more directed manner. They can be particularly effective for cleaning up buffer zones following large-scale aerial treatments.

Backpack sprayers can be outfitted with booms for small-scale treatments (Figure 45). These treatments can be very selectively applied and

Figure 43. Aerial treatment of medusahead

Willow Creek watershed, Lassen County, CA. (Photo: Robert G. Wilson, UCCE)

Figure 45. Backpack application
(Photo: David Bakke, USFS)

present a low risk of drift. However, they are not efficient for treating large areas. Backpack treatments are most effective for cleanup of small infestations, especially on terrain too rugged for vehicle applications.

Risks

The potential risks associated with herbicide use have been widely publicized both in the scientific literature and the popular press. Although these risks are often greatly exaggerated, improper use of herbicides can cause problems such as spray or vapor drift, water contamination, animal or human toxicity, selection for herbicide resistance in weeds, and reduction in plant diversity.

Spray and vapor drift

Herbicide drift may injure susceptible crops, ornamentals, or non-target native species. Drift can also cause non-uniform application in a field and/or reduce efficacy of the herbicide in controlling weeds (DiTomaso 1997). Several factors influence drift, including spray droplet size, wind and air stability, humidity and temperature, physical properties of herbicides and their formulations, and method of application. For example, the amount of herbicide lost from the target area and the distance it moves both increase as wind velocity increases. Under inversion conditions, when cool air is near the surface under a layer of warm air, little vertical mixing of air occurs. Spray drift is most severe under these conditions, since small spray droplets fall slowly and can move to adjoining areas even with very little wind. Low relative humidity and high temperature cause more rapid evaporation of spray droplets between sprayer and target. This reduces droplet size, resulting in increased potential for spray drift.

Another type of drift can occur when certain residual herbicides are applied to dry, powdery soil which blows off-site. The preemergence herbicides in the ALS inhibitor family, discussed below, can pose a risk of moving with blown soil.

Vapor drift can occur when an herbicide volatilizes. The formulation and volatility of the compound determine its vapor drift potential. Potential of vapor drift is greatest under high temperatures and with ester formulations. Most herbicides used for medusahead control do not pose a high risk of volatilization.

Nozzle height depends on the type of application (e.g., airplane, helicopter, ground sprayer) and determines the distance a droplet falls before reaching the weeds or soil. Greater application heights, such as aerial applications, result in more potential for drift. For one thing, the droplets are in the air for a longer time. In addition, wind velocity often increases with elevation above the ground. Finally, aerial applications are more likely to be above any inversion layer, which inhibits downward movement of herbicide droplets and increases the potential for long-distance drift. However, studies have found that careful aerial applications with 100-ft (30-m) buffers around sensitive areas can be performed with minimal drift (e.g., DiTomaso et al. 2004).

A number of measures can be taken to minimize the potential for herbicide drift. Chemical treatments should be made under calm conditions, preferably when humidity is high and temperatures are relatively low. Ground equipment (versus aerial equipment) reduces the risk of spray drift, and rope wick or carpet applicators nearly eliminate it. Use of the correct formulation under a particular set of conditions is important. For example, if long-residual preemergence herbicides must be applied on a site with loose, dry soil, this should be done after a recent rainfall or when precipitation is expected. (But not when the forecast predicts heavy rain to the point of runoff – see below.)

Groundwater and surface water contamination

Most herbicide groundwater contamination results from "point sources." Point source contaminations include spills or leaks at storage and handling facilities, improperly discarded containers, and rinsing equipment in loading and handling areas, e.g., into adjacent drainage ditches. Point sources are characterized by discrete locations discharging relatively high local concentrations. These contaminations can be avoided through proper calibration, mixing, and cleaning of equipment.

Non-point source groundwater contaminations of herbicides are relatively uncommon. They can occur, however, when a soil-mobile herbicide is applied in an area with a shallow water table. In this situation, the choice of an appropriate herbicide or alternative control strategy can prevent contamination of the water source.

Surface water contamination can occur when herbicides are applied intentionally or accidentally into ditches, irrigation channels or other bodies of water, or when soil-applied herbicides are carried away in runoff to surface waters. Herbicide may be applied directly into surface water for control of aquatic species. In this case, there is a restriction period prior to the use of this water for human activities. In many situations, alternative methods of herbicide treatment, including rope wick application, will greatly reduce the risk of surface water contamination when working near open water.

Loss of a preemergence herbicide through erosion may occur when a heavy rain follows a chemical treatment. Herbicide runoff to surface waters can be minimized by monitoring weather forecasts before applying herbicides. Application of preemergence herbicides should be avoided when forecasts call for heavy rainfall. However, moderate precipitation between 0.5 and 1 inch (1.3 to 2.5 cm) helps a preemergence herbicide to percolate into the soil profile, thus minimizing the subsequent risk of surface runoff.

Toxicology

When used improperly, some herbicides can pose a health risk. This can be minimized with proper safety techniques. Applicators should follow label directions and wear appropriate safely apparel. This is particularly important during mixing, when the applicator is exposed to the highest concentration of the herbicide. Although animals can also be at some risk from herbicide exposure, most herbicides registered for use in noncrop areas, particularly natural ecosystems, are relatively nontoxic to wildlife. To prevent injury to wildlife, care should be taken to apply these compounds at labeled rates.

The trend in herbicide toxicity of the past 25 years has been toward registration of less toxic compounds. From 1970 to 2014, the number of registered herbicides with an LD_{50} (dose in mg herbicide kg^{-1} animal weight lethal to 50% of male rats) below 500 mg kg^{-1} decreased from 17 compounds to 8, while herbicides in the least toxic category (LD_{50} >5000 mg kg^{-1}) increased from 20 compounds to 50. The average LD_{50} of herbicides registered in the United States increased from 3031 to 3803 mg kg^{-1} (Weed Science Society of America 1970, 2014).

Most herbicides used on rangelands and wildlands, particularly preemergence chemicals, are applied at very low rates, just a few ounces of active ingredient per acre. This is a significant change from the early days of herbicide usage, when rates of up to several pounds of active ingredient per acre were commonly applied.

Herbicide resistance

Selection for herbicide-resistant weed biotypes is greatly accelerated by continuous use of herbicides, particularly those with a single mode of action. Though resistance has not been reported for medusahead, another species in the medusahead tribe of grasses (Triticeae), hare barley (*Hordeum murinum*), has developed resistance to ACCase (acetyl Co-A carboxylase) inhibitors such as clethodim and fluazifop, and ALS (acetolactate synthase) inhibitors such as sulfometuron. Resistance in this species was first detected in 1996 in Australia, according to the International Survey of Herbicide Resistant Weeds (Heap 2014). Other less closely related grasses showing resistance to herbicides in various locations include oats (*Avena* spp.), bromes (*Bromus* spp.), barnyardgrass (*Echinochloa* spp.), sprangletops (*Leptochloa* spp.), ryegrass (*Lolium* spp.), panicums (*Panicum* spp.), canarygrass (*Phalaris* spp.), foxtails (*Setaria* spp.), and johnsongrass (*Sorghum halepense*).

In general, the risk of herbicide resistance developing in weeds of rangeland and wildland is much lower than the risk in weeds of intensive agriculture, because uncultivated areas tend not to receive the same herbicide treatment year after year. We do have concerns about the potential for resistance developing following treatment with low rates of glyphosate, as described in Table 4. Overreliance on this method might select for medusahead biotypes with some degree of glyphosate resistance, which could develop into resistant populations over the course of a few years. However, this would likely require multiple years of treatment with glyphosate. With any herbicide control strategy, using integrated approaches which include other control methods can greatly reduce the incidence of herbicide resistant biotypes.

Effects of herbicides on plant diversity

The benefits of medusahead control with herbicides must be weighed against the possible impacts on other species. When herbicides are used carefully, this impact can be positive. For example, in one study in the Great Basin, a one-time application of imazapic both controlled medusahead and resulted in increased cover of native forbs (Kyser et al. 2013).

However, continuous broadcast use of a single type of herbicide will select for the most tolerant plant species. In the absence of a healthy plant community composed of desirable species, one noxious weed may be replaced by another equally undesirable species insensitive to the herbicide treatment. For example, the indiscriminate use of broadleaf herbicides to control yellow starthistle can lead to an increase in undesirable annual grasses such as medusahead, ripgut brome, downy brome, or barb goatgrass.

Population shifts through repeated use of a single herbicide may also reduce plant diversity and cause nutrient changes that decrease the total vigor of the range (DiTomaso 1997). For example, legume species are important components of rangelands, pastures, and wildlands, and are highly sensitive to aminopyralid. Repeated use of aminopyralid over multiple years may have a long-term detrimental effect on legume populations. Herbicide use on rangelands is generally more successful when incorporated as part of an integrated weed management system.

Methods and Timing

As with other control methods, the goal of using herbicides to control medusahead is to prevent the plants from producing seed. This can be accomplished with either preemergence herbicides or postemergence herbicides.

Postemergence herbicides are applied in spring to growing plants. On high-elevation rangeland, small medusahead plants can be controlled with low rates of the nonselective herbicide glyphosate; these rates are relatively safe for established perennials (Table 4). Glyphosate can also be used at high rates to control medusahead in low-elevation annual grassland in late spring after most other species have senesced. Selective herbicides that control only grasses are available (Table 6), but these are not widely used on rangeland (and pose a risk of injury to other, more desirable grass species).

Preemergence herbicides are applied to the soil in fall before medusahead germinates (Table 5 and Table 7). On roadsides and in industrial areas, nonselective preemergence herbicides are sometimes used to control all vegetation. However, on rangeland the goal is to control medusahead while leaving as much of the desirable vegetation as possible. The ideal selective herbicide would control 100% of the medusahead without affecting any other species, but this is essentially impossible to achieve. Most of the preemergence herbicides used for managing medusahead on rangeland are somewhat selective, but all are likely to have some effect on at least some other plant species.

Table 4. Glyphosate

Glyphosate is a nonselective, foliar-applied herbicide originally patented under the name *Roundup®*. Glyphosate is in the herbicide family of aromatic amino acid inhibitors. It is nonselective (high rates will kill most plants) and has no soil residual, so plants emerging after application will not be controlled. Note that glyphosate is available in many formulations with different concentrations. Rates given here are for 41% glyphosate product [3 lb acid equivalent (a.e.) /gallon].

In Great Basin shrub ecosystems, low rates of glyphosate can be applied over-the-top of native perennial species. Applied ideally at the tillering stage of medusahead, these rates are high enough to control immature medusahead plants but not high enough to injure established perennials (Kyser et al. 2012a) (Figure 46). On low-elevation annual rangeland, glyphosate can be applied at higher rates to medusahead in the early flowering stage. At this timing, similar to the best timing for mowing or grazing, most forage species have already completed their life cycle. As a result, glyphosate can prevent medusahead seed production without damage to desirable plants (T. Becchetti, personal communication). In revegetation projects, glyphosate can be applied to control emerged weeds at the time of seeding; this is only recommended when there are very few desirable species present.

Prices are for comparison only. Actual prices can vary greatly by region, point of sale, and time of year.

Glyphosate *Roundup Pro*, *Accord XRT* , and others	**Rate:** 0.75 to 1 pt product (41% glyphosate)/acre (4.5 to 6 oz a.e./acre) for early-season selective control in shrubland or other perennial systems; 1 to 2 qt product/acre (0.75 to 1.5 lb a.e./acre) for late-season, non-selective control. **Cost (2014)**[1] **:** $16/gal (~$2/acre for early-season treatment, ~$4 to $8/acre for late-season treatment) **Timing:** For selective control in shrubland, apply postemergence in spring after all seedlings are up and before heading; the tillering stage is ideal. For late-season, non-selective control, apply to rapidly growing plants before seeds are produced. **Remarks:** Glyphosate is a non-selective herbicide with no soil activity.

[1] Ferrell and Sellers (2014)

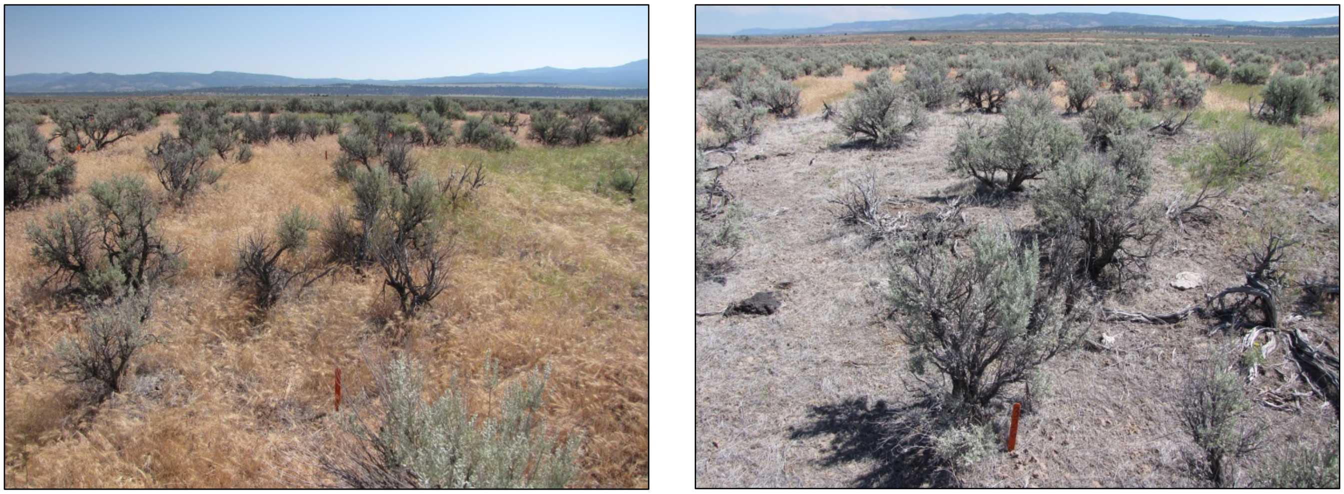

Figure 46. Great Basin sagebrush steppe trial

Untreated plot (left) vs. plot treated with a low rate of glyphosate at medusahead tillering stage (Kyser et al. 2012a). (Photos: Alan Uchida, US-BLM, Alturas, CA)

Table 5. Preemergence herbicides

Preemergence chemicals have soil residual activity of up to several months, and generally require some rainfall to move into the soil. The herbicides listed here are in the family of ALS inhibitors. These are usually applied in fall, before medusahead emerges. Their residual activity breaks down more quickly in warm environments, so these chemicals tend to be most useful in cold-winter intermountain ecosystems. None are perfectly selective, but most are safe on established perennial grasses and shrubs. Drawbacks include

- most have plantback and/or grazing restrictions
- selectivity and efficacy may vary with soil type, presence of thatch, and moisture conditions.

Prices are for comparison only. Actual prices can vary greatly by region, point of sale, and time of year.

Imazapic *Plateau* *Panoramic 2SL*	**Rate:** 4 to 12 fluid oz product/acre (1 to 3 oz a.e./acre) **Cost (2013)[1] :** $165/gal (~$5 to $15/acre) **Timing:** Fall or spring. In warm-winter areas, fall applications may be most effective. In colder climates, spring applications after snow melt are better. **Safety on established perennial grasses:** Safe **Plantback interval:** 8 months **Grazing restriction:** None **Remarks:** Has some soil residual activity and mixed selectivity. Safe on Asteraceae and established grasses, so it is useful on intermountain rangeland where the goal is not to damage sagebrush or perennial grasses. Use a spray adjuvant for postemergence applications. Effects vary depending on soil texture and soil organic matter. Heavy soils and high organic matter may require higher rates. Can tie up in litter, and efficacy is reduced where there is lots of thatch on the soil surface; activity is improved by burning or other thatch removal before application. Also available mixed with glyphosate (sold as *Journey*). Not registered for use in California.
Rimsulfuron *Matrix SG* *Matrix FNV*	**Rate:** 4 oz product/acre (1 oz active ingredient (a.i.)/acre) **Cost (2014)[2] :** $15/oz (~$60/acre) **Timing:** Preemergence (fall) to early postemergence (early spring) **Safety on established perennial grasses:** Fall applications are safe for established perennial grasses grown under dryland conditions. Application to rapidly growing or irrigated perennial grasses may result in their injury or death. **Plantback interval:** 7 to 12 months **Grazing restriction:** 1 year **Remarks:** Controls several annual grasses and broadleaves. It provides soil residual control in cool climates but degrades rapidly under warm conditions. Add a surfactant when applying postemergence.
Sulfometuron *Oust XP* and others	**Rate:** 0.75 to 1.5 oz product/acre (0.56 to 1.13 oz a.i./acre) **Cost (2014)[2] :** $88/lb (~$4 to $8 per acre) **Timing:** Preemergence to early postemergence. Preemergence (fall) applications are generally more effective. **Safety on established perennial grasses:** Minor injury possible **Plantback interval:** 3 to 6 months **Grazing restriction:** 1 year **Remarks:** Broad-spectrum herbicide that is fairly safe on native perennial grasses. Use lower rates in arid environments, higher rates in wetter areas (>20 inches rainfall) and on high organic matter soils. It has fairly long soil residual activity. Use caution when ap-

	plying on dry, powdery soils – when bound to light soils, this chemical can blow in the wind and cause off-site damage. Sulfometuron was found to produce long-term reductions in native forb populations in one study in Oregon (Louhaichi et al. 2012).
Sulfometuron + chlorsulfuron *Landmark XP*	**Rate:** 1.5 to 2.25 oz product/acre **Cost (2014)**[3] **:** \$13/oz (~\$19 to \$29 per acre) **Timing:** Preemergence, in fall or after soil thaws in spring. **Safety on established perennial grasses:** Minor injury possible **Plantback interval:** 3 to 6 months **Grazing restriction:** 1 year **Remarks:** See sulfometuron.

[1] North Dakota State University (2013)
[2] Ferrell and Sellers (2014)
[3] eVegetationmanager (2014)

Table 6. Grass-selective herbicides

These chemicals are in the herbicide family of ACCase inhibitors. They control most grasses but will not affect most broadleaf plants. These herbicides are applied postemergence to young, growing plants. They have no soil residual, so plants emerging after application will not be controlled. Some users report that these herbicides are safe for established bunchgrasses, when applied at low rates (e.g., Bell et al. 2013). However, we recommend *extreme caution*, and a small trial application, when trying to use these herbicides for selectively controlling medusahead in a perennial grass system.

Prices are for comparison only. Actual prices can vary greatly by region, point of sale, and time of year.

Clethodim *Arrow 2EC*	**Rate:** 4 to 8 fluid oz product/acre (1 to 2 oz a.e./acre) **Cost (2013)**[1] **:** \$120/gal (~\$4 to \$8/acre) **Timing:** Early postemergence **Safety on established perennial grasses:** May vary by species and growth stage. Older, established bunchgrasses should be safe but may show injury. Annual grasses will be severely injured or killed. **Plantback interval:** None **Grazing restriction:** Depending on the type of application, label restrictions vary all the way from no restriction to “Do not graze.” Check with your county before use. **Remarks:** Registered for use on noncrop, fallow ground, and native prairie restoration projects. Check with your county to make sure your intended use is permitted.
Fluazifop *Fusilade DX*	**Rate:** 24 fluid oz product/acre (6 oz a.e./acre) **Cost (2014)**[2] **:** \$170/gal (~\$32/acre) **Timing:** Early postemergence **Safety on established perennial grasses:** May vary by species and growth stage. Older, established bunchgrasses should be safe but may show injury. Annual grasses will be severely injured or killed. **Plantback interval:** None **Grazing restriction:** do not graze for 12 months after application **Remarks:** Registered for use on noncrop and fallow ground; 24(c) registration for wildland in California and Oregon. Check with your county to make sure your intended use is permitted.

[1] North Dakota State University (2013)
[2] Ferrell and Sellers (2014)

Table 7. Growth regulator herbicides

Most growth regulator herbicides are broadleaf-selective, but recent research has found that two of these chemicals can be used to control medusahead. These herbicides are usually applied preemergence in fall, and have soil residual activity for several months. These chemicals will injure or kill some broadleaf species, including most legumes. Legumes should recover from the seedbank in the years following the application. Unlike the preemergence herbicides discussed above, these chemicals are not affected by thatch.

Prices are for comparison only. Actual prices can vary greatly by region, point of sale, and time of year.

Aminocyclopyrachlor + chlorsulfuron *Perspective*	**Rate:** 5 oz product/acre (2 oz aminocyclopyrachlor + 0.8 oz chlorsulfuron/acre) **Cost (2014)[1] :** $80/lb (~$25/acre) **Timing:** Preemergence to early postemergence **Safety on established perennial grasses:** Safe, but can injure young grasses. Some other young annual grasses may be injured, but most major forage grasses are not affected. **Plantback interval:** 12 months **Grazing restriction:** Under current label, do not graze treated forage; this may change on future labels. **Remarks:** Newly registered; check with your county to make sure your intended use is permitted. A broadleaf-selective herbicide – very effective on thistles – that is safe on most grasses. Can injure trees if applied in the root zone. Aminocyclopyrachlor is also available in a mix with metsulfuron (*Streamline* – not registered for use in California).
Aminopyralid *Milestone*	**Rate:** 7 to 14 fluid oz product/acre (1.75 to 3.5 oz a.e./acre) **Cost (2014)[1] :** $300/gal (~$16 to $33/acre) **Timing:** Preemergence in fall **Safety on established grasses:** Safe, but can injure young grasses. Some other young annual grasses may be injured, but most major forage grasses are not affected. **Plantback interval:** We recommend 1 to 3 months for grasses, and 1 to 2 years for legumes. **Grazing restriction:** None **Remarks:** Broadleaf-selective – very effective on thistles – and safe on most grasses. There is a 2(ee) supplemental label for medusahead control in Arizona, California, Colorado, Idaho, Oregon, Washington, Wyoming, and Utah. In California's Central Valley, 14 oz of *Milestone* (spot treatment rate)/acre gave ~90% control of medusahead, and 7 oz/acre gave ~60% control (Kyser et al. 2012b) (Figure 47). A split treatment of 7 oz/acre in fall followed by 7 oz/acre in winter may be an even better treatment than 14 oz in fall (DiTomaso and Kyser, unpublished data). Recent research suggests that *Milestone* applied at early flowering may stop medusahead from producing viable seed (Rinella et al. 2014). *Milestone* has not been tested for medusahead control in Great Basin sites. This treatment is most useful on sites with noxious thistles as well as medusahead.

[1] Ferrell and Sellers (2014)

Figure 47. Control with aminopyralid

A dense medusahead infestation in an untreated plot (left) contrasts with a good stand of rye grass in a plot treated with 14 oz acre^{-1} *of* Milestone *in fall (right). (Photo: Josh Davy)*

Chapter 8: Integrated Management

Most often a single control method doesn't achieve sustainable management of a rangeland weed such as medusahead. A successful long-term management strategy usually includes some combination of mechanical, cultural, biological, and chemical control techniques. A combination of management strategies is known as integrated management (also called integrated pest management, or IPM).

Integrated management requires the land manager to adapt to shifting conditions on the ground and, if necessary, try different control techniques. Ideally, control methods are chosen to support each other, rather than tried at random. For example, maintaining a healthy rangeland system – sometimes including revegetation – is an important part of an integrated management program for medusahead. But before revegetation can succeed, a dense medusahead infestation must be controlled using burning, herbicides, or other control techniques. The combination of medusahead control followed by revegetation is one example of integrated management.

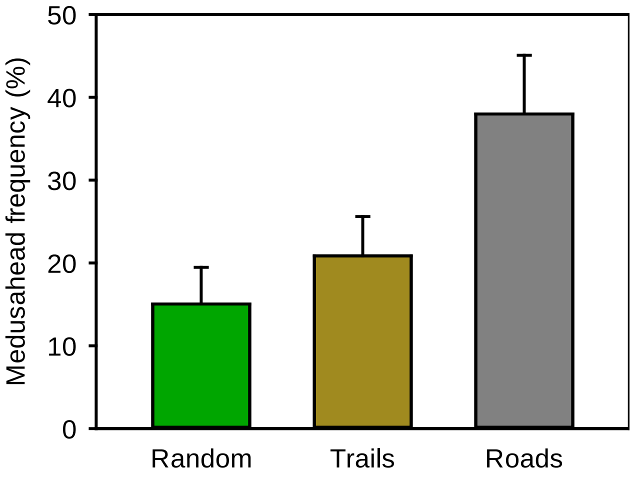

Figure 48. Occurrence in eastern Oregon

Medusahead distribution on different sites (mean values plus standard error bars). Adapted from Davies et al. (2013)

Prevention

Preventing the introduction and establishment of medusahead in new areas is far more cost-effective than attempting to eliminate an established infestation (Cal-IPC 2012). Thus prevention is an important strategy for long-term integrated management of medusahead. From a policy perspective, surveys have found that the general public is more supportive of programs to prevent invasion of new species into public lands than of programs to rehabilitate infested, degraded rangeland (Rollins and Taylor 2012).

The major elements of a prevention program are preventing introduction of medusahead seed, reducing the susceptibility of the ecosystem to medusahead establishment, establishing a program for early detection and monitoring, and developing effective education materials and activities (DiTomaso 2000).

Preventing introduction of seed

In a landscape-level survey of medusahead distribution in southeastern Oregon, Davies et al. (2013) found that infestations were concentrated along travel routes, primarily unimproved roads and secondarily trails and animal paths (Figure 48). This suggests that vehicle traffic – including cars and trucks, construction equipment, and farm machinery – is a primary source for introduction of medusahead seed, followed by movement of livestock.

The best ways to prevent introduction of medusahead seed into new areas include:

Vehicle, clothing, and livestock hygiene.

Vehicles and equipment working in medusahead-infested areas, particularly during summer months when the heads have viable seed, should be cleaned on site before moving to new, uninfested areas. Vehicles entering uninfested areas, especially agricultural, construction, and fire-fighting equipment, should be inspected and cleaned if necessary.

Field workers should check their clothing and brush off any clinging seeds before leaving infested areas and before entering clean sites. Medusahead seeds are most commonly found in shoelaces and shoe eyelets, socks, and pants cuffs.

It is probably unrealistic to ask ranchers to inspect and clean seed from their livestock. However, seed dispersal by livestock can be greatly reduced if livestock are not transported directly from infested sites to clean sites during summer (Davies 2008). If transport has to be done at this time, it is advisable to hold the animals between sites for a few days to give them a chance to shed attached seed. Sites where animals are unloaded from transport should be inspected periodically for new infestations.

(Photos: Erica Spotswood, UC Berkeley)

Control along infestation corridors.

Controlling medusahead infestations along transportation routes entering clean areas is of the highest priority (Davies et al. 2013; Johnson and Davies 2012). Not only are infestations more likely to occur along travel routes, but vehicles and animals moving along infested roads and trails can move seed into new areas.

Preventing local seed movement.

A medusahead-infested area next to a clean site poses a high risk of invasion. If possible, the infestations closest to the uninfested area should be controlled to leave more of a protective buffer.

Because most medusahead seeds drop near the plant and don't self-disperse over greater distances, vegetative buffers can help to contain infestations. In one study, the perennial grass desert wheatgrass was planted in containment "fences" 20 ft (6 m) wide around medusahead infestations. These barriers prevented about 98% of medusahead seed movement out of infested areas (Davies 2008; Davies et al. 2010). Used as exclosures, such buffers might serve to limit medusahead encroachment into ecologically sensitive sites.

Using clean materials.

When agricultural or construction materials must be introduced to a clean site, these products should be free of medusahead seed. For example, seed mixes for revegetation projects, and hay for forage, should be certified weed-free. Gravel and fill material for construction should be inspected at the source site to ensure they are weed-free, and the sites where such material is used should be inspected periodically for new infestations.

Reducing ecosystem susceptibility

One of the ways to prevent medusahead from establishing on a clean site is to maintain a strong stand of competitive vegetation. This may require grazing management or other cultural practices which favor desirable species. Soil disturbance should be avoided, as this can allow medusahead to establish. Some sites may require revegetation to fill in weak or patchy stands.

Grazing management.

As discussed previously, proper management of livestock grazing can reduce populations of medusahead. Likewise, grazing can be managed to maintain desirable vegetation.

On low-elevation rangeland, other annual grasses are very competitive with medusahead and can help to prevent it from establishing. Overgrazing of low-elevation rangeland during early spring can reduce seed production by desirable grasses, leaving fewer propagules to maintain a strong stand in the following year. Annual grassland should not be grazed hard just before or during flowering times for forage grasses.

On high-elevation rangeland, grazing too hard, especially in spring, can reduce the vigor of competitive perennial grasses. The season of use should be rotated so that perennial grasses can set seed prior to grazing at least every other year. Best grazing management for these rangelands is often a rotation system where sites are grazed during the growing season one year, after seed set the next year, and not at all (rest from grazing) in the third year.

Minimizing disturbance.

Soil disturbances such as construction projects, mechanical brush removal, grading, and so on should be conducted with caution in uninfested rangeland. If these activities take place near the edge of a clean area, adjacent to an infested site, medusahead can readily establish in the disturbed soil. If the disturbance zone is linear, as with construction of a road, powerline right-of-way, or pipeline, it may conduct a medusahead infestation into the clean site. After soil disturbance projects are finished, especially projects near or crossing the edge of a clean area, the disturbed soil should be inspected periodically for new infestations.

Revegetation.

On high desert rangeland, perennial grasses are more competitive with medusahead than are forbs or shrubs. In this environment, the best way to limit establishment and spread of medusahead is to manage for a strong stand of two or three types of bunchgrasses, and to seed in grasses if necessary (Sheley and James 2010). (See the discussion under Revegetation.)

Monitoring, early detection, and rapid response

It may not always be possible to prevent medusahead seed from arriving on a site. However, monitoring the site for new infestations, paying particular attention to those areas at highest risk of invasion, can help to detect a medusahead infestation in its early stages. At this point, medusahead can be eradicated before the plant becomes widespread, crowds out other species, and develops a soil seedbank. The previous paragraphs provide some hints on how to do this.

Concentrate on areas at highest risk of invasion.

Monitoring efforts should be concentrated in areas where medusahead seed is most likely to be introduced. The areas of highest risk include areas adjacent to roads, trails, and facilities, especially toward the edge of the clean site; livestock staging sites; recently disturbed soils, or places where gravel or other fills have been introduced; and edges of the clean site which may be adjacent to infested areas. Another priority might be areas with high scenic or ecological value.

Monitor at times of year when medusahead is easy to see.

In early spring, medusahead is hard to distinguish from other grasses. Later in the season, when medusahead begins to flower, it is easier to see. Unfortunately, by this time medusahead may already be producing viable seed. Monitoring is most effective when coupled with rapid-response tactics, e.g., pulling, hoeing, or spot-treating with glyphosate as soon as plants are found. If the seeds appear to have filled, it is advisable to remove, bag, and dispose of the plants. It is also useful to mark the site of the infestation using a GPS unit so the location can be watched closely in future.

Education

Education is a proactive and inexpensive means of preventing medusahead invasion. Workers, cooperating agencies, and recreational users of a clean site should know how to identify medusahead and should be made aware of the consequences of a medusahead infestation.

Who should be informed.

- Ranchers and other landholders on neighboring properties, and on properties which source livestock to the site
- On-site workers, including short-term workers such as fire crews, construction companies, and transportation and delivery services
- Agency personnel and recreational users, such as hunters, campers, and hikers, who may access the site

What they should know.

- The potential economic and environmental consequences of an unmanaged medusahead infestation
- How to identify medusahead in the flowering stage, and what the seeds look like
- Major risk factors and introduction routes for medusahead seed
- Basic seed hygiene for vehicles, equipment, clothing, and livestock
- How to report newly detected infestations (e.g., to the site land manager)

Developing a Management Strategy

Implementing a Strategic Plan

Medusahead can be managed by proper use of grazing, prescribed burning, mechanical removal, or herbicides. However, integrating some of these methods can provide even better control (Davies 2010; Davies and Sheley 2011; Kyser et al. 2007; Monaco et al. 2005). For example, several methods of controlling medusahead also remove medusahead thatch (i.e., burning, tillage, and sometimes mowing or grazing). Thatch removal can result in improved grazing, better efficacy of preemergence herbicides, and more successful establishment of revegetation plantings.

Table 8 (end of this chapter) gives a summary of medusahead management options.

Examples of Integrated Management Programs

Burning followed by preemergence herbicide

In a study conducted at two sites in California (Fresno and Yolo counties), medusahead management was monitored in a two-year integrated program using prescribed burning and the herbicide imazapic, either alone or in combination (Kyser et al. 2007). At each site, four different treatments were compared with untreated control plots. Treatments included two consecutive years of prescribed burning (May or June), two consecutive years of imazapic (applied in fall), burning in the first year followed by imazapic treatment in fall, or imazapic treatment in the first year followed by burning in the second year.

Medusahead cover in untreated sites averaged 45% in Fresno County and 71% in Yolo County. A single burn gave 98% control of medusahead in Fresno County and 85% in Yolo County. After a second year burn, control was better than 96% at both sites. By comparison, the combination of a late spring burn (which removed the thatch) followed by a fall imazapic treatment nearly always gave 100% control of medusahead the following year. In this study, using these combined techniques, it was possible to achieve complete control of medusahead in a single year.

Preemergence herbicide and revegetation

As discussed earlier, a vigorous stand of perennial grasses can help to prevent medusahead from establishing. Yet it is difficult to establish perennial grasses on a medusahead-infested site. This presents the land manager with a catch-22 situation. One solution is to control the infestation before seeding, using a preemergence herbicide.

Some researchers have suggested treating with imazapic and seeding with desirable species at the same time (the “single-entry” approach; Sheley et al. 2012a, 2012b) (Figure 49). However, recent comparison trials suggest that seeded species establish more successfully if seeding is delayed after treatment with imazapic. Davies et al. (2014) established plots where seeding was delayed for one year after burning and treating with imazapic, versus plots where treating

Figure 49. Treatment and seeding in a single pass

The single-entry approach shown here is an efficient method of seeding and applying herbicide simultaneously. However, seeded species show improved establishment if planted a year after imazapic application. (Photo: Brett Bingham, Eastern Oregon Agricultural Research Center, Burns, OR) and seeding were conducted at the same time. Two years after seeding, perennial grass cover was six to eight times higher in plots where seeding was delayed, compared to plots where treating and seeding were conducted at the same time (and more than 20 times higher than in plots with no treatment at all). Wilson et al. (2010) found that even a six-month delay (treating with imazapic in fall and planting in early spring) resulted in poor perennial grass establishment; these researchers likewise recommended waiting a full year.

In these studies, burning probably improved herbicide efficacy by removing litter. Thatch removal, medusahead suppression, and the release of nutrients tied up in the thatch all contributed to improved establishment of bunchgrasses.

Use of imazapic to manage medusahead can be most successful when there is a good population of established resident vegetation. This herbicide is relatively safe on established perennial grasses and sagebrush, so the presence of these plants can help to jump-start revegetation efforts. Davies and Sheley (2011) found that the combination of burning followed by imazapic resulted in improved control of medusahead and greater increases in resident perennial bunchgrasses than did burning or imazapic applied individually.

In areas without much desirable resident vegetation, it may be useful to apply glyphosate at the time of planting to control emerged weeds (Wilson et al. 2010). Glyphosate has no soil residual and will not affect newly planted seed. Though the research hasn't been done, to our knowledge, this might be a good application of the single-entry approach described above.

Mowing or grazing as part of an integrated strategy

Reed (2010) found that mowing medusahead before seed production for two years resulted in improved establishment of seeded native grasses and forbs. Like burning, mowing can both suppress medusahead and remove thatch, improving a site for reseeding. Using mowing or burning to remove medusahead thatch has also been shown to increase the effectiveness of subsequent sheep grazing (Lusk et al. 1961).

Following fall application of a preemergence herbicide to control medusahead, mowing can be used in spring to control escapes before they produce seed. Postemergence herbicides may also be useful as a follow-up treatment.

Table 8. Options for managing medusahead

This summary of options discussed in this guide will give the land manager some idea of how different techniques can be combined into a management strategy. See linked sections for more details.

Main goals	Management activity		Limitations	Timing
Prevent medusahead from producing seed	Mechanical control	Hand removal	Impractical for large infestations	Mid to late spring
		Mowing	Limited by terrain; can spark a fire; not recommended for high desert	Mid to late spring
		Tillage (disc)	Limited by terrain and rocky soil; not recommended for high desert	Spring
	Grazing management		Overgrazing or grazing too early can damage desirable forage	Mid spring
	Prescribed burning		Air quality, fire escapes, temporary forage loss; not recommended for high desert	Early summer
	Chemical control	Preemergence	Off-site movement; resistance; non-target effects. May be improved by removing thatch.	Fall
		Postemergence	Off-site movement; resistance; non-target effects	Mid to late spring
Remove medusahead thatch	Mechanical control	Mowing	Limited by terrain; can spark a fire; not recommended for high desert	Mid to late spring
		Tillage (disc)	Limited by terrain and rocky soil; not recommended for high desert	Spring
		Tillage (harrow)		Any time
	Grazing management		Overgrazing or grazing too early can damage desirable forage	Mid spring
	Prescribed burning		Air quality, fire escapes, temporary forage loss; not recommended for high desert	Early summer
Improve rangeland	Remove medusahead thatch			
	Grazing management			
	Revegetation		Can introduce nonnative species. Success is improved by removing thatch and controlling medusahead.	Fall or spring
Prevent medusahead reinvasion	Improve rangeland	See above. Also, minimize soil disturbance in areas adjacent to infestations		
	Prevent seed introduction	Make sure human activities, livestock, and imported materials are free of seed		Any time
	Monitoring	Watch site for medusahead escapes, especially along roads and trails		Late spring
	Education	Inform site workers and visitors about medusahead		Any time

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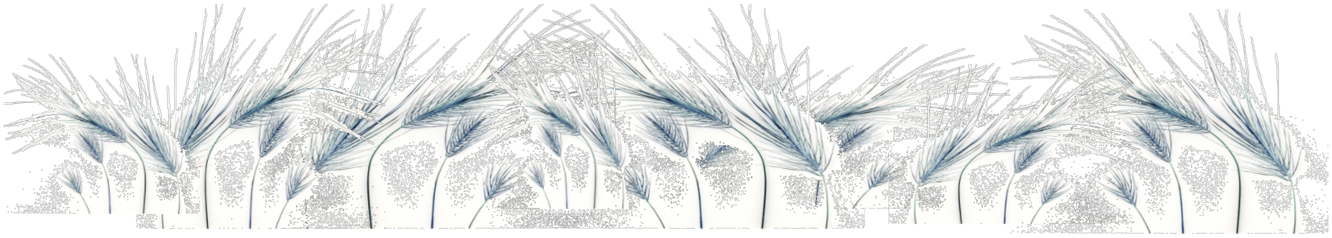
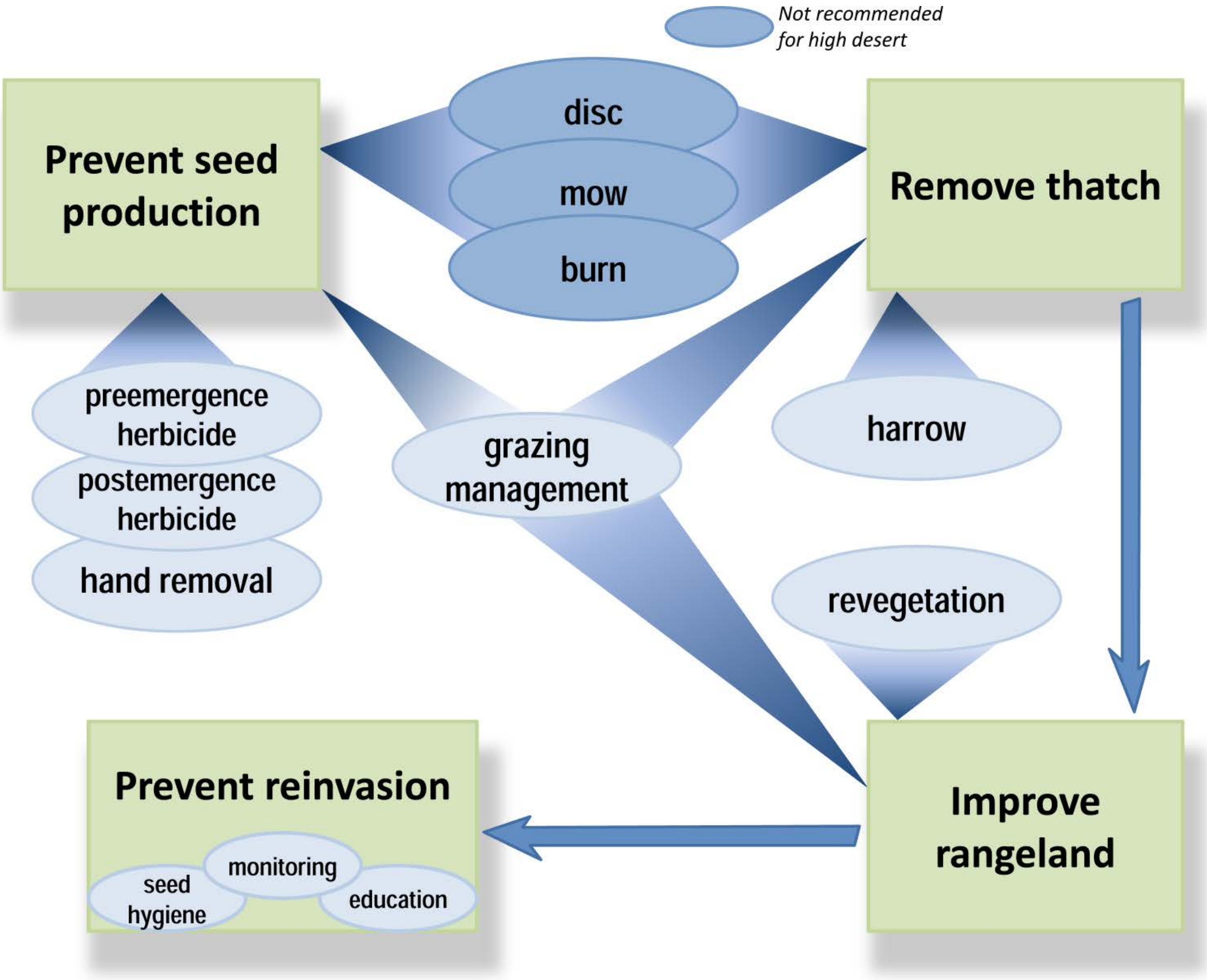
for the Western States





Not recommended for high desert

Prevent seed production

disc

mow

burn

Remove thatch

preemergence herbicide

postemergence herbicide

hand removal

grazing management

harrow

revegetation

Prevent reinvasion

seed hygiene

monitoring

education

Improve rangeland

University of California
Weed Research & Information Center