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Evaluating Integrated Weed Management: Russian Knapweed Control With Goat Grazing and Aminopyralid

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EVALUATING INTEGRATED WEED MANAGEMENT: RUSSIAN KNAPWEED CONTROL WITH GOAT GRAZING AND AMINOPYRALID

by

Clarke G. Alder

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Plant Science
(Weed Science)

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ABSTRACT

Evaluating Integrated Weed Management: Russian Knapweed Control with Goat Grazing and Aminopyralid

by

Clarke G. Alder, Master of Science

Utah State University, 2012

Major Professor: Dr. Corey V. Ransom
Department: Plants, Soils, and Climate

Russian knapweed (*Acroptilon repens*) is an invasive perennial forb that has become well established in much of the western United States and Canada since the late 1800s. Aminopyralid is a relatively new pyridine carboxylic acid herbicide registered for use on rangelands and has provided excellent control of Russian knapweed in many studies. Research trials were conducted on two adjacent plot sites at Dinosaur National Monument to evaluate the effects of a single spring goat grazing paired with a fall application of aminopyralid at 0, 53, 70, 88, and 105 g ae ha^{-1} on Russian knapweed control. Russian knapweed density, canopy cover, and biomass were reduced to 0 or near 0 by all rates of aminopyralid, regardless of grazing treatment. Conversely, desirable grass cover and biomass increased at all rates of aminopyralid regardless of grazing treatment. Aminopyralid provided excellent control of Russian knapweed at all rates tested. Desirable perennial grass species have the potential to be injured when growth regulator herbicides are used for broadleaf weed control. Greenhouse trials performed at Utah State University and field trials performed in Logan, UT from 2009-2011 evaluated tolerance and response of six native perennial bunchgrasses to growth regulator herbicides. Grasses used in the study included tall wheatgrass, bluebunch wheatgrass, Great Basin wildrye, Indian ricegrass, big bluegrass, and bottlebrush squirreltail. Two rates each of aminopyralid, aminocyclopyrachlor, and clopyralid were evaluated. Herbicide test rates were based on the labeled rate for control of Russian knapweed and other creeping perennials. Tolerance to herbicides varied among grass species. Petri-dish trials showed reductions in root length by all three herbicides in all six speceis 14 days after treatment (DAT). Shoot length was significantly reduced by both rates of aminopyralid (123 and 246 g ae ha^{-1}) and 280 g ai ha^{-1} of amincyclopyrachlor. The same species were evaluated in the field and greenhouse in response to postemergence applications of the same herbicides. Of the six grass species tested, ‘Sherman’ big bluegrass appeared to be highly tolerant to aminopyralid, clopyralid, and aminocyclopyrachlor, and ‘Magnar’ Great Basin wildrye and Anatone bluebunch wheatgrass appeared to be the most sensitive to aminopyralid and aminocyclopoyrachlor in both the field and the greenhouse.

(115 pages)

PUBLIC ABSTRACT

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Invasion of natural communities by introduced plants is considered one of the biggest threats to biodiversity. Weeds in rangelands cause an estimated loss of $2 billion per year in the United States. These costs include losses in forage quality and yield, grazing interference, animal poisoning, lowering land values, depleting soil water and resources available to native plants, increasing costs of managing livestock, and impacts on wildlife habitat and forage. Integrated weed management (IWM) is a way for land managers such as farmers, ranchers, and government agencies to control invasive weeds. IWM uses several different control methods working in conjunction to produce the most effective results in ways that are both economical and, in many cases, better for the environment than a single method alone. Because of the immense impacts invasive weeds have on wildlife habitat and the overall health of the infested land, Dinosaur National Monument (DNM) is especially interested in IWM for invasive species. Land

managers at DNM and other national parks have been targeting invasive species for several years with a combination of management techniques including, but not limited to, chemical applications, targeted grazing, and mechanical removal of selected species with much success.

Russian knapweed (*Acroptilon repens*) is an invasive perennial forb found throughout DNM. This species typically invades recently disturbed sites, abandoned pastures, and otherwise low-quality landscapes and like many invasive perennial weeds, causes problems by quickly displacing native vegetation important to the survival of wildlife and the overall quality of the landscape. Control of Russian knapweed is important to maintain plant and animal species diversity in these invaded areas and throughout the DNM.

In 2009, approximately $50,000 was allocated to Utah State University for a two-year study researching IWM methods for control of Russian knapweed in DNM. These methods included targeted grazing of an area infested with Russian knapweed and a late-season application of the herbicide aminopyralid (Milestone®). Part of the resources were used for greenhouse and field trials evaluating the relative tolerance of perennial grass species to growth regulator-type herbicides commonly used to control broadleaf species like Russian knapweed. All of the grass species studied are native to the Western United States and are often present in areas where Russian knapweed has invaded or are used in revegetation efforts in areas recently treated for invasive perennial weeds like Russian knapweed.

The effects of these herbicides on non-target species such as perennial grasses are important to quantify and while these effects are only a part of what needs to be considered when creating an integrated management plan, the data will be used to assess the economics and safety of the herbicides to non-target plants in the areas they are to be applied. Land managers will have better information from which to make informed decisions when forming land management plans for different areas like those at DNM.

Dedicated to my family. Thank you for all the understanding,
love and support. Seeing your faces every day
is a warm reminder of why I do what I do.

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CHAPTER 1

LITERATURE REVIEW

Origin and Distribution

Acroptilon repens (L.) DC., commonly known as Russian knapweed, is a member of the Asteraceae family. Its native distribution spans from Mongolia to Iran and Turkish Armenia to parts of Asia Minor (Watson 1980). Common names synonymous with Russian knapweed include mountain bluet, Turkestan thistle, creeping knapweed, and Russian starthistle. In the past, Russian knapweed has been known taxonomically as *Centaurea repens* L. and *Centaurea picris* Pallas ex Willd., with the most common being *C. repens.* While grouped by the scientific community into the genus *Centaurea* for decades, extensive studies from as early as the 1940s and into the 1970s produced data showing physiological, morphological, and even pathological (Savile 1970) differences from members of *Centaurea*, therefore providing enough evidence for segregation from the genus (Watson 1980). Although there is still debate as to which group Russian knapweed should belong to, with another closely related genus, *Rhaponticum,* being considered by some taxonomists today (Hidalgo et al. 2006), Russian knapweed remains one of two members of the genus *Acroptilon* with its official name being *Acroptilon repens* (L.) DC. (USDA-ARS 2011).

Most likely introduced during the late 1800s through the sale and distribution of contaminated Turkestan alfalfa (*Medicago sativa* L.) seed (Groh 1940; Rogers 1928), Russian knapweed has become an invasive pest species of range and agricultural lands in the western United States and many parts of Canada (Enloe et al. 2008). Having been declared noxious in 25 states in the U.S. and four provinces in Canada (Rice 2006) and infesting over 600,000 ha (1,561,714 ac) in the western U.S. alone (Duncan 2001), it has become a species that is strongly disliked by land managers and agriculturalists alike. Russian knapweed is an aggressive competitor in crop and fallow land (Maddox et al. 1985). Through a combination of competitive and allelopathic interactions (Maddox et al. 1985; Whitson 1999), Russian knapweed causes problems by displacing desirable vegetation and forming monocultures which effectively reduce forage quality and can also increase soil erosion (Roché and Roché 1988). Other negative effects include a decline in native species diversity and changes in the total vegetation composition of the landscape.

Morphology and Description

Russian knapweed is a creeping, deep-rooted, highly aggressive, perennial forb (Goslee et al. 2003) with small, solitary flower heads that produce pink, purple and sometimes white flowers. The flower heads have fine papery bracts that aid in distinguishing the plant from other knapweeds. Shoots of Russian knapweed range from 30 to 90 cm (12 to 36 in) tall and are heavily branched at maturity (Beck 1996; Welsh et al. 1993). Tiny hairs or “knap” cover the entire plant causing a soft gray look which is more noticeable when the plant is young. Shoots emerge in the early spring as soon as soil temperatures remain above freezing (Watson 1980). Formation of vegetative buds along the horizontal roots begins in the fall and continues through the winter, finally forming rosettes early the following spring (Beck 1996). The formation of vegetative buds which arise at irregular intervals throughout the season (Watson 1980) allows the knapweed to respond to disturbances in way that are positive for the plant, but also makes it difficult to control. For example, in areas where shallow tillage has been used for control of Russian knapweed, small pieces that used to be part of the same root now can emerge into single plants and potentially increase the density of the knapweed over the course of the season if another control method is not implemented. Russian knapweed typically bolts in late May to mid-June and flowers from June to October in the United States (Watson 1980). Seeds tend to be oblong, grey to brown in color, and approximately 1.5 mm (0.06 in) in length. They are ridged, covered with fine white hairs, and have a ring of bristles on the apex of the seed (North Dakota Department of Agriculture 2005). Russian knapweed can produce 50 to 500 seeds per shoot and up to 1200 seeds per plant. These seeds can stay viable for up to 3 years in the soil (Ivanova 1966). Moreover, despite its ability to produce viable seed, Russian knapweed lacks effective mechanisms for seed dispersal (Watson 1980) as the seed heads tend to stay closed for much of the season and the seeds themselves have an extremely small pappus. Consequently the spread of Russian knapweed seeds is mainly limited to the handling and distribution of contaminated hay (Renney 1959; Rogers 1928) or the knapweed plants themselves. The primary method of reproduction for Russian knapweed then becomes the spread of an extensive and complex rooting system. The black scaly roots of a single Russian knapweed plant have been found as deep as 2.4 m (8 ft) and are capable of covering up to 12 m^2 (14 yd^2) in just two growing seasons (Beck 1996; Ivanova 1966; Selleck 1964). Its deep roots allow it to take up water and nutrients sooner and become active before annual and shallow-rooted perennial competitors (Goslee et al. 2003; Selleck 1964; Watson 1980). Because of its widespread rooting system, Russian knapweed is a strong competitor capable of suppressing growth of other plant species and producing single species stands in a relatively short amount of time. These Russian knapweed stands have the potential to exist almost indefinitely. Watson (1980) reported an infestation at Indian Head, Saskatchewan which had persisted for over 75 years.

Biology and Habitat

As an early successional C_3 forb, Russian knapweed can typically be found in heavy soils following disturbance and in places with low to moderate annual rainfall (18-73 cm) (Goslee et al. 2003). According to Rogers (1928), however, Russian knapweed is not necessarily associated with any single soil type, rather it can adapt to many different soil types and textures. It tolerates poor drainage well and is able to survive in highly compacted soils because of its strong, extensive root system (Beck 1996). In its native region, Russian knapweed often grows in orchards and vineyards where soil is regularly disturbed by tilling or other means (Koloren et al. 2008). In the United States, Roché and Roché (1988) reported that 47% of Russian knapweed mapped in eastern Washington was found on pasture and rangelands. The remaining 53% was found in areas such as railroads, roadsides, rights-of-way, and other areas with poor quality and highly compacted soils. Goslee et al. (2003) found Russian knapweed most often on sites with low June precipitation, low elevation, and high percentages of soil clay.

Although Russian knapweed tends to create more of a monoculture once it is well established, other vegetation, mostly annual and perennial grasses and small forbs are also associated with young knapweed stands (Zouhar 2001). A dense patch of Russian knapweed usually contains 100 to 300 shoots m^{-2} (Ivanova 1966; Sellek 1964). Under moist conditions, competition from perennial grasses helps to reduce knapweed density by competing for available resources and providing extra canopy cover. Dall'Armellina and Zimdahl (1988) found that Russian knapweed is very sensitive to decreased sunlight and does not compete well with shading from heavy canopy cover of other plants; however in drier locations knapweed will readily out-compete the surrounding vegetation (Sellek 1964). Rogers (1928) claimed that Russian knapweed is able to survive in any crop in any tillable soil.

Plant Interactions

Once Russian knapweed is introduced to a new area, often it is able to become established quickly due to the lack of native competitors and predators specific to Russian knapweed (Blumenthal et al. 2010). As it becomes established, its lengthy roots begin to dominate the soil profile, reaching deep into the ground for water and nutrients. Because many western rangelands have already been invaded by non-native annual grasses such as cheat grass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*) with shorter lifespans and shallow roots, these areas become even more susceptible to further invasion by creeping perennials like leafy spurge (*Euphorbia esula*) and Russian knapweed (DiTomasso 2000). Once Russian knapweed is established, most of the annual and shallow-rooted perennial plants are unable to compete with its ability to take up nutrients and sequester limiting resources and therefore struggle to meet their own needs—often dying as a result.

LeJune and Seastedt (2001) suggest that many of the knapweeds, including Russian knapweed, may also have the ability to alter resource availability and nutrient cycling in ways that can exclude the native species around them, making native perennial grass-dominated areas susceptible as well.

As more of the native and desirable plants disappear from the landscape and the total number of plants is reduced, increased soil erosion and runoff also become a problem. Lacey et al. (1989) found that surface water runoff and stream sediment yields were 56% and 192% higher, respectively, in a spotted knapweed (*Centaurea stoebe*) dominated site compared to an adjacent native perennial site. Their study also emphasized that increased runoff resulted in less infiltration into the soil making it harder for existing annuals and shallow-rooted perennials to receive water essential to their survival.

Although Russian knapweed is often successful in taking up water and nutrients before other competing plants, other attributes may also lead to its success as an invader. LeJune and Seastedt (2001) suggest that a change in the ratio of resources available to plants over the last 200 or so years has also contributed to the successful establishment of many invasive species. This change in resource ratio refers to an overall increase in nitrogen (N) availability, or the decrease in N limitation due to region-wide direct and indirect fertilization resulting from cattle grazing, decreased fire frequency due to fire suppression by humans, and increased atmospheric N deposition (Day and Detling 1990;

McNaughton et al. 1997; Seastedt et al. 1991). Because of increased availability of N in the soil, slower growing plants with a lower N requirement no longer have a competitive advantage over faster growing plants like knapweed that have a higher requirement for N. For decades, Russian knapweed has also been the source of intense studies regarding allelopathy and its ability to slow the development of adjacent plants using biochemicals. Specifically, Russian knapweed secretes a phytotoxic flavonoid through its roots called 7, 8-benzoflavone (Alford et al. 2007). Flavonoids are chemicals common in plants that are often used as a protection against harmful microbes and insects. Although most flavonoids have relatively low toxicity to other plants, 7, 8-benzoflavone has been found to inhibit seed germination and cell growth (Berhow and Vaughn 1999) in many species. Data from the study conducted by Alford et al. (2007) suggest that 7, 8-benzoflavone is secreted early in the growing season and therefore may be able to affect other species, especially annuals, during very susceptible but critical life stages. In some cases, very early germination may be the only chance some species have to become established among Russian knapweed (Tyrer et al. 2007).

Animal Interactions

As native vegetation is forced out, Russian knapweed not only promotes soil erosion and decreases soil quality and native plant diversity, but affects wildlife diversity and habitat quality as well. Simmons (1985) reported that from 1920 to 1980 Russian knapweed spread annually at a rate of 8% and caused a 55% average annual reduction in livestock carrying capacity. In the United States it is estimated that about $2 billion is lost each year as a direct result of dealing with invasive weed species on rangelands

(DiTomaso 2000). Impacts include loss of forage quality and yield for domestic livestock, loss of livestock due to poisonous invasive plants, reduction of recreational and aesthetic qualities, soil depletion, and overhead costs for management of these invasive species (DiTomaso 2000; Hirsch and Leitch 1996; Lacey et al. 1989). Russian knapweed dramatically decreases the productivity of desirable forage plants (Harris and Cranston 1979; Maddox 1979; Watson and Renney 1974) which affects wildlife that feed on them. Because of Russian knapweed's low nutritive quality, bitter taste, and higher fiber content (Maddox 1979; Watson and Renney 1974), it tends to be less desirable to wildlife for grazing most of the season. As native forage sources are depleted and fewer palatable plants exist, animals begin to look for alternatives, often moving out of an area to find food or turning to other less palatable, sometimes more harmful plants. Russian knapweed also has a negative impact on horses specifically. Repin, a sesquiterpene lactone contained in Russian knapweed, and its close cousin, yellow starthistle (*Centaurea solstitialis*), has been linked to a nervous system disorder in horses called equine nigropallidal encephalomalacia, also known as "chewing disease" (Stevens 1982). Prolonged ingestion of Russian knapweed or yellow starthistle, at least 28-35 days for knapweed and slightly longer for yellow starthistle (Chang et al. 2011), results in paralysis of the lips and tongue, reduced jaw tone, and most importantly, the softening and necrosis of specific brain tissues, eventually causing symptoms much like Parkinson's disease in humans (Chang et al. 2011; Stevens et al. 1990; Young et al. 1970). The effects of this disease are almost always fatal (Cordy 1954). Conversely, repin appears to have no effect on cattle or sheep, making them both potential candidates for control through targeted grazing. In addition, Bohnert et al. (2006) found the protein content of Russian knapweed to be similar to that of alfalfa, suggesting that Russian knapweed could actually be a possible substitute for alfalfa for beef cows grazing in already low-quality forage areas. Most of the time livestock will avoid the knapweeds because of the high tannin content and very bitter taste; however, Mote et al. (2008) reported that sheep altered their diets to include more types of food containing tannins and/or terpenes when the availability of more palatable and nutritious grasses and forbs was restricted. Kelsey and Mihalovich (1987) also reported that in the spring and early summer, when the plants are succulent and actively growing and have lower concentrations of plant secondary compounds such as tannins or terpenes, sheep and cattle have been observed grazing spotted knapweed, sometimes even prior to moving on to other grasses and small forbs.

Control

Numerous methods have been studied for control and management of Russian knapweed including targeted grazing (Koloren et al. 2005; Williams and Prather, 2006), burning (Zouhar, 2001), herbicide application (Derschied et al. 1960; Enloe and Kniss 2009, Enloe et al. 2008), mowing (Benz et al. 1999; Sheley et al. 2003), cultivation (Derschied et al. 1960) , various forms of biological control (Djamankulova et al. 2008; Ou and Watson 1993; Watson and Clement 1986), and revegetating controlled areas with competitive perennial grasses (Mangold et al. 2007; Sheley et al. 2007). Today, the most commonly used methods tend to be integrated approaches combining two or more methods in order to achieve acceptable control. At times, characteristics of the infested site and other circumstances such as agency budgets may limit the number of alternatives that can be used for control. This emphasizes the importantance of factors such as overall labor costs, equipment type, and availability of laborers and equipment in determining which method(s) to use. One of the major challenges faced when deciding on a control method for many invasive rangeland species is the topography of the infested land. In the case of Russian knapweed, a large percentage of infested landscapes are topographically uneven, low-value lands (Benz, 1999) which can be very difficult to access with larger equipment such as truck sprayers or tractors thus limiting effective alternatives to smaller equipment, more laborers and less convenient, often more expensive methods of control.

Chemical Control. One of the most heavily explored methods for the control of Russian knapweed involves the use of chemical herbicides. Chemicals have been used to control Russian knapweed for as long as they have been available. Rogers (1928) suggested the use of chemicals for the control of Russian knapweed as early as the late 1920s. Chemicals such as 2, 4-D (Derscheid et al. 1960; Jones and Evans 1973; Laufenberg et al. 2005; Sheley et al. 2004; Sheley et al. 2007), glyphosate (Laufenberg et al. 2005; Sheley et al. 2007), fosamine (Laufenberg et al. 2005; Sheley et al. 2007), clopyralid (Laufenberg et al. 2005; Sheley et al. 2002; Sheley et al. 2007), picloram (Berezovskii and Krumzdorov 1971; Ferrell et al. 1986; Morrison et al. 1995; Sheley et al. 2002), dicamba (Fizyunov et al. 1977; Jones and Evans 1973; Mordovets and Holovin 1976), chlorsulfuron (Sebastian and Beck 1993), metsulfuron (Sebastian and Beck 1993), diflufenzopyr (Enloe and Kniss 2009), and aminopyralid (Enloe et al. 2008) have all been studied and evaluated for their efficacy on Russian knapweed in the last several decades.

The most success has been from the use of carboxylic acids such as 2,4-D (Derscheid et al. 1960), picloram (Bottoms and Whitson 1998; Morrison et al. 1995), clopyralid (Benz et al. 1999; Laufenberg et al. 2005), and more recently, aminopyralid (Bukun et al. 2010; Enloe et al. 2008; Jacobs and Denny 2006).

Among the pyridine-carboxylic acids, aminopyralid is the most recent chemical registered for rangeland weed control (Carrithers et al. 2005). Registered in August, 2005 to Dow AgroSciences LLC under the trade name Milestone™, aminopyralid is a relatively new herbicide that has proven very effective for control on many members of the Asteraceae family (Carrithers et al. 2005; Enloe et al. 2007; Enloe et al. 2008). Some of the major advantages of aminopyralid include its low soil mobility (Bukun et al. 2010) and greater ability to control a large sperctrum of broadleaf weeds more effectively and with less active ingredient being applied than previously used pyridine carboxylic acid herbicides (Enloe et al. 2007). Because of the rate at which it breaks down in water, it can also be sprayed near riparian areas (United States Office of Prevention 2005).

One major component of using herbicides for control of Russian knapweed is the timing of application. Some carboxylic acid herbicides produce similar results whether applied in the spring or in the fall. Most often however, late fall to very early winter applications have proven best for control of Russian knapweed (Enloe et al. 2008; Jacobs and Denny 2006). This particular timing corresponds with the growth and formation of vegetative buds on the plant roots and negatively affects emergence the following spring. In addition, most desirable grass species are dormant during this time of year and remain unaffected by the majority of herbicide treatments used for Russian knapweed control.

Grazing. Targeted or prescribed grazing is another control method that has drawn interest from the scientific community for quite some time. Grazing by livestock has happened naturally since time began, making it one of the oldest weed management tools in existence along with fire (Launchbaugh and Walker 2006). The concept of targeted grazing is aimed toward enhancement of the landscape through removal of an invasive species via intense livestock grazing during the most susceptible growth stage. For Russian knapweed, this tends to be from the early vegetative stage to just before flowering (Wilson et al. 2006). Sheep and goats will eat many invasive species including leafy spurge (*Euphorbia escula*), oxeye daisy (*Leucanthemum vulgare*) and most knapweed species (Sheley et al. 2004) and therefore are used extensively in grazing studies on rangeland as well as for real-world applications. There is a lot of literature evaluating targeted grazing for control of spotted knapweed (Kennett et al. 2009; Olson et al. 1997; Sheley et al. 2004; Thrift et al. 2008; Williams and Prather 2006) diffuse knapweed (Maxwell et al. 1992; Sheley et al. 1997), and yellow starthistle (Benefield et al. 1999; Thomsen et al. 1989; Thomsen et al. 1993), but relatively small amounts of data have been published in regards to Russian knapweed response to targeted grazing. Olson et al. (1997) reported that three consecutive years of repeated sheep grazing resulted in lower seedling, rosette, and mature plant densities of spotted knapweed in grazed versus un-grazed areas. Native grasses and forbs also increased due to less competition from the knapweed, indicating that repeated sheep grazing over a long period of time may slow the rate of infestation by spotted knapweed. Similar results were achieved by Williams and Prather (2006) using goats in Lemhi County, Idaho. Targeted grazing is usually used as part of an integrated approach to weed control. Land managers will often combine grazing with herbicide treatments or other methods in order to maximize control of an invasive species. Sheley et al. (2004) experimented with a combination of 2,4-D and grazing with sheep in an attempt to rehabilitate an area infested with spotted knapweed. Results from the study indicated that a spring applied herbicide released perennial grasses from competition with spotted knapweed and also changed the weed composition from older, more mature plants to younger, softer, and more palatable plants that were preferred by the sheep. In the study, 2,4-D alone resulted in 40% control of spotted knapweed 4 years after application. Integration with grazing showed significantly greater control during the same time period. Based on their results, however, Sheley et al. (2004) concluded that the sites would return to spotted knapweed quickly if only a single method was used and therefore suggested that an integrated method with repeated applications would be needed in order to maintain control of the species. Olson et al. (1997) also stated that a long term grazing plan could only slow the development of an infestation of spotted knapweed implying that integration with another method may be useful and likely more successful.

Biological Control. Biological control is another potentially major component of knapweed management (Duncan 2001) as collection, screening, and release of biocontrol agents continues to be an area of focus for many invasive plants. Biological control of Russian knapweed was first attempted in the 1970s when a gall-forming nematode, *Subanguina picridis,* was discovered to have significant impacts on the plant. Although the host range of *S. picridis* also includes a few closely related species in the Asteraceae family, Russian knapweed seems to be the only plant that is highly susceptible to the nematode (Watson 1986). The effects of *S. picridis* are still being evaluated today. Currently, the nematode has been released on limited sites in seven states (CO, MT, NM, OR, UT, WA, and WY) in the US and in Alberta and British Colombia, Canada (Duncan 2001).

More recently however, while investigating a native range of Russian knapweed, researchers discovered a gall wasp and a gall midge, *Aulacidea acroptilonica* and *Jaapiella ivannikovi*, respectively, that are specific only to Russian and one or two other knapweed species (Schaffner et al. 2006). In a study done by Djamankulova et al. (2008), these two insects were found to reduce above ground biomass of Russian knapweed as well as cause a significant reduction in seed output. They concluded that the impacts of these two species depend on timing of release, population size, and size of the infestation; and while reducing seed output of Russian knapweed would definitely contribute to the management of this invasive species, further research is still needed before any formal conclusion can be reached regarding these two species. One major issue that should always be addressed when considering a biological control component of any management plan for an invasive species is the impact that natural predators could have on non-target species in or near the same area.

Revegetation. Revegetation is often considered a critical portion of integrated weed management (Jacobs et al. 1999). Native and other desirable grass species are important forage sources for wildlife and livestock, and they can also provide good competition for invasive species. Sheley et al. (2002) explain that the establishment of competitive plants is important for rehabilitating infested communities and maintaining desirable ecosystems. Many grass species have the potential to compete well with Russian knapweed; however, some of these grasses have difficulty becoming established if planted in an area that is already heavily infested with Russian knapweed. In these situations, it is common to accompany planting of desirable grass species with an herbicide application to temporarily suppress Russian knapweed growth and allow establishment of the grass seedlings to occur. This can be done both in a multiple entry-type setting where the herbicide is applied, and several days later, desirable species are planted (Mangold et al. 2007) or in a single entry setting where the seeds of the desirable species are planted and the herbicide is sprayed over the top of the soil (Sheley 2007). In either case, special attention should be paid to the potential impacts of the herbicide on the species being planted. For example, timing of herbicide application is critical to maximize grass establishment. When attempting to revegetate a Russian knapweed infested site with Siberian wheatgrass (*Agropyron fragile*) in the spring, Sheley (2007) found that a spring application of clopyralid significantly reduced Siberian wheatgrass biomass. Benz et al. (1999) found minor injury to crested wheatgrass when clopyralid + 2,4-D was applied mid-summer. Tolerance of grass species to herbicides used for broadleaf control is higher for some species than for others, depending on the species and the herbicide. Sheley et al. (2002) found that both crested wheatgrass (*Agropyron cristatum*) and pubescent *(Thinopyrum intermedium)* wheatgrass had higher vigor estimates and biomass than bluebunch wheatgrass *(Pseudorogneria spicata)* when exposed to several rates of picloram and clopyralid, but overall, each species studied was able to tolerate both growth regulator herbicides and provide effective weed suppression through competition. Revegetation has long been recognized as a method of weed control that compliments other methods well, particularly herbicide applications (Bottoms and Whitson 1998; Grant et al. 2003). The presence of strong established native and desirable perennial grass species is important to the long-term health of western rangelands. The competition provided by these species is critical in keeping invasive species out. In addition, tolerance of these grasses to herbicides used for invasive broadleaf weed control is important information that will continue to aid land managers in determining which control methods will be the safest and most effective in a particular plant community or ecosystem.

Objectives

The objectives of this research are outlined as follows:

1) Determine the effect of a single grazing with goats followed by fall aminopyralid treatments on Russian knapweed-infested rangeland , and
2) Study the effects of aminopyralid and other growth regulator herbicides on desirable grasses.

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CHAPTER 2

RUSSIAN KNAPWEED MANAGEMENT: EFFECTS OF GRAZING AND AMINOPYRALID

Abstract

Russian knapweed (*Acroptilon repens*) was introduced into the western United States in the late 1800s. Since that time, it has continued to be invasive and has negatively affected both crop and rangelands in the west. Field studies were established in 2009 and 2010 in the Cub Creek Watershed of Dinosaur National Monument near Jensen, Utah to evaluate the effects of a single spring grazing with goats accompanied by fall application of the pyridine carboxylic acid herbicide aminopyralid at five different rates. Grazing treatments had no significant effects in most cases. Biomass, cover, and density of Russian knapweed were reduced to at or near zero for all rates of aminopyralid. Other forbs also decreased with the same rates, following the same trend as the knapweed. Biomass and cover of desirable grasses tended to increase across all rates as Russian knapweed and other forbs decreased. Higher moisture during spring and summer 2010 may have influenced the overall biomass and cover of desirable grasses in 2011, however the same overall trends were exhibited in both experiments. Desirable grass density seemed to have little or no correlation with the amount of precipitation or the amount of herbicide applied. Neither Russian knapweed nor forb data reflected any significant effects from the amount of precipitation. Being able to utilize rates lower than the labeled rate to achieve the same amount of control is economically advantageous in any setting, allowing land managers to allocate funds to other areas of their management

plans. Knowledge of the effects of treatments on the surrounding vegetation and environment are also important aspects of integrated weed management.

Introduction

Russian knapweed (*Acroptilon repens*) is an aggressive, deep-rooted perennial forb in Asteraceae. Its native distribution spans from Mongolia to Iran and Turkish Armenia to parts of Asia Minor (Watson 1980). Introduced during the late 1800s through the sale and distribution of contaminated Turkestan alfalfa (*Medicago sativa*) seed (Rogers 1928), Russian knapweed has become an invasive pest species of range and agricultural lands in the western United States and many parts of Canada (Enloe et al. 2008). Russian knapweed is an aggressive competitor in crop and fallow land (Maddox et al. 1985) and causes problems by displacing desirable vegetation and forming monocultures which significantly reduce forage quality and can also increase soil erosion (Roché and Roché 1988). In extreme cases it can cause the complete abandonment of croplands (Maddox et al. 1985). Russian knapweed has also been the subject of many studies regarding potential allelopathic properties (Alford et al. 2007; Morris et al. 2006; Tyrer et al. 2007;). Russian knapweed seeds are carried from site to site most likely via handling of contaminated crops or the knapweed itself (Rogers 1928), however, once in a site, the spread of Russian knapweed is primarily due to an extensive and complex rooting system which can grow very deep very quickly (Beck 1996; Ivanova 1966; Selleck 1964). The large root structure of Russian knapweed also provides an advantage for resource allocation in early spring. It is able to become established early in the season and is actively growing by the time many other plants break dormancy (Goslee et al.

2003; Selleck 1964; Watson 1980). Characteristics such as these allow Russian knapweed to become a very strong competitor capable of suppressing all other plant growth and producing single species stands in a relatively short amount of time.

Methods studied for the control of Russian knapweed include cultivation (Derscheid et al. 1960), mowing (Sheley et al. 2003), burning (Vermiere and Rinella 2009; Zouhar 2001), biological control (Ou and Watson 1993), targeted grazing (Koloren et al. 2005; Popay and Field 1996), herbicides (Derscheid et al. 1960; Jones and Evans 1973; Sebastian and Beck 1993), reseeding with competitive species (Mangold et al. 2007; Whitson 2001), or a combination of two or more of these methods. One of the most common and effective ways to control Russian knapweed is through the application of herbicides. Traditionally, carboxylic acid herbicides such as clopyralid, picloram, dicamba, and 2,4-D have been the most widely used to control Russian knapweed with varying levels of success. Aminopyralid, a relatively new pyridine-carboxylic acid herbicide has shown high levels of success in controlling Russian knapweed at significantly lower rates than other herbicides with the same mode of action (Carrithers et. al. 2005; Enloe et al. 2008). Targeted grazing has also been successfully conducted as a method of control for many invasive species. Sheep and goats will eat many invasives without adverse effects to their health and thus provide a very useful tool for integrated weed management. Land managers will often combine chemical applications and grazing as part of an integrated management plan. In a Russian knapweed infested site, Sheley et al. (2004) showed that applying 2,4-D in the spring facilitated the release of important perennial grasses which then changed the plant composition from older, less palatable knapweed plants to younger softer plants which were then more desired by grazing sheep. In the experiment, integration with grazing showed significantly greater control of Russian knapweed than areas that only had an herbicide applied. One of the most critical factors for successful control of Russian knapweed seems to be the availability of competitive species such as perennial grasses in the system (Benz et al. 1999; Enloe et al. 2008). Whitson (1999; 2001) stated that any treatment that provides control of Russian knapweed must either facilitate the release of species present in the understory or be combined with reseeding in order to produce long-term sustainable control of Russian knapweed.

The objective of this research was to evaluate the effects of a single spring grazing treatment combined with fall applied aminopyralid at different rates on the control of Russian knapweed and the resultant effects on the surrounding plant community, namely perennial grasses. We hypothesized that an early spring grazing treatment with goats would suppress vegetative growth of the knapweed enough to a) allow for higher efficacy of lower rates of aminopyralid and b) facilitate the early release of other competitive species and allow them to become established with less competition from the knapweed.

Materials and Methods

Study Site. Field studies were conducted on two adjacent plot areas in the Cub Creek Watershed near the Josie Morris Cabin Historic Site of Dinosaur National Monument from 2009 to 2011 to evaluate the effects of a single spring grazing by goats paired with fall applied aminopyralid (Milestone®, Dow AgroSciences LLC, Indianapolis, IN) at 0, 53, 70, 88, and 105 g ae ha^{-1} to rangeland infested with Russian knapweed. Both areas were in a mixed grass pasture believed to have once been used to grow alfalfa—presumed to be the cause for the presence of Russian knapweed. At the beginning of the study, the area was heavily infested by Russian knapweed, although both native and introduced perennial grasses and forbs were still present in the area. The sites are located approximately 16 aerial km northeast of Jensen, Utah, making up roughly 0.9 ha (2.2 ac) at 40° 25' 25.36" N, 109° 10' 9.5" W and 1631 m (5351 ft) in elevation. The annual precipitation at the sites is approximately 220 mm (8.5 in) with around 120 frost-free days each year. The mean high temperature during the year recorded at the nearest weather station nearly 11 kilometers west of the sites is 26.6 C (79.8 F), with the mean low being -16.5 C. Soils at the sites were classified as Green River Coarse-Loamy, mixed, superactive, calcareous, mesic, Oxyaquic Torrifluvents consisting of fine sandy loam in the top 13 cm of the profile and a stratified coarse-sand to loam mixture from 13 to 152 cm. Soil pH ranged from 7.8 to 8.1. Soil textures in the top 30 cm ranged from a loamy sand with 1.5 to 2.5% organic matter to a sand with 2.1% organic matter. The terrain of the study area is relatively flat with less than a 2% slope and a southwest aspect. Russian knapweed density was approximately 81 shoots m^{-2} at both sites at the beginning of the study. Grass species present in the area were smooth brome (*Bromus inermis* Leyss.), downy brome (*Bromus tectorum* L.), needle and thread (*Hesperostipa comata* (Trin. & Rupr. Barkworth ssp. *comata*), Kentucky bluegrass (*Poa pratensis* L.), sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray), saltgrass (*Distychlis spicata* (L.) Greene), intermediate wheatgrass (*Thinopyron intermedium* L.), crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), and western wheatgrass (*Pascopyrum smithii* (Rydb.) A. Löve). Several forbs were present at each site in small quantities including yellow sweetclover (*Melilotus officinalis* (L.) Lam.), desert globe mallow (*Sphaeralcea ambigua* A. Gray), prickly pear (*Opuntia* sp.) and a few annual mustard species.

Experimental Design. At the same location, two studies were initiated one year apart. Run 1 was initiated in May 2009 and run 2 in May 2010. Treatments were arranged in a randomized split-plot design with 4 replicates. Grazing served as whole plot treatments and herbicide treatments as subplots. Subplots were 3 by 9 m making whole plots 9 by 15 m. Experimental layout and data collection methods were identical for each site. A barbed wire fence was built around the entire area, encompassing both sites, to exclude cattle and other large herbivores from the research area.

Treatments. Approximately 20 Boer goats ranging from 23 to 50 kg (50 to 110 lbs) each were supplied by a local rancher to graze the whole-plots. Goats had been used previously for targeted grazing of Russian knapweed within the monument. Water was pumped from a nearby spring and no additional supplements were given to the goats. Goat pens were built using several 1.2 by 1.8 m (4 by 6 ft) fence panels for the main enclosure. An additional enclosure with a heavy tarp on top was added adjacent to the main enclosure. The goats were moved to the smaller enclosure during the night to ensure protection from predators. Biomass samples were collected from designated grazing plots before and immediately after grazing was completed using a 30 by 100 cm frame laid down at the bottom center of each plot. Utilization for each plot was calculated using the difference between the two biomass samples. Grazing commenced during the first two weeks of June and the goats were allowed to graze each treatment area until maximum utilization of Russian knapweed was achieved (approximately 3 days). All vegetation except for the prickly pears was utilized by the goats and therefore almost all vegetation, including perennial grasses, had high utilization percentages immediately after grazing (Table 2-1). After utilization data was collected, plot areas were allowed to grow approximately 4 months prior to herbicide treatments. Grazing was conducted June 4 through June 15, 2009 for run 1 and June 14 through June 24, 2010 for run 2. Grazing methods were the same for both runs. Aminopyralid treatments at 0, 53, 70, 88, and 105 g ae ha^{-1} were applied on October 15, 2009 to run 1 and October 14, 2010 to run 2. All treatments included a nonionic surfactant (Activator 90, alkyl polyoxyethylene ether and free fatty acids, Loveland Industries, Greeley, CO 80634) at 0.25% v/v and were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} at 207 kPa.

Data Collection. Density, species cover, and biomass data were collected throughout the study. Plant densities were collected in May of each year by placing four 30 by 100 cm frames beginning 5 cm inside the plot, and parallel to a centered transect down the long axis of each plot. Frames were then laid down every 1.8 m. Individual stems inside the frame were counted. Densities were recorded for all species found inside each frame and recorded as stems m^{-2}. Species cover data were collected in May and August of each year using the point intercept method. Species cover was determined by recording the species intersected every 15.24 cm (6 in) along a centered transect for a total of 60 recorded points for each plot. A percentage per plot area was calculated based on the number of points intersected by each species. Biomass was collected in May and August of each year using a single 30 by 100 cm frame in each plot and removing all biomass inside the frame approximately 2.54 cm (1 in) above the ground. Biomass was placed in bags, dried for approximately 14 days at 60 C (140 F) and then weighed. Although data were collected for all species present, it was later compiled into 4 main species groups of interest: Russian knapweed (*Acroptilon repens*), downy brome (*Bromus tectorum*), forbs, and desirable perennial grasses. The perennial grass category included western wheatgrass (*Pascopyrum smithii*), intermediate wheatgrass (*Thinopyron intermedium*), crested wheatgrass (*Agropyron cristatum*), smooth brome (*Bromus inermis*), sand dropseed (*Sporobolus cryptandrus*), saltgrass (*Distychlis spicata*), Kentucky bluegrass (*Poa pratensis*), and needle and thread (*Hesperostipa comata*).

Data Analysis. Data were analyzed using the glimmix procedure in SAS (SAS version 9.3, SAS Institute, Cary, NC 27513) and tested for normality and homogeneity of variance. Data were transformed as needed using a log, square root, cube root, or logit transformation. For some data, transformations did not improve normality or constant variance but data are still included. In all cases the original data is presented for clarity. Treatment means were separated using Fisher's Protected LSD ($P<0.05$).

Results and Discussion

Grazing Treatments. There were very few significant grazing by herbicide rate interactions (Tables 2-2 and 2-3) so treatment effects are discussed separately. Treatment effects were non-significant for most species groups in response to grazing with some exceptions: Fall measurements of forb biomass indicate lower overall values in ungrazed plots when compared to grazed plots in run 1, however this was not observed in run 2. Grazing data also showed significant overall increase of perennial grass cover in ungrazed plots compared to grazed plots in spring measurements in run 2, however this was not observed in run 1. As the interactions with grazing were so few and inconsistent, overall, our data indicates that a single spring grazing treatment has little to no significant effect on species density, cover, or biomass.

Herbicide Treatments. Aminopyralid reduced Russian knapweed stem density, cover, and biomass for all treated plots compared to the untreated control, including plots treated with the lowest rate tested of 53 g ae ha^{-1} (3 fl oz a^{-1}) (Anonymous, 2008). Herbicide rates were not significantly different from each other for Russian knapweed density, cover and biomass. They were, however, all significantly different from the untreated control. Russian knapweed stem density in run 1 was reduced from 88 stems m^{-2} in the untreated plots to an average of 0.5 stems m^{-2} across all rates of aminopyralid 8 months after treatment (MAT) (Tables 2-4 and 2-5). Similar results were observed 20 MAT with the control plots containing 66 stems m^{-2} and herbicide treatments reducing all others to 0.75 stems m^{-2} on average. An unexplained year by rate interaction occurred for Russian knapweed in run 1. Density means of the control plots were lower in 2011 than in 2010. November and December 2010 and May and July 2011 showed moisture totals that were much higher than average (Figure 2-1). The timing of the moisture coupled with slightly below average monthly temperatures during April, May, and June 2011 (Figure 2-2) may have enhanced perennial grass growth earlier in the season by providing sufficient moisture in early summer as well as reducing the transpirational requirements demanded by higher temperatures. The enhanced growth of the grass species may have allowed them to compete more readily for limiting resources while suppressing growth of Russian knapweed (Selleck 1964). As stands of perennial grass species increased, available light to Russian knapweed rosettes and seedlings under the canopy likely decreased. Dall'Armellina and Zimdahl (1988) found that Russian knapweed is extremely sensitive to reductions in light, concluding that Russian knapweed has a disadvantage and would be more susceptible to control through competition when emerging in the midst of an already established vegetative canopy. Russian knapweed cover was also reduced to zero or near zero in treated plots (Tables 2-6 through 2-9). The same trend was exhibited in both spring and fall. Russian knapweed cover in run 1 was reduced from 38% in untreated plots to 1% on average in treated plots in fall and from 29% to 0.41% in run 2. Also in run 2, Russian knapweed density, cover, and biomass were lower in untreated plots than in run 1 untreated plots. This may be another reflection of the above average moisture received in certain months in 2011 coupled with slightly lower monthly temperatures, facilitating the more rapid growth of perennial grasses early in the season. Russian knapweed biomass in spring showed similar trends to density and cover, being reduced 99% in both runs by all rates of aminopyralid (Tables 2-10 and 2-11). Similarly, fall biomass was also reduced 98 and 96% in runs 1 and 2, respectively (Tables 2-12 and 2-13).

Main effects for downy brome density, cover, and biomass were all non-significant. There were, however, year interactions within each main effect in run 1

(Table 2-14). Downy brome appeared to increase at least two fold from 2010 to 2011. This was observed in both spring and fall data, similar to the perennial grasses, could be a result of above average moisture in November and December 2010 and in May 2011 as no herbicide treatment effects were observed in any of the downy brome data. Downy brome biomass showed a year by grazing interaction in which there was a significant increase in biomass the second year after treatment in grazed plots while the increase in ungrazed plots was non significant. This could indicate a situation that is favored by grazing. It is possible that grazing has the potential to favor a species like downy brome by opening up safe areas where downy brome can readily establish. In the past, at locations in the Monument heavily infested with Russian knapweed but with fewer remnant perennial grasses, very dense stands of downy brome have been observed the second season after removal of Russian knapweed (Tamara Naumann personal conversation), possibly indicating suppression of downy brome by aminopyralid. DiTomaso and Kyser (2011) reported roughly 60 percent control of medusahead using preemergence applications of aminopyralid in foothill rangeland in California, indicating that suppression of annual grasses besides downy brome is also possible with varying rates of aminopyralid. This was not observed at this particular site however. Downy brome was observed to be almost non-existent in the second year in run 1 and during the first year of run 2 (Tables 2-5, 2-7, 2-9, 2-11, and 2-13) which suggests effects besides herbicide treatment influenced the growth of downy brome at this site. This may be a result of a relatively low initial population of downy brome at the site combined with a healthy population of perennial grasses that readily established with higher moisture once Russian knapweed was removed (Whitson and Koch 1998).

No treatments significantly affected desirable grass density; however, desirable grass cover and fall biomass of desirable grasses increased with all rates of aminopyralid. Similar to results for Russian knapweed, treated plots were generally significantly different from the untreated, but not from each other. For example, spring desirable grass cover nearly doubled in run 1, increasing from 38% in the untreated to an average of 62% across all treated plots and increasing from 55% in the untreated to 66% in treated plots in run 2. Run 2 showed an interaction with grazing with slightly higher grass cover overall in ungrazed plots 8 MAT. Desirable grass cover in the fall increased from 38% and 43% in the untreated plots to 70% and 68% in treated plots in runs 1 and 2, respectively. Changes in desirable grass biomass were non-significant for measurements taken in spring for both experiments. Since perennial grass species were not fully matured at the time of the spring measurements, it can be expected that a noticeable change in desirable grass biomass may not be seen until later in the season when they are fully matured. Desirable grass biomass in fall displayed trends similar to spring and fall cover, increasing from 97.29 g m^{-2} to an average of 136.44 g m^{-2} in run 1 (a 40% increase). Interestingly, in both runs, desirable grass biomass showed a very nearly significant difference between the highest rate of aminopyralid (105 g ha^{-1}) and the next lowest rate (88 g ha^{-1}), possibly indicating injury or suppression by the herbicide at 105 g ha^{-1}, the labeled rate for Russian knapweed control.

Forb stem density was significantly lower in the untreated plots than in all treated plots in run 1 (Table 2-4). Although non-significant in run 2, a similar trend was observed in the data (Table 2-5). Forb cover in spring was decreased by all rates in run 1 showing a decrease from 5% in the untreated to approximately 1% averaged across treated plots (Table 2-6). Fall cover showed similar trends as spring cover for forbs although not significant. Fall forb cover was not significant in either run. Forb biomass data in general showed similar trends to cover and density data with the untreated having higher biomass than all other treated plots (Tables 2-10 through 2 -12). The only exception to this was run 1 in fall, where grazed plots treated with 53 g ha^{-1} had a mean biomass of 13.05 g m^{-2} which was higher than all treated and untreated plots. Overall, forb data at both sites were similar to that of the knapweed in response to aminopyralid treatments. This is to be expected as this herbicide is active in controlling broadleaf weeds and would likely have similar effects on most forbs in the area.

Although the grazing treatments produced very few significant effects as performed in this study, the concept of targeted grazing should not be ruled out as part of an integrated approach to weed control. Targeted grazing has provided excellent control of other perennial weeds similar to Russian knapweed in the past (Lym et al. 1997; Olson et al. 1997; Thrift et al. 2008) and has been proven to be a worthy part of an integrated weed management plan in many areas (DiTomaso 2000; Lym et al. 1997; Maxwell et al. 1992). It is likely that lower rates of aminopyralid or more frequent grazing treatments would have initiated a clearer response from both the native vegetation as well as the Russian knapweed at this site. In this study, as indicated by the data, aminopyralid provided excellent control of Russian knapweed with all applied rates when evaluated 8 and 20 MAT in run 1 and 8 MAT in run 2. Visual evaluations at both sites also support this as aminopyralid at 53 g ha^{-1} provided 99% control in spring 20 MAT in run 1 and 100% in spring 8 MAT in run 2 (data not presented). These evaluations are similar to research conducted by Enloe et al. (2008) in which 91% control was observed 12 MAT and 83% 21 MAT when aminopyralid was applied in the fall at 50 g ha^{-1}. It is important to note that the rate used by Enloe et al. (2008) is slightly lower still than the lowest rate used in this study. Similar to their conclusions, we observed that aminopyralid is extremely effective at controlling Russian knapweed at low rates. Similarly, Almquist and Lym (2010) found aminopyralid applied in the fall at 120 g ha^{-1} reduced Canada thistle stem density nearly completely 10 MAT. Based on their results and the data from run 1 of this study, it is expected that results from run 2 will be very similar to those of run 1, 20 MAT. In this study, aminopyralid treated plots also had increased cover of perennial grasses. By suppressing Russian knapweed with aminopyralid treatments, resource availability for desirable and other native species was likely increased to a point to which the competitive advantage was once again in favor of those species. This was also observed by Almquist and Lym (2010). Perennial grass species cover increased 113% after the removal of Canada thistle in a tallgrass prairie. Samuel and Lym (2008) also saw in increase of perennial grasses when aminopyralid was applied to Canada thistle in the fall. Our data, along with these examples support the statement made by Krueger-Mangold et al. (2006) that plant communities dominated by invasive weeds often require a direct management input, such as an herbicide, to suppress the invasive species and direct the community toward a more desirable native community. Samuel and Lym (2008) also point out that one factor that should not be overlooked is that areas recovering from the removal of an invasive species largely depend on reestablishment from seed of desirable plants. As the invasive species has likely reduced native vegetation seedbank reserves for quite some time, long term control of the invasive species is of the utmost importance in order to allow native and other desirable species to become well established once again. Almquist and Lym (2010) found species richness, evenness, and diversity all decreased after aminopyralid treatments to Canada thistle-infested sites. However, it is important to remember that the benefits of controlling Canada thistle, Russian knapweed, or any other invasive perennial and the potential increase in native and perennial grass cover outweigh the short-term disadvantages that might occur within a community with lower richness, evenness, or diversity. In the long term, the community should move toward a more improved community in terms of stability and vegetation composition once the invasive species are able to be kept out. Aminopyralid seems to control Russian knapweed well for at least 2 years after treatments are applied, however, somewhat less is known of its long-term efficacy. As long as there is a healthy population of perennial grasses present, it is possible that repeat treatments of aminopyralid at a low rate will only be needed every 3-5 years, in order to fully remove Russian knapweed from this area. Further research is still needed in this regard to fully explore aminopyralid and its potential role for integrated management of Russian knapweed. Similarly, further research should be conducted to address the role of targeted grazing of Russian knapweed in an area with remnant perennial grasses. While the results from this study were inconclusive in regards to grazing being an effective tool for Russian knapweed control, studies regarding targeted grazing of other similar invasive species have been successful and lead us to conclude that more positive effects of grazing might be observed in experiments better designed to address grazing alone as a control method for Russian knapweed.

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Table 2-1. Vegetation utilization (in percent) by boer goats[a] grazing Russian knapweed in research plots at Dinosaur National Monument during 2009 and 2010.

	Run 1				Run 2			
Replicate	Russian knapweed	Desirable grasses	Forbs	Grazing days	Russian knapweed	Desirable grasses	Forbs	Grazing days
	%							
1	88.46	93.81	100	2.5	74.68	81.94	100	3
2	76.99	96.67	100	2	87.15	92.57	—	3
3	65.86	97.47	—[b]	3	91.32	91.59	100	3
4	85.02	100.00	—	3.5	100.00	100.00	100	4

[a] Blocks were grazed from Jun. 4 to Jun. 15, 2009 and from Jun. 14 to Jun. 24, 2010 by approximately 20 boer cross goats ranging from 23 to 50 kg each.

[b] No measurable forbs were observed in these blocks, therefore no utilization values were able to be calculated.

Table 2-2. P values for main effects and main effect interactions in run 1 evaluating Russian knapweed and other species response to goat grazing and aminopyralid.

	Spring												
	Density				Cover					Biomass			
Effect	Knapweed	Desirable Grasses	Downy Brome	Forbs	Knapweed	Desirable Grasses	Downy Brome	Forbs	Bare Ground	Knapweed	Desirable Grasses	Downy Brome	Forbs
	P Value												
Rate	<0.0001	0.1712	0.2999	0.0003	<0.0001	<0.0001	0.3608	0.0013	0.5220	<0.0001	0.2911	0.5508	0.8022
Grazed	0.4911	0.5846	0.8984	0.4512	0.3626	0.7868	0.9534	0.4240	0.7539	0.0072	0.4680	0.2167	0.4701
Grazed*Rate	0.7212	0.4207	0.1559	0.2482	0.1497	0.9820	0.1694	0.6540	0.9414	0.1226	0.6045	0.5832	0.3323
Year	0.2780	<0.0001	0.0072	0.2763	0.2290	0.0609	0.0361	0.1731	0.0017	0.2922	<0.0001	0.0006	0.2144
Rate*Year	0.1103	0.9224	0.9535	0.2399	0.0844	0.9880	0.8028	0.6835	0.6813	0.3447	0.8323	0.6605	0.5438
Grazed*Year	0.9468	0.8305	0.4839	0.8552	0.6844	0.8510	0.4851	0.1319	0.3657	0.9375	0.2559	0.0148	0.3435
Grazed*Rate*Year	0.9998	0.9051	0.9945	0.3944	0.9279	0.8017	0.6707	0.5315	0.7548	0.4875	0.7527	0.9184	0.5558
	Fall												
	P Value												
Rate	---	---	---	---	<0.0001	<0.0001	0.4569	0.1160	0.0023	<0.0001	0.0002	0.5674	0.0224
Grazed	---	---	---	---	0.6362	0.8792	0.6264	0.4554	0.6786	0.6502	0.6677	0.3808	0.0870
Grazed*Rate	---	---	---	---	0.9568	0.6871	0.5954	0.0910	0.6322	0.9036	0.1500	0.1584	0.0121
Year	---	---	---	---	0.3973	<0.0001	<0.0001	0.0409	0.0815	0.0004	<0.0001	0.0151	0.2030
Rate*Year	---	---	---	---	0.8641	0.5061	0.4569	0.8622	0.8534	0.1774	0.7142	0.5674	0.5975
Grazed*Year	---	---	---	---	0.1955	0.1999	0.2936	1.000	0.0053	0.4292	0.3853	0.3808	0.4220
Grazed*Rate*Year	---	---	---	---	0.8712	0.4250	0.5954	0.7270	0.9442	0.8466	0.4644	0.1584	0.4642

Table 2-3. P values for main effects and main effect interactions in run 2 evaluating Russian knapweed and other species response to goat grazing and aminopyralid.

	Spring												
	Density				Cover					Biomass			
Effect	Knapweed	Desirable Grasses	Downy Brome	Forbs	Knapweed	Desirable Grasses	Downy Brome	Forbs	Bare Ground	Knapweed	Desirable Grasses	Downy Brome	Forbs
	P Value												
Rate	<0.0001	0.1828	0.5168	0.5401	<0.0001	0.0032	0.5370	0.6488	0.0276	0.0002	0.7092	0.4229	0.0414
Grazed	0.4550	0.2308	0.5762	0.0868	0.8807	0.1630	0.1880	0.1203	0.5849	0.7786	0.9327	0.3253	0.1621
Grazed*Rate	0.9812	0.6781	0.3437	0.6472	0.9989	0.0438	0.5370	0.6922	0.0655	0.9869	0.9273	0.4229	0.0657
	Fall												
	P Value												
Rate	---	---	---	---	<0.0001	<0.0001	0.5537	0.3823	0.0109	<0.0001	0.0067	---	0.0685
Grazed	---	---	---	---	0.9846	0.8757	0.1757	0.1135	0.1389	0.0900	0.2325	---	0.1270
Grazed*Rate	---	---	---	---	0.5935	0.3690	0.5537	0.7234	0.0648	0.4987	0.9687	---	0.3616

Table 2-4. Russian knapweed, downy brome, perennial grass, and forb densities in response to aminopyralid applied in fall 2009 to Russian knapweed infested rangeland in Dinosaur National Monument[a].

	Knapweed					Saltgrass			
Aminopyralid rate	8 MAT	20 MAT	Downy Brome	Smooth brome	Wheatgrass	Grazed	Ungrazed	Desirable grasses	Forbs
g ae ha^{-1}	shoots m^{-2}								
0	88 a	66 a	63 a	70 a	51 a	62 a-c	97 ab	243 a	7 a
53	2 bc	3 b	35 a	97 a	87 a	60 bc	107 ab	295 a	1 b
70	0 c	0 bc	26 a	100 a	72 a	95 a	76 a-c	292 a	3 b
88	0 c	0 bc	11 a	86 a	95 a	108 ab	42 c	296 a	3 b
105	0 c	0 b	39 a	88 a	67 a	67 a-c	42 c	255 a	3 b
P value	0.0392		0.2999	0.7206	0.2177	0.0202		0.1712	0.0003

[a] Means in the same column or in the same set of species columns followed by the same letter are not significantly different according to Fisher's Protected LSD (P ≤ 0.05).

Table 2-5. Russian knapweed, downy brome, perennial grass, and forb densities in response to aminopyralid applied in fall 2010 to Russian knapweed infested rangeland in Dinosaur National Monument[a].

Aminopyralid rate	Knapweed	Downy brome	Smooth brome	Wheatgrass	Saltgrass	Desirable grasses	Forbs
g ae ha^{-1}	shoots m^{-2}						
0	60 a	1 a	101 a	121 a	43 a	284 a	12 a
53	0 b	0 a	93 a	175 a	18 a	293 a	6 a
70	0 b	11 a	64 a	177 a	40 a	308 a	6 a
88	0 b	0 a	90 a	129 a	19 a	280 a	3 a
105	1 b	0 a	60 a	136 a	22 a	247 a	6 a
P value	<0.0001	0.5168	0.4084	0.3347	0.0599	0.1828	0.1622

[a] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD (P ≤ 0.05).

Table 2-6. Spring foliar cover of Russian knapweed, downy brome, perennial grass, and forbs in response to aminopyralid applied in fall 2009 to Russian knapweed infested rangeland in Dinosaur National Monument[a].

Aminopyralid rate	Knapweed	Downy brome	Smooth brome	Wheatgrass	Saltgrass	Desirable grasses	Forbs	Bare ground
g ae ha^{-1}					%			
0	23.06 a	7.00 a	25.94 a	4.13 b	5.06 a	37.69 b	4.56 a	27.44
53	0.38 b	5.50 a	30.63 a	18.94 a	8.81 a	59.81 a	1.75 b	31.38
70	0.63 b	5.13 a	33.94 a	18.81 a	8.25 a	64.25 a	0.75 b	28.69
88	0.50 b	3.38 a	34.44 a	20.19 a	4.94 a	64.19 a	0.19 b	30.94
105	0.19 b	6.81 a	33.31 a	10.38 ab	5.56 a	58.13 a	1.19 b	33.25
P value	<0.0001	0.3608	0.4457	0.0358	0.2940	<0.0001	0.0013	0.5220

[a] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD (P ≤ 0.05).

Table 2-7. Spring foliar cover of Russian knapweed, downy brome, perennial grass, and forbs in response to aminopyralid applied in fall 2010 to Russian knapweed infested rangeland in Dinosaur National Monument[a].

						Desirable grasses			
Aminopyralid rate	Knapweed	Downy brome	Smooth brome	Wheatgrass	Saltgrass	Grazed	Ungrazed	Forbs	Bare ground
g ae ha^{-1}					%				
0	15.00 a	0.25 a	35.50 a	10.63 a	3.13 a	53.00 d	55.25 cd	3.00 a	23.63 b
53	0.00 b	0.25 a	26.25 a	29.75 a	4.89 a	54.50 d	69.50 a	1.25 a	33.13 a
70	0.00 b	1.25 a	29.38 a	21.50 a	4.25 a	66.75 ab	65.00 ab	1.88 a	29.75 ab
88	0.00 b	0.00 a	33.00 a	15.13 a	2.88 a	60.00 b-d	67.25 ab	1.75 a	32.50 a
105	0.00 b	0.00 a	34.89 a	19.13 a	3.38 a	63.00 a-c	63.75 ab	0.89 a	32.38 a
P value	<0.0001	0.5370	0.5027	0.2482	0.9690	0.0438		0.6488	0.0276

[a] Means in the same column or in the same set of species columns followed by the same letter are not significantly different according to Fisher's Protected LSD (P ≤ 0.05).

Table 2-8. Fall foliar cover of Russian knapweed, downy brome, perennial grass, and forbs in response to aminopyralid applied in fall 2009 to Russian knapweed infested rangeland in Dinosaur National Monument[a].

Aminopyralid rate	Knapweed	Downy brome	Smooth brome	Wheatgrass	Saltgrass	Desirable grasses	Forbs	Bare ground
g ae ha^{-1}	%							
0	37.81 a	3.81 a	—[b]	—	—	37.81 b	3.13 a	16.81 c
53	1.31 b	5.25 a	—	—	—	67.25 a	3.00 a	21.75 bc
70	0.69 b	2.81 a	—	—	—	72.50 a	2.13 a	21.44 bc
88	1.00 b	1.31 a	—	—	—	71.69 a	0.69 a	25.19 ab
105	0.75 b	3.63 a	—	—	—	67.63 a	1.19 a	26.89 a
P value	<0.0001	0.4569	—	—	—	<0.0001	0.1160	0.0023

[a] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Data were not collected for species individually, so only total desirable grass cover is included.

Table 2-9. Fall foliar cover of Russian knapweed, downy brome, perennial grass, and forbs in response to aminopyralid applied in fall 2010 to Russian knapweed infested rangeland in Dinosaur National Monument[a].

Aminopyralid rate	Knapweed	Downy brome	Smooth brome	Wheatgrass	Saltgrass	Desirable grasses	Forbs	Bare ground
g ae ha^{-1}	%							
0	29.00 a	0.00 a	8.13 a	15.00 b	8.50 a	43.00 b	3.25 a	15.00 c
53	0.88 b	0.25 a	11.88 a	35.00 a	9.50 a	66.38 a	2.50 a	26.00 a
70	0.00 b	0.38 a	17.25 a	32.75 a	14.00 a	64.88 a	1.63 a	22.34 ab
88	0.25 b	0.00 a	13.00 a	40.00 a	11.63 a	66.89 a	1.13 a	24.13 a
105	0.50 b	0.00 a	12.88 a	32.88 a	12.25 a	73.25 a	0.38 a	18.38 bc
P value	<0.0001	0.5537	0.5032	0.0076	0.6943	<0.0001	0.3823	0.0109

[a] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Table 2-10. Spring biomass of Russian knapweed, downy brome, perennial grass, and forbs in response to aminopyralid applied in fall 2009 to Russian knapweed infested rangeland in Dinosaur National Monument[a].

Aminopyralid rate	Knapweed	Downy brome	Smooth brome	Wheatgrass	Saltgrass	Desirable grasses	Forbs
g ae ha^{-1}	g m^{-2}						
0	28.05 a	3.21 a	57.75 a	36.75 a	6.48 a	98.10 a	1.32 a
53	0.27 b	1.92 a	60.39 a	49.38 a	6.66 a	117.93 a	0.54 a
70	0.48 b	0.78 a	48.27 a	45.54 a	8.10 a	106.08 a	0.60 a
88	0.00 b	2.85 a	57.72 a	46.59 a	8.70 a	117.54 a	0.30 a
105	0.30 b	2.28 a	45.78 a	40.59 a	5.46 a	103.41 a	0.54 a
P value	<0.0001	0.5508	0.9321	0.8510	0.6931	0.2911	0.8022

[a] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Table 2-11. Spring biomass of Russian knapweed, downy brome, perennial grass, and forbs in response to aminopyralid applied in fall 2010 to Russian knapweed infested rangeland in Dinosaur National Monument[a].

Aminopyralid rate	Knapweed	Downy brome	Smooth brome	Wheatgrass	Saltgrass	Desirable grasses	Forbs
g ae ha^{-1}	g m^{-2}						
0	21.09 a	0.03 a	57.75 a	53.07 a	7.20 a	119.49 a	4.62 a
53	0.12 b	0.00 a	60.39 a	62.28 a	1.59 a	120.75 a	1.65 ab
70	0.00 b	0.00 a	48.27 a	67.26 a	7.44 a	131.76 a	0.00 b
88	0.00 b	0.00 a	57.72 a	39.60 a	5.46 a	117.87 a	0.39 b
105	0.00 b	0.00 a	45.78 a	49.80 a	3.48 a	115.89 a	0.00 b
P value	0.0002	0.4229	0.9321	0.1495	0.0934	0.7092	0.0414

[a] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Table 2-12. Fall biomass of Russian knapweed, downy brome, perennial grass, and forbs in response to aminopyralid applied in fall 2009 to Russian knapweed infested rangeland in Dinosaur National Monument[a].

							Forbs	
Aminopyralid rate	Knapweed	Downy brome	Smooth brome	Wheatgrass	Saltgrass	Desireable grasses	Grazed	Ungrazed
g ae ha^{-1}	g m^{-2}							
0	64.23 a	1.77 a	—[b]	—	—	97.29 c	0.57 b	0.66 b
53	1.47 b	0.21 a	—	—	—	119.01 b	13.05 a	0.00 b
70	1.47 b	0.75 a	—	—	—	133.23 ab	0.00 b	0.11 b
88	1.14 b	0.63 a	—	—	—	155.31 a	0.39 b	0.00 b
105	0.12 b	0.48 a	—	—	—	138.36 ab	0.00 b	0.00 b
P value	<0.0001	0.5674	—	—	—	0.0002	0.0121	

[a] Means in the same column or in the same set of species columns followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Data were not collected for species individually, so only total desirable grass biomass is included.

Table 2-13. Fall biomass of Russian knapweed, downy brome, perennial grass, and forbs in response to aminopyralid applied in fall 2010 to Russian knapweed infested rangeland in Dinosaur National Monument[a].

Aminopyralid rate	Knapweed	Downy brome	Smooth brome	Wheatgrass	Saltgrass	Desirable grasses	Forbs
g ae ha^{-1}	g m^{-2}						
0	56.67 a	—[b]	53.25 a	69.33 a	22.20 a	183.36 b	3.93 a
53	2.82 b	—	54.69 a	111.12 a	10.50 a	247.32 a	1.35 ab
70	6.42 b	—	40.50 a	112.00 a	20.70 a	221.58 a	0.93 ab
88	0.06 b	—	53.07 a	66.18 a	19.50 a	212.28 ab	1.14 ab
105	0.09 b	—	50.61 a	75.93 a	13.70 a	189.33 b	0.00 b
P value	<0.0001	—	0.6665	0.0630	0.5707	0.0067	0.0685

[a] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] No downy brome was present in the samples, so there are no biomass data for this species.

Table 2-14. Russian knapweed, downy brome, wheatgrass, desirable grasses, and bare ground means in response to year and grazing by year interactions in run 1[a].

Year	Season	Knapweed	Downy brome		Wheatgrass	Desirable grasses	Bare ground	
		density (shoots m^{-2})						
2010	Spring	17 a	23 b		52 b	327 a	—[b]	
2011	Spring	14 a	47 a		98 a	225 b	—	
P value		0.2760	<0.0001		0.0007	<0.0001	—	
		cover (%)						
2010	Spring	5 a	4 b		8 b	54	34 a	
2011	Spring	5 a	7 a		21 a	59	27 b	
P value		0.8664	0.0361		0.0012	0.0609	0.0014	
							Grazed	Ungrazed
2010	Fall	9 a	0 b		—[c]	69 a	23 ab	20 b
2011	Fall	8 a	7 a		—	58 b	21 ab	27 a
P value		0.7822	0.0001		—	<0.0001	0.0053	
		biomass (g m^{-2})						
			Grazed	Ungrazed				
2010	Spring	6.36 a	0.78 b	0.12 b	33.48 b	73.44 b	—	
2011	Spring	5.28 a	6.72 a	1.23 ab	54.06 a	143.79 a	—	
P value		0.4980	0.0148		0.0103	<0.0001	—	
2010	Fall	7.38 b	0.00 b		—	110.01 b	—	
2011	Fall	20.01 a	1.54 a		—	147.27 a	—	
P value		0.0152	0.0151		—	<0.0001	—	

[a] Means of the same type in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Densities and biomass could not be calculated for bare ground, so only cover data is presented.

[c] Data were not collected for species individually in fall, so only total desirable grass cover is included.

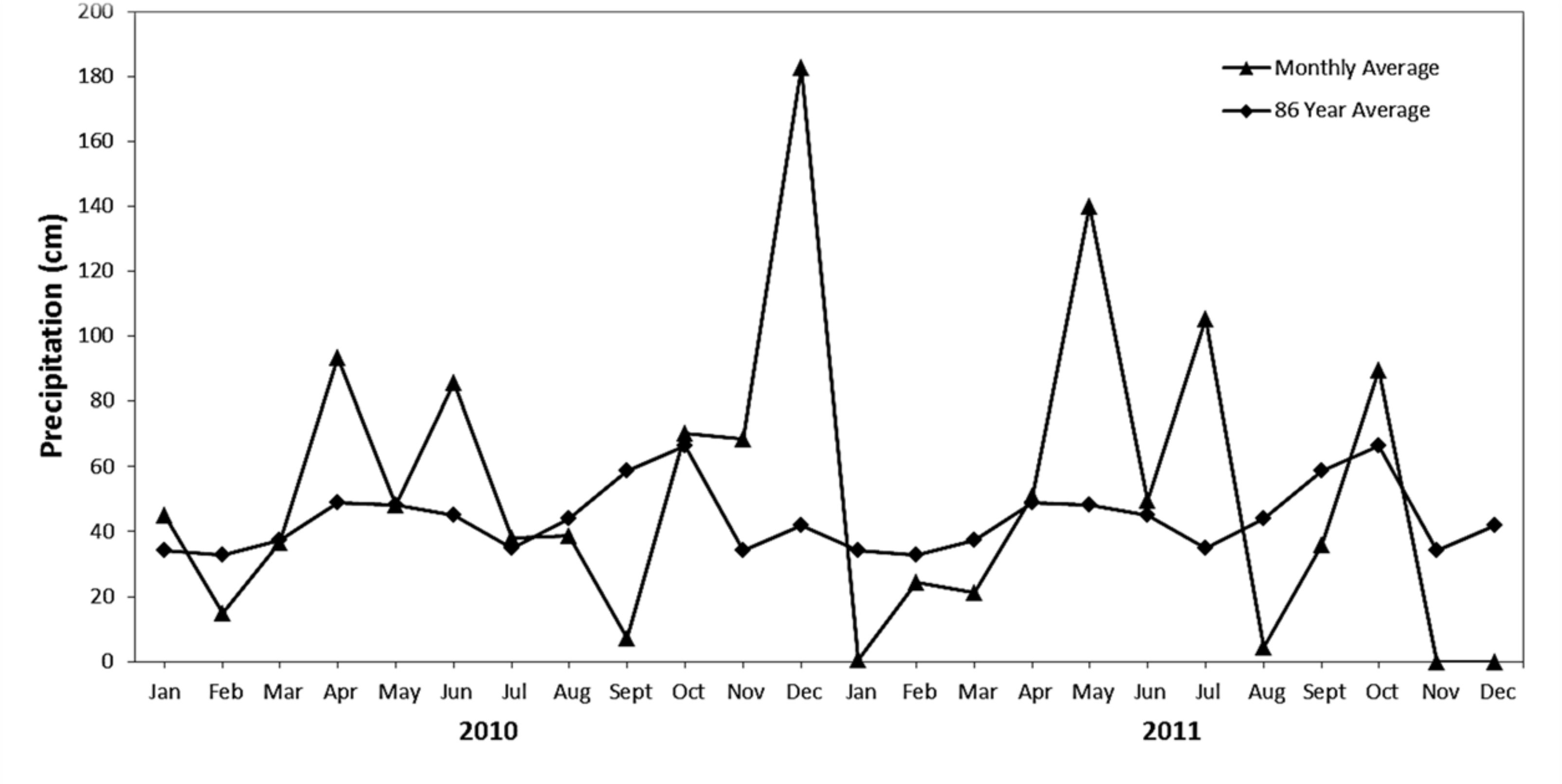

Figure 2-1. Precipitation graph for 2010 and 2011 compared to the 86 year average taken from the weather station at Jensen, UT, 11 km from the research site.

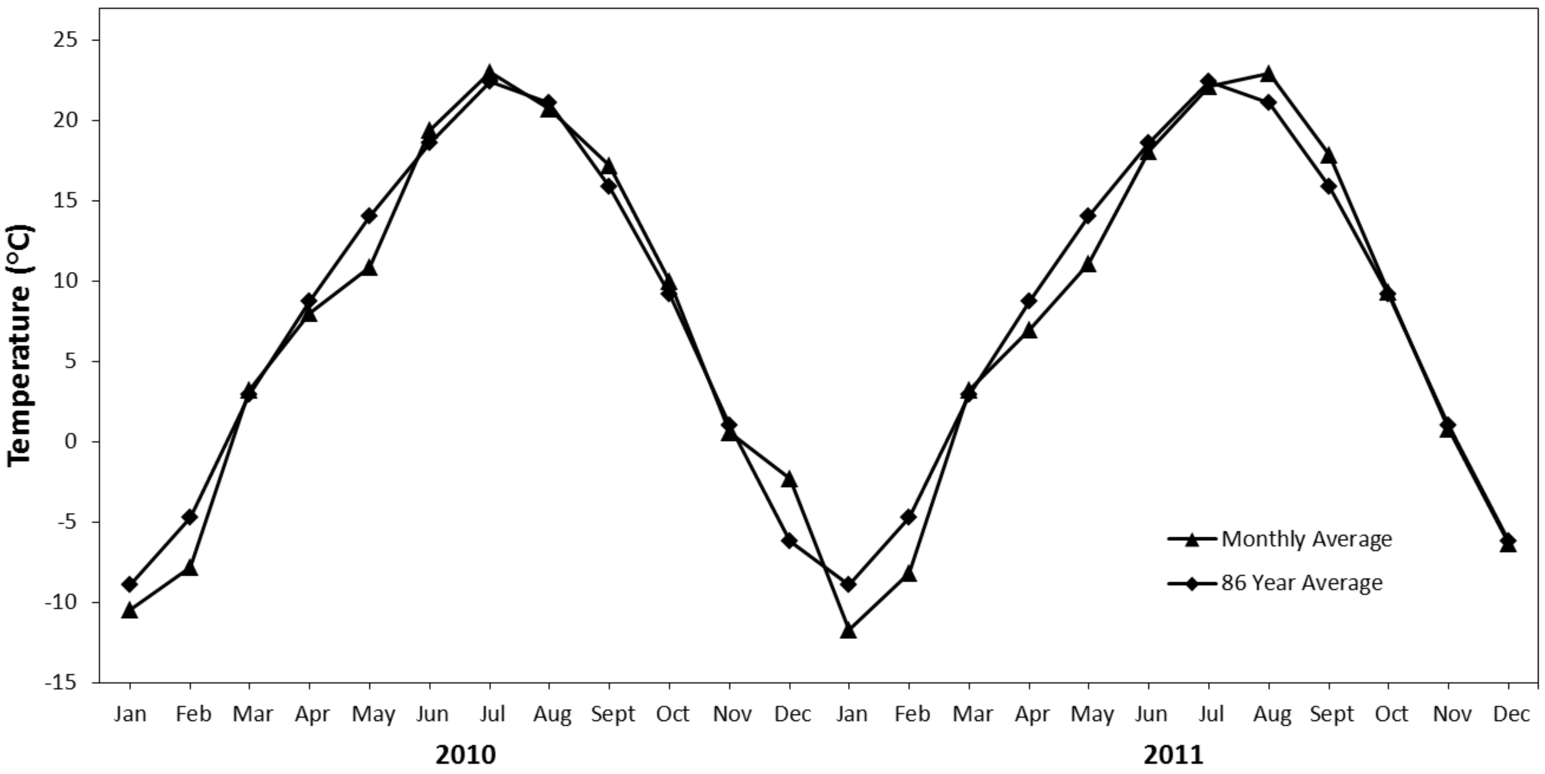

Figure 2-2. Temperature means at Dinosaur National Monument research plots during 2010 and 2011. Values were taken from a weather station at Jensen, UT, 11 km from the research site.

CHAPTER 3

TOLERANCE OF SIX RANGE GRASSES TO THREE GROWTH REGULATOR HERBICIDES

Abstract

The competitive advantage of perennial grasses and other rapidly establishing desirable vegetation is important to land managers when considering their use in revegetating land that has been invaded by noxious weeds. Pre-germination trials were established in 2012 in the lab using petri-dishes to evaluate the effects different rates of the growth regulator herbicides aminopyralid, clopyralid, and aminocyclopyrachlor on seeds of six perennial grass species commonly used in rangeland revegetation efforts. Postemergence trials were also established both in the field and in the greenhouse from 2009-2012. Herbicide rates were based on labeled rates for control of Russian knapweed (*Acroptilon repens*). In pre-germination trials, seed germination was not significant 14 DAT for any species evaluated. Clopyralid showed the least suppression of root and shoot length and shoot biomass in all six species in pre-germination trials. Aminopyralid at both rates and the high rate of aminocyclopyrachlor appeared to provide the most suppression of roots, shoots, and shoot biomass. Results differed slightly between the field and greenhouse data regarding the relative injury of aminopyralid compared to aminocycylopyrachlor. Injury was negligible for all species evaluated at field rates. In both field and greenhouse trials ‘Sherman’ big bluegrass (*Poa ampla*) appeared to be among the most tolerant to all three herbicides studied, rarely sustaining over 50% injury.

Both ‘Magnar’ Great Basin wildrye (*Elymus cinereus*) and Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*) were very susceptible to aminopyralid and aminocyclopyrachlor in both the field and the greenhouse with injury rates often more than 75% with the highest rate of aminocyclopyrachlor. Great Basin wildrye was also the most sensitive to clopyralid of all the species evaluated in all three trials. ‘Alkar’ tall wheatgrass (*Thinopyrum ponticum*) showed 94% injury in the field 60 days after treatment (DAT) with aminocyclopyrachlor at 280 g ai ha^{-1}, but injury declined to 59% 365 DAT. There were differences in tolerance to growth regulator herbicides between grasses used for revegetation efforts in the West. These differences can mean a great deal to land managers when searching for insight into the ecological and economical sustainability of a particular management plan as most grasses are generally not perceived as being sensitive to growth regulator-type herbicides.

Introduction

Both native and non-native perennial grasses are used often for revegetating pastures and rangelands that have been infested with invsasive species in the Western United States. Perennial grasses provide an important forage source for wildlife and domestic livestock (Currie 1969), reduce wind and water erosion (Bugg et al. 1998), are capable of slowing the frequency of wildfires (Farve 1942), and play an important role as competitors against invasive species (Berube and Myers 1982; Ferrell et al. 1998). The competitive advantage of perennial grasses and other rapidly establishing desirable vegetation is important to land managers when considering their use in revegetating land that has been invaded by noxious species. Sheley et al. (2002) explain that the establishment of competitive plants is important for rehabilitating infested communities and maintaining desirable ecosystems. An important goal of most land managers is to establish and maintain healthy lands with plant communities that are relatively resistant to future invasions (Maxwell et al. 1992; Sheley et al. 1996). In situations where an invasive species has not established a monoculture and the diversity of desirable plant species is still somewhat high, reseeding may not be necessary as native and other desirable species still exist in the area and are competing with the invasive species. An integrated approach for this scenario would still require initial treatment of the invasive species to open up a window of opportunity for fast-growing desirable species to reestablish (Mangold et al. 2007; Samuel and Lym 2008; Whitson 1997). As the invasive species are suppressed, desirable species present in the system become instrumental in establishing an ecosystem that will capture available resources and be more resistant to future invasions (Carpinelli 2000; Samuel and Lym 2008).

In other sysems where the invasion is more advanced and the number of remnant perennial grass species present in the system is very low, revegetation may be required. Many grass species have the potential to compete well with Russian knapweed (*Acroptilon repens*) and other invasive perennials such as leafy spurge (*Euphorbia esula*) and hoary cress (*Cardaria draba*), however, some of these grasses have great difficulty becoming established initially if planted in an area that is already heavily infested with well established, resource-hungry perennial weeds (Blumenthal et al. 2010). In these situations, it is common to accompany revegetation efforts with an herbicide application to temporarily suppress or control the invasive species and allow seeded species to establish. Typically, for invasive perennial forbs such as Russian knapweed, the most success has been from the use of growth regulator herbicides such as 2,4-D (Derscheid et al. 1960), picloram (Bottoms and Whitson 1998; Morrison et al. 1995), or aminopyralid (Bukun et al. 2010; Enloe et al. 2008; Jacobs and Denny 2006).

As integrated methods are studied and implemented for control of invasive species in western rangelands, land managers should be cognizant of the potential effects some control methods, namely herbicide applications, have on the surrounding environment to minimize collateral damage to native plant communities. Several studies have analyzed the relative tolerance of certain grasses and forbs common on range and pasture lands to different growth regulator herbicides used for control of invasive species. For example, Sheley et al. (2002) found crested wheatgrass (*Agropyron cristatum*) and pubescent wheatgrass (*Thinopyron intermedium*) were more tolerant of clopyralid and picloram applied before seeding than bluebunch wheatgrass (*Pseudorogneria spicata*). Also, Samuel and Lym (2008) studied the effects of aminopyralid on native plants in Canada thistle-infested rangeland.

Generally, as growth regulator herbicides are used mainly for control of broadleaf weeds, perennial grasses are often not considered to be overly sensitive to them. However, many studies have found that in some cases, both desirable perennial and undesirable annual grasses can be injured in ways that are not always immediately noticeable. If a herbicide rate used to control the broadleaf weeds is too high or if it is applied at a susceptible growth stage for the grasses, injury is more likely to occur to the grasses in the system. Once an herbicide has been selected for control of a particular invasive species, the timing of application becomes the next critical component in order to maximize the establishment of the species selected for revegetation (Arnold and Santelmann, 1966; Canode 1974; Sheley et al. 2002). Rinella et al. (2010) found picloram reduced seed production of Japanese brome (*Bromus japonicus*) nearly 100 percent when applied at elongation, boot, or heading stages in the greenhouse. DiTomaso and Kyser (2011) controlled medusahead (*Taeniatherum caput-medusae*) by 60% with a preemergence application of aminopyralid in California. In the case of desirable perennial grasses, picloram significantly reduced germination in blue grama (*Bouteloua gracilis*) when applied preemergence in the greenhouse, however, blue grama was not affected when picloram was applied at the 4-leaf stage or later (Arnold and Santelmann 1966). When attempting to revegetate a Russian knapweed (*Acroptilon repens*) infested site with Siberian wheatgrass (*Agropyron fragile*) in spring, Sheley et al. (2007) found that an application of clopyralid significantly reduced Siberian wheatgrass biomass and thus reduced its effectiveness in competing with the knapweed. Studies show that tolerance of grass species to different growth regulating herbicides tend to be highly variable as not all grass species are the same physiologically. Arnold and Santelmann (1966) found that germination of side-oats gramma (*Bouteloua curtipendula*), big bluestem (*Andropogon gerardi*), switchgrass (*Panicum virgatum*), and blue gramma (*Bouteloua gracillis*) was prevented by picloram; however, 2,4-D only reduced the number of side-oats gramma plants and left the other species essentially unharmed.

Aminopyralid and clopyralid are two closely related growth regulator herbicides labeled for use on rangeland and are frequently used for control of Russian knapweed.

Aminocyclopyrachlor is an experimental herbicide that is being evaluated for use in similar settings. Any knowledge gained regarding the relative tolerance of native and other plants to these and other growth regulator herbicides is important information that will be an aid to land owners and managers in determining which herbicides will be the safest and most effective in a particular area, as well as provide options for revegetation in their respective management scenarios.

The objective of this research was to evaluate the relative tolerance of six perennial grasses species commonly used in rangeland rehabilitation in the Western United States, to the growth regulator herbicides aminopyralid, clopyralid, and aminocyclopyrachlor.

Methods and Materials

Petri-dish Germination Trials. Two germination trials were initiated in January 2012 to observe the effects of aminopyralid, clopyralid, and aminocyclopyrachlor applied directly to petri-dishes containing seeds of ‘Alkar’ tall wheatgrass [*Thinopyrum ponticum* (Podp.) Z.-W. Liu & R.-C. Wang], Anatone germplasm bluebunch wheatgrass [*Pseudoroegneria spicatum* (Pursh.) Scribn. & J.G. Sm.], ‘Magnar’ Great Basin wildrye [*Elymus cinereus* (Scribn. & Merr.) A. Löve], ‘Rimrock’ Indian ricegrass [*Achnatherum hymenoides* (Roem. & Shult.) Barkworth], ‘Sherman’ big bluegrass [*Poa ampla* Merr.], and Toe Jam Creek germplasm bottlebrush squirreltail [*Elymus elymoides* (Raf.) Swezey]. The experiments were a randomized complete block design with 4 replications within each grass species. Plots were a single petri-dish.

Twenty seeds from each of the six grass species were put into 90 mm dimeter petri dishes (PML Microbiologicals, bioMerieux Inc., Durham, NC) lined with Whatman number 3 filter paper (Whatman Inc. Piscataway, NJ) to retain moisture. Aminopyralid (Milestone, Dow AgroSciences LLC, Indianapolis, IN) at 0, 126, and 246 g ae ha^{-1}, clopyralid (Transline, Dow AgroSciences LLC, Indianapolis, IN) at 0, 560, and 1120 g ae ha^{-1}, and aminocyclopyrachlor (DPX-MAT28, DuPont Crop Protection, Wilmington, DE) at 0, 140, and 280 g ai ha^{-1} were applied directly to the petri dishes containing seeds using an enclosed research track sprayer with an 8002 even flat fan nozzle calibrated to deliver 187 L ha^{-1} at 207 kPa. Herbicide rates were based on the recommended use rates for control of Russian knapweed (i.e. aminopyralid at 123 g ae ha^{-1}, clopyralid at 560 g ae ha^{-1}, and aminocyclopyrachlor at 140 g ai ha^{-1}) (Anonymous 2008; Anonymous 1999; Anonymous 2009). Untreated control dishes received only 4 ml of water with no spray treatment. Once treated dishes were removed from the sprayer, 4 ml water was promptly added to each petri dish. Dishes were then sealed with parafilm (Parafilm M, Bemis Company Inc. Neenah, WI) to maintain moisture. Dishes were placed in a box that was sealed to block out light. The boxes containing the dishes were kept in a dark room at approximately 18 C and were opened only on the dates of evaluation.

Dishes were pulled from the box 1 replicate at a time in the lab under full light and the number of germinated seeds was counted 7 and 14 days after treatment (DAT). After counting 7 DAT, dishes were immediately placed back in the sealed box until the next observation. Percent germination was calculated by dividing the number germinated by the number of seeds in the petri-dish. Root and shoot lengths of germinated seeds were measured and recorded 14 DAT and were based on a subsample of five germinated seeds from each dish. A small rubber cork approximately 7 by 14 mm (0.25 by 0.5 in) was randomly dropped into each dish and the five germinated seeds closest to it were harvested and roots and shoots measured. Shoots were then collected from all germinated seeds in each dish, including those used for lengths, placed in small envelopes, dried for 48 hours at 80 C and weighed. Data in tables includes average root and shoot lengths and shoot biomass.

Postemergence Greenhouse Trials. Greenhouse studies were initiated in March 2010 and November 2010 evaluating relative tolerance of ‘Alkar’ tall wheatgrass, Anatone germplasm bluebunch wheatgrass, ‘Magnar’ Great Basin wildrye, ‘Rimrock’ Indian ricegrass, ‘Sherman’ big bluegrass, and Toe Jam Creek germplasm bottlebrush squirreltail to aminopyralid, clopyralid, and aminocyclopyrachlor. Seed from each of the six grass species was planted in March 2010 and November 2010 in 164 ml (10 in^3) cone-tainers (SC10 Super Ray Leach Cone-tainer Cells, Stuewe and Sons Inc., 2290 SE Kiger Island Drive Corvallis, OR) using a 50/50 mix of peat moss and vermiculite as soil medium. Plants were thinned to one plant per cone-tainer approximately 10 days after planting. Grasses were watered daily by hand and were allowed to grow until they reached 3-4 leaf stage (approximately 30 days). Artificial lighting was set to allow 16 hours of light. Air temperature in the greenhouse ranged from 23 to 26 C.

Treatments were arranged in a randomized complete block design with four replications within each grass species and the experiment was repeated. Plots consisted of seven individual cone-tainers each containing a single plant. Treatments included aminopyralid at 0, 123, and 246, g ae ha^{-1}, clopyralid at 0, 560, and 1120 g ae ha^{-1}, and aminocyclopyrachlor at 0, 140, and 280 g ai ha^{-1}. Similar to the petri-dish trials, treatments were again based on the recommended field rates for control of Russian knapweed and similar perennial forbs (Anonymous 1999; Anonymous 2008; Anonymous 2009). All treatments included a non-ionic surfactant (Activator 90, alkylpolyoxyethylene ether and free fatty acids, Loveland Industries, Greeley, CO) at 0.25% v/v. Herbicide treatments were applied when each species reached the 3 to 4 leaf stage using an enclosed research track sprayer with a TeeJet 8002 even flat fan nozzle (TeeJet 8002, Spraying Systems Co., Wheaton, IL) calibrated to deliver 187 L ha^{-1} at 207 kPa.

Injury, height, and biomass data were collected consistently throughout both greenhouse studies. Herbicide injury was evaluated visually at 7, 14, and 28 days after treatment (DAT) by comparing treated plants to an untreated control plot. Injury data were recorded as a percentage with 0 representing no visual effect on the plant and 100 representing plant death. Heights were measured 14 DAT and both height and biomass data were collected 28 DAT. Within plots, individual plant heights were measured and averaged across the entire plot. To obtain biomass, plants were clipped at soil level, dried for 14 days at 60 C and weighed.

Field Trials. Field studies were conducted at two locations in Cache Valley, Utah in 2009 and 2010 to evaluate the tolerance of several perennial grass species to broadleaf growth regulator herbicides. The Utah State University Evans Farm site is located approximately 2.2 km (1.5 mi) south of Logan, UT at 41 41’ 48.04” N and 111

50’ 2.69” W with an elevation of 1376 m (4516 ft) above sea level. The site at the Utah Agricultural Experiment Station Greenville Research Farm is in North Logan, UT at 41 46’ 11.72” N and 111 49’ 15.47” W at an elevation of 1387 m. The mean annual precipitation in the area of both sites is 360 to 430 mm (14 to 17 in), with approximately 140 frost free days each year. The mean high temperature during the year is 25 C (77 F) with the mean low being -12 C. Soil at the Evans farm site is classified as a Nibley fine, mixed, active, mesic Aquic Agrixeroll. It is a somewhat poorly drained soil composed of silty clay loam in the top 30 cm (12 in) and silty clay from 31 to 147 cm. The soil had a pH was 7.5 and contained approximately 1.6% organic matter. At the Greenville Farm site the soil was a moderately well drained Millville coarse-silty, carbonic, mesic Typic Haploxeroll with silt loam composing most of the profile from 0 to 165 cm. The soil had a pH of 8.0 and contained approximately 1.4% organic matter. Both sites are relatively flat with a 0 to 3% overall slope.

Field trials were laid out in a strip plot design with four replicates. Plots were 3 by 9 m and consisted of seven rows of each grass species with 15 cm row spacing. Herbicides were applied in a randomization perpendicular to the rows of grass in each replicate. Experimental design and data collection methods were the same at each site.

Several perennial grass species were planted at each site using a cone seeder (Hege 500, Wintersteiger Ag, Austria). ‘Alkar’ tall wheatgrass, Anatone germplasm bluebunch wheatgrass, ‘Magnar’ Great Basin wildrye, ‘Rimrock’ Indian ricegrass, ‘Sherman’ big bluegrass, and Toe Jam Creek germplasm bottlebrush squirreltail were planted at the Greenville farm site at 16.3, 15.5, 16.3, 12.6, 2.8, and 10.5 kg ha^{-1}, respectively, on May 13, 2009. Species planted at the Evans farm site also included Anatone, Magnar, Rimrock, and Sherman at 16.8, 21.3, 16.1, and 3.4 kg ha^{-1}, respectively. Species were planted at the Evans farm site on May 21, 2010. Aminocyclopyrachlor and aminopyralid were applied at 0, 35, 70, 140 g ai ha^{-1} and 280, and 0, 53, 123 and 246 g ae ha^{-1}, respectively, on July 6, 2009 at the Greenville farm and on July 9, 2010 at the Evans Farm site. All treatments included a non-ionic surfactant at 0.25% v/v and were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 187 L ha^{-1} at 207 kPa.

Injury, canopy cover, and biomass data were all collected throughout the study. Plant heights were also collected at the Greenville farm site. Injury was evaluated visually at 20, 60, and 365 days after treatment (DAT) at Evans Farm and at 30, 108, and 365 DAT at Greenville by comparing all treated plots to an un-treated control. Injury data were recorded on a percentage scale with 0 being no visual effects on the plant and 100 being plant death. Canopy cover was also estimated visually 365 DAT at both sites and data were recorded as a percentage. Biomass data were collected at 60 and 365 DAT at Evans farm and at 365 DAT at Greenville. Evans farm biomass at 60 DAT and Greenville biomass at 365 DAT were both collected using a lawnmower and catch bags. All mower catch bags were tared in order to have equal empty weights. Fresh weights of each plot were taken on site. Grass species were significantly larger in 2011 at the Evans farm site so fresh weights at 365 DAT were collected using a forage plot harvester (Hege 212, Wintersteiger Ag, Austria). Moisture content at both sites was determined by collecting a grab sample of each species within each replicate. Fresh weight was recorded and samples were ovendried for approximately 10 days at 60 C, and weighed again. Subsample moisture percentages were used to adjust whole plot yields to dry weights.

All data were analyzed using the glimmix procedure in SAS (SAS version 9.3, SAS Institute, Cary, NC). Assumptions for normality and homoscedasticity of variance were checked. Significant site or run interactions were observed in all but a small number of data sets, therefore data were not combined between sites or runs. Data were combined where permissible and are presented accordingly in tables. Data were also transformed where needed using log or square root transformations to meet assumptions for constant variance. Original data are presented for clarity. Treatment means were separated using Fisher’s Protected LSD ($P<0.05$).

Results and Discussion

Petri-dish Germination Trials. Data for percent germination were variable between species, however this is to be expected as different species often respond differently to the same treatments due to differences in physiology and/or morphology. Although there were differences between runs and plots, none of the treatments appeared to have consistent effects on germination of any particular species 7 or 14 DAT (Table 3-1). The only execption to this was bottlebrush squirreltail, and it was the only species to show a significant decrease in percent of seeds germinated with aminopyraild at 246 g ae ha^{-1}. Most observable herbicide effects were manifest in the actual root and shoot growth of each species. Root length of germinated seeds was significantly reduced by all herbicides at all rates compared to the control (Table 3-2). Aminopyralid at 123 and 246 g ae ha^{-1} and aminocyclopyrachlor at 280 g ai ha^{-1} reduced root length of all species to 0 or near 0. Root lengths of Indian ricegrass were reduced to near 0 for all treatments with clopyralid treatments being the least damaging. Shoot length of all species was also consistently reduced by both 123 and 246 g ae ha^{-1} of aminopyralid and, in most cases, 280 g ai ha^{-1} of aminocyclopyrachlor (Table 3-3). While clopyralid significantly reduced root length for most species at both rates applied, it only occasionally reduced shoot length significantly at 1120 g ae ha^{-1} when compared to the control and was fairly inconsistent. Similar to its reduction in root length, shoot lengths of Indian ricegrass were also reduced nearly 50% by all three herbicides. This species appears to be the most susceptible to all the herbicides in this experiment. In contrast, tall wheatgrass appears to have the most growth of all the species but root and shoot growth were still heavily affected by both rates of aminopyralid and the highest rate of aminocyclopyrachlor. Bluebunch wheatgrass showed effects similar to tall wheatgrass for shoot growth. Clopyralid at 560 g ae ha^{-1} did not significantly reduce shoot growth for bluebunch wheatgrass, Great Basin wildrye, big bluegrass, or bottlebrush squirreltail in either run compared to the control. Aminopyralid at 246 g ae ha^{-1} was the only treatment that consistently caused the greatest reduction in root and shoot length across all species in both runs. Aminocyclopyrachlor at 280 g ai ha^{-1} had very similar effects on root and shoot length as the high rate of aminopyralid in many but not all species. In general, aminopyralid appeared to have the greatest impact on root and shoot growth of the species studied in this trial. Both rates of aminopyralid and aminocyclopyrachlor reduced shoot biomass significantly for all species except big bluegrass in both runs compared to the control (Table 3-4). Similar to shoot lengths, the highest rates of aminopyalid and aminocyclopyrachlor produced very similar results and resulted in the greatest reduction of biomass for most species. In most cases, dishes treated with clopyralid had biomass that was not significantly different from the control. The exception was Great Basin wildrye with clopyralid at 1120 g ae ha^{-1} resulting in a significant reduction in biomass in both runs.

Postemergence Greenhouse Trials. Greenhouse trials exhibited significant run by treatment interactions so data were not combined between runs in most cases. Despite these interactions, several similar trends were exhibited in both runs. Overall, visual injury (Table 3-5) was fairly unreliable in these experiments because of the difficulty in quantifying the several types of injury that occurred, and therefore will not be discussed further.

Plant heights were somewhat variable and not completely consistent between runs, however, some major trends can still be observed. Aminopyralid at both 123 and 246 g ae ha^{-1} significantly reduced plant heights compared to the control for all species but Indian ricegrass and big bluegrass in run 1 (Table 3-6). For big bluegrass, only aminopyralid at 123 g ae ha^{-1} had a significant reduction in plant height. In run 2, however, only bottlebrush squirreltail height was significantly reduced in by aminopyralid at 246 g ai ha^{-1}. Great Basin wildrye was the only species to show any response to clopyralid at any rate in run 1, however, only the 1120 g ae ha^{-1} rate was significantly different from the control and the same trend was not repeated in run 2. Bluebunch wheatgrass showed a significant reduction in plant height with aminocyclopyrachlor at 280 g ai ha^{-1} compared to the control and was the only species to respond consistently to aminocyclopyrachlor in both runs. As mentioned previously, heights of tall wheatgrass, big bluegrass, and Indian ricegrass all seemed largely unaffected by most treatments when compared to their respective controls. Overall, plant heights were extremely variable in both runs and therefore only provide limited insight into the tolerance of these species to these herbicides.

Biomass was affected by treatements more in run 1 than in run 2. Aminopyralid, however, was consistently the most injurious in both runs. Biomass was reduced for all species in run 1 by aminopyralid at 246 g ae ha^{-1} and for tall wheatgrass, Great Basin wildrye and bottlebrush squirreltail in run 2 (Table 3-7). Bluebunch wheatgrass biomass was significantly reduced by the low rate of aminopyralid in both runs and the high rate in run 1. Great Basin wildrye biomass was significantly reduced by both rates of clopyralid in both runs. These results are similar to the germination experiments where root and shoot length of Great Basin wildrye were significantly reduced by clopyralid at 1120 g ae ha^{-1}. Bluebunch wheatgrass and bottlebrush squirreltail also showed significant reductions in biomass in run 1 with clopyralid at 1120 g ae ha^{-1} but did not repeat the response in run 2. Aminocyclopyrahlor at 280 g ai ha^{-1} significantly reduced bluebunch wheatgrass and Great Basin wildrye biomass compared to the control in both runs with big bluegrass and bottlebrush squirreltail only showing significant effects from aminocyclopyrachlor in run 1.

Data from the greenhouse trials suggest that aminopyralid at 246 g ae ha^{-1} was the most injurious to all six species compared to the other two herbicides at either of their respective rates 28 DAT. Big bluegrass showed the least response to all treatments, often showing no difference between any treatments in the greenhouse. Great Basin wildrye biomass and height were significantly reduced by the highest rates of all herbicides and was the most susceptible to clopyralid of the species studied. Bluebunch wheatgrass was the only species to consistently respond to aminocyclopyrachlor at 280 g ai ha^{-1} in the greenhouse as both heights and biomass were significantly reduced by this treatment.

Field Trials. Field data generally contained higher injury than the greenhouse data, possibly because the initial evaluation in the field was 60 DAT compared to 28 DAT in the greenhouse. Similar to our results from the greenhouse, 'Sherman' big bluegrass appeared to the most tolerant grass species to both aminopyralid and aminocyclopyrachlor, having low injury totals in the field as well. (Tables 3-8 and 3-9). At the Evans Farm site, Indian ricegrass also appeared to show some tolerance to both herbicides 60 DAT suffering a maximum 21% and 23% injury for aminocyclopyrachlor and aminopyralid respectively at their highest rates. Aminocyclopyrachlor consistently caused higher injury overall than aminopyralid in the field. For example, excluding big bluegrass, injury to grasses ranged from 21 to 94% across both sites with the high rate of aminocyclopyrachlor and only 9 to 23% at the high rate of aminopyralid 246 g ae ha^{-1} 60 DAT (Table 3-8). Consistent with the greenhouse data, among the most susceptible to aminocyclopyrachlor at both sites were bluebunch wheatgrass and Great Basin wildrye with the addition of tall wheatgrass and bottlebrush squirreltail at the Greenville Farm site. Great Basin wildrye showed the most injury (61%) with the high rate of aminocyclopyrachlor at Evans Farm followed closely by bluebunch wheatgrass with 56%

injury 60 DAT. At the Greenville site, tall wheatgrass showed the most injury (94%) with the high rate of aminocyclopyrachlor 60 DAT, followed by bluebunch wheatgrass, and bottlebrush squirreltail with 91% and 83% injury, respectively. Bottlebrush squirreltail was the most susceptible to aminopyralid at 246 g ae ha^{-1} with 31% injury 60 DAT. Injury 365 DAT decreased for all grass species studied excluding bottlebrush squirreltail which continued to increase in injury and eventually died as a result of aminocyclopyrachlor applications of 140 g ai ha^{-1} or higher (Table 3-9). Excluding bottlebrush squirreltail, injury 365 DAT ranged from 2 to 78% across all species while injury 60 DAT ranged from 5 to 94%. If we exclude the highest rate of aminocyclopyrachlor, the results look better with a range of 5 to 80% 60 DAT and from 2 to 56% 365 DAT. Aminocyclopyrachlor was still highly injurious 365 DAT at the highest rate of 280 g ai ha^{-1} for most species in both runs indicating prolonged activity in the soil. Injury evaluations at Greenville, show bottlebrush squirreltail was killed with the highest rate of aminocyclopyrachlor while only suffering 18% injury from the highest rate of aminopyralid. While injury data 365 DAT still exhibited a slightly detectable dose response with aminocyclopyrachlor treatments on some species at Evans farm, aminopyralid treated plots were still not significantly different from each other. Interestingly, Indian ricegrass showed significantly higher injury at the Greenville site 365 DAT (Table 3-9), but seemed fairly tolerant to all treatments at the Evans Farm site. One possible explanation for this might be found in the timing of emergence of this species between the two sites. Although the two sites were planted at the same time of year, Indian ricegrass at the Greenville site emerged later in the season than at the Evans

Farm site. At the time of spraying Indian ricegrass had emerged with the rest of the remaining species at the Evans Farm site, however, at the Greenville site, as indicated in several of the tables, Indian ricegrass had not emerged adequately to collect data. This may have resulted in the herbicide affecting germination and establishment of much of the Indian ricegrass at the Greenville site. As a result, the higher injury numbers at the Greenville site for Indian ricegrass compare more similarly to the root and shoot data in the petri-dish trials than to the injury results at the Evans Farm site and in the greenhouse.

Grass species at Evans Farm showed no significant differences in foliar cover between any of the herbicide treatments 365 DAT (Table 3-10) with the exception of big bluegrass. Big bluegrass data was able to be combined between sites and showed significantly reduced foliar cover at the highest rate of aminocyclopyrachlor. Interestingly, foliar cover in big bluegrass plots with this treatment averaged the same as the control plots, possibly indicating a certain amount of weed competition existed in the control plots, but then was eliminated with the herbicide treatments. Big bluegrass may have also been injured slightly by aminocyclopyrachlor at 280 g ai ha^{-1}. Aminopyralid treatments were not significantly different from the controls for any of the species at the Greenville site indicating little to no effect on foliar cover from aminopyralid at 53, 123, or 246 g ae ha^{-1}. At the Greenville site, bottlebrush squirreltail foliar cover was reduced to 0 by aminocyclopyrachlor at 140 and 280 g ai ha^{-1}, confirming the 100% injury rating at 365 DAT previously discussed. Tall wheatgrass, bluebunch wheatgrass, and Great Basin wildrye all showed a significant dose response for aminocyclopyrachlor at 70, 140, and 280 g ai ha^{-1} with bluebunch wheatgrass suffering the biggest reduction (96%) in foliar cover between the highest rate of amincyclopyrachlor and the control followed by Great Basin wildrye with a 93% reduction and tall wheatgrass at 86%.

For most grass species at both sites, biomass still appeared to increase slightly with the lowest rates of both aminocyclopyrachlor and aminopyralid as weed competition was eliminated, however, aminocyclopyrachlor at 140 g ai ha^{-1} or above injured grasses significantly and biomass began to decrease (Table 3-11). Aminopyralid appeared to control the broadleaf weeds very well at the two lowest rates and very little injury to desirable grasses occurred. At 246 g ae ha^{-1} or above some reductions in biomass, although not always significant, began to occur when compared to the control. Biomass of big bluegrass was not significantly different from the control for any of the treatments applied. Indian ricegrass at the Evans Farm site and bottlebrush squirreltail at the Greenville site were the only two species to show a decreasing trend in biomass for all rates of aminopyralid compared to the control. Biomass increased in tall wheatgrass, Great Basin wildrye, and big bluegrass at the Greenville site with all rates of aminopyralid suggesting a possible reduction in weed competition. Overall, aminopyralid did not show significant biomass differences between rates for any species at either site 365 DAT. Aminocyclopyrachlor at 280 g ae ha^{-1} caused significant reductions in biomass of bluebunch wheatgrass compared to the control at the Evans Farm site and for tall wheatgrass, bluebunch wheatgrass, and Great Basin wildrye, at the Greenville site.

The objective of these studies was to evaluate the tolerances of six perennial bunchgrasses native to the Western United States to three growth regulator herbicides commonly used to control invasive perennial weeds. Results from the studies suggest that growth regulator herbicides intended for broadleaf weed control can induce injury in non-target grass species. As indicated in the pre-germination trials, these herbicides may not necessarily affect seed germination of a particular grass species. Instead, effects tended to show up later in root and shoot development of seedlings. If any conclusions could be drawn from that study and applied to the field, they would be that growth regulator herbicides could possibly affect seedling establishment of non-target perennial grasses more than actual germination when applied pre-emergence in field settings. However, the trials done in petri-dishes represent a worst-case scenario in which the seeds are in direct contact with an herbicide solution. Many variables could possibly alter the results in a field setting. For example, soil properties such as texture, pH, cation exchange capacity, and organic matter content all affect the way herbicides behave in the soil. Precipitation and the ability of an herbicide to leach through the soil profile also affect how much herbicide solution comes in contact with a seed. Therefore, caution must be used when applying conclusions from a lab experiment to the field.

In addition to the observed effects of growth regulator herbicies on non-target desirable grasses, we noticed that different grass species [and sometimes the same species] have different levels of tolerance for these types of herbicides depending on the rates and timings the herbicides are applied. For example, Indian ricegrass appeared to be very sensitive to all three herbicides in the pre-germination petri-dish trials and when it emerged after the herbicide was applied in the field, but was fairly tolerant of aminopyralid and aminocyclopyrachlor at the Evans Farm site where the herbicides were applied postemergence. That said, aminopyralid at both rates and aminocyclopyrachlor at the highest rate applied prevented root growth and significantly reduced shoot growth of nearly every species evaluated in pre-germination trials. Again, cautiously drawing conclusions from lab data, it may not be advisable to apply either of these two herbicies immediately prior to planting any of these species on the range. Further research is needed in the field to evaluate a proper interval between herbicide application and planting of these species. In postemergence trials, both greenhouse and field data indicated high tolerance of ‘Sherman’ big bluegrass to aminopyralid, clopyralid, and aminocyclopoyrachlor at up to twice the labeled rates for control of aggressive perennial forbs (i.e. Russian knapweed). Big bluegrass appears to be a good candidate for revegetation projects that might include any of the herbicies used in these studies. The literature also supports that big bluegrass can be very tolerant to many types of herbicides (Ferrell et al. 1992; Sexton et al. 2000; USDA-ARS 2012), including growth regulators. Conversely, both ‘Magnar’ Great Basin wildrye and Anatone bluebunch wheatgrass were the most sensitive to the three herbicides used in the study, with Great Basin wildrye also showing the the highest sensitivity to clopyralid of any of the species evaluated. Unlike any of the other species, Great Basin wildrye appeared to respond to clopyralid in both the pre-germinaton trials and postemergence trials, indicating possible susceptibility to clopyralid at several growth stages and therefore would not be the best choice for a land manager to plant in areas where clopyralid has been or will be applied. Other research has also documented the sensitivity of Great Basin wildrye to different growth regulator herbicides (Sexton et al. 2000; Wilson and Sbatella 2010). Our results in the both the greenhouse and the field are somewhat similar to Swearingen and Whitson (1990) as well, in which they noticed the tolerance of ‘Sherman’ big bluegrass to glyphosate to be greater than that of ‘Magnar’ Great Basin wildrye. It is unclear why Great Basin wildrye would be so susceptible to growth regulator herbicide injury. One hypothesis is that the increased leaf area of this species compared to all other species in the study allowed for more herbicide interception and absorption by the plant. Tall wheatgrass also showed similar susceptibility to aminocyclopyrachlor at the Greenville site in the field trials. The cause of this could be similar to that of Great Basin wildrye as tall wheatgrass has much wider leaves than several other species used in this study at the growth stages evaluated however, further research is needed to determine the actual cause of the differences in relative tolerances between species to herbicides with this particular mode of action.

An interesting difference observed between the two types of postemergence trials was the difference in injury caused by aminocyclopyrachlor versus aminopyralid in the field and greenhouse. Although field trials show aminocyclopyrachlor as being more injurious than aminopyralid on the six tested species in the field, nearly the opposite was observed in the greenhouse. Although the timelines of the trials and of the evaluations of these field and greenhouse trials were somewhat different, one would expect that the relative tolerances of the same six species to the same herbicides would be similar in both a greenhouse and a field setting. It is uncertain, but possible that some effects similar to those in the field could be observed in the greenhouse if plants were grown for a longer period of time. Other factors such as those mentioned previously regarding soil properties, moisture in the field versus the greenhouse, and artificial lighting versus natural light may have had some effect on how the plants reacted to these two herbicides. At 28 DAT in the greenhouse, however, the effects of aminopoyralid at 123 g ai ha^{-1} and aminocyclopyrachlor at 280 g ai ha^{-1} on these six varieties were not that different from each other. Aminocyclopyrachlor may have more residual effects in the field which were not observed in the greenhouse due to a shorter duration experiment.

The results from this study not only support current research regarding relative tolerances to native bunch grass species to growth regulator herbicides, but they will help to provide additional sources and insight to those managers deciding on which grass species to use in revegetation and reclamation programs. The information contained here will also help determine what rates to apply these specific herbicides in order to maximize regrowth potential of existing grasses similar to those studied here. The differences in herbicide tolerance of native and other desirable grasses are important to land managers when exploring the ecological and economical sustainability of a particular management plan. As more knowledge becomes available about how native and non-native species react to management practices, better decisions can be made regarding the most effective methods to use in restoring lands to a condition that is suitable for use by people and wildlife.

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Table 3-1. Percent of total seed germinated 14 days after treatment with growth regulator herbicides. Herbicides were applied directly to petri dishes containing pure live seed of several perennial range grass species[a].

		Run 1						Run 2					
Herbicide	Rate[b]	ELYEP[c]	AGRSP	ELYCI	ORZHY	POAAM	SITHY	ELYEP	AGRSP	ELYCI	ORZHY	POAAM	SITHY
	g ai ha^{-1}	%											
Control	0	98 a	75 ab	99 a	92 a	32 a	92 a	99 a	89 a	83 a	91 a	45 ab	86 a
Aminopyralid	123	100 a	74 ab	94 a	85 ab	29 a	76 abc	99 a	75 b	86 a	86 a	30 c	62 c
	246	100 a	73 ab	98 a	86 ab	35 a	68 c	94 a	78 ab	80 a	90 a	40 bc	64 bc
Clopyralid	560	99 a	72 b	91 a	90 a	31 a	76 abc	99 a	79 ab	86 a	86 a	55 a	80 ab
	1120	100 a	71 b	93 a	90 a	33 a	86 ab	98 a	80 ab	83 a	82 a	38 bc	75 abc
Aminocyclopyrachlor	140	93 b	84 a	91 a	77 b	38 a	80 abc	95 a	56 c	84 a	82 a	38 bc	69 bc
	280	99 a	80 ab	93 a	94 a	35 a	70 bc	97 a	81 ab	75 a	83a	41 bc	77 abc

[a] Means followed by the same letter within a column or variety are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Rates are in g ai ha^{-1} for MAT28, g ae ha^{-1} for clopyralid and aminopyralid.

[c] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

Table 3-2. Root length of germinated seeds 14 days after application of growth regulator herbicides. Herbicides were applied directly to petri dishes containing pure live seed of several perennial range grass species. Data are based on a subset of 5 randomly selected germinated seeds from each petri dish[a].

		Run 1						Run 2					
Herbicide	Rate[b]	ELYEP[c]	AGRSP	ELYCI	ORZHY	POAAM	SITHY	ELYEP	AGRSP	ELYCI	ORZHY	POAAM	SITHY
	g ai ha^{-1}	cm plant^{-1}											
Control	0	3.9 a	4.5 a	3.3 a	2.4 a	1.0 a	2.8 a	4.7 a	2.7 a	2.1 a	0.8 a	1.3 a	1.9 a
Aminopyralid	123	0 d	0.1 d	0.1 c	0 b	0 c	0 c	0.1 e	0 c	0 d	0 b	0 c	0 d
	246	0 d	0 d	0.1 c	0 b	0 c	0 c	0.1 e	0 c	0 d	0 b	0 c	0 d
Clopyralid	560	2.2 b	1.0 b	0.6 b	0.2 b	0.5 b	0.9 b	2.7 b	0.9 b	0.52 b	0.2 b	0.4 b	0.4 b
	1120	1.6 b	0.3 cd	0.3 bc	0.1 b	0.3 bc	0.1 c	1.5 c	0.5 bc	0.5 bc	0.1 b	0.4 b	0.3 bc
Aminocyclopyrachlor	140	0.7 c	0.5 bc	0.5 b	0 b	0.2 bc	0 c	0.6 d	0.1 c	0.4 bcd	0 b	0.1 c	0.1 cd
	280	0.2 d	0.2 cd	0 c	0 b	0 c	0 c	0.1 e	0 c	0.1 cd	0 b	0 c	0 d

[a] Means followed by the same letter within a column or variety are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Rates are in g ai ha^{-1} for MAT28, g ae ha^{-1} for clopyralid and aminopyralid.

[c] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

Table 3-3. Shoot length of germinated seeds 14 days after application of growth regulator herbicides. Herbicides were applied directly to petri dishes containing pure live seed of several perennial range grass species. Data are based on a subset of 5 randomly selected germinated seeds from each petri dish[a].

		Run 1						Run 2					
Herbicide	Rate[b]	ELYEP[c]	AGRSP	ELYCI	ORZHY	POAAM	SITHY	ELYEP	AGRSP	ELYCI	ORZHY	POAAM	SITHY
	g ai ha^{-1}	cm plant^{-1}											
Control	0	12.9 a	10.0 a	7.5 a	6.6 a	2.3 b	8.1 a	10.6 a	9.8 ab	8.5 a	5.1 a	3.1 a	6.7 a
Aminopyralid	123	3.7 c	3.2 c	2.2 c	2.8 bc	1.2 c	2.8 d	4.6 b	3.5 cd	2.9 d	2.6 cd	1.1 bc	2.4 c
	246	3.4 c	3.3 c	2.4 c	1.9 c	0.9 c	2.5 d	3.4 c	3.1 d	2.5 e	2.0 d	0.9 c	2.7 c
Clopyralid	560	9.4 b	11.7 a	5.6 a	3.4 b	2.9 ab	7.8 a	10.4 a	10.1 a	6.2 b	3.7 b	3.3 a	6.4 a
	1120	8.9 b	10.4 a	5.4 a	3.4 b	3.2 a	6.2 b	9.8 a	8.4 b	6.1 b	3.6 b	3.1 a	6.7 a
Aminocyclopyrachlor	140	4.8 c	5.9 b	3.6 b	1.9 c	1.6 c	4.1 c	4.6 b	4.8 c	4.0 c	3.0 c	1.4 b	4.5 b
	280	3.8 c	4.9 bc	2.8 bc	1.3 c	1.0 c	3.6 c	3.9 bc	4.8 c	3.2 d	3.6 b	1.3 bc	3.2 bc

[a] Means followed by the same letter within a column or variety are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Rates are in g ai ha^{-1} for MAT28, g ae ha^{-1} for clopyralid and aminopyralid.

[c] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

Table 3-4. Biomass for all germinated shoots within a variety 14 days after application of growth regulator herbicides. Herbicides were applied directly to petri dishes containing pure live seed of several perennial range grass species[a].

		Run 1						Run 2					
Herbicide	Rate[b]	ELYEP[c]	AGRSP	ELYCI	ORZHY	POAAM	SITHY	ELYEP	AGRSP	ELYCI	ORZHY	POAAM	SITHY
	g ai ha^{-1}	μg plant^{-1}											
Control	0	1611 a	902 a	638 a	745 a	0 b	507 a	1659 a	961 a	736 a	670 a	65 a	455 a
Aminopyralid	123	529 d	277 d	284 cd	183 c	7 b	112 de	623 c	396 bc	462 b	293 cd	0 b	70 e
	246	535 d	269 d	232 d	136 cd	0 b	106 de	544 c	323 c	273 c	253 d	0 b	142 de
Clopyralid	560	1327 b	779 ab	652 a	366 b	49 a	376 b	1562 a	858 b	576 ab	543 ab	77 a	433 a
	1120	1180 b	712 b	516 b	274 bc	34 ab	254 bc	1514 a	872 a	513 b	474 abc	30 ab	342 ab
Aminocyclopyrachlor	140	881 c	513 c	353 c	38 de	6 b	209 cd	877 b	558 b	394 bc	339 bcd	11 b	318 bc
	280	618 d	380 cd	378 c	15 e	8 b	71 e	675 c	563 b	435 bc	335 bcd	8 b	216 cd

[a] Means followed by the same letter within a column or variety are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Rates are in g ai ha^{-1} for MAT28, g ae ha^{-1} for clopyralid aminopyralid.

[c] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

Table 3-5. Grass injury[a] 28 DAT in response to growth regulator herbicides applied postemergence in the greenhouse to six perennial range grasses[b].

			Run 1					Run 2				
Herbicide	Rate[c]	ELYEP[d]	AGRSP	ELYCI	ORZHY	POAAM	SITHY	AGRSP	ELYCI	ORZHY	POAAM	SITHY
	g ai ha^{-1}	%										
Aminopyralid	123	36 a	78 a	73 b	33 b	53 a	61 a	63 a	48 a	44 a	40 a	57 ab
	246	50 a	70 a	76 a	68 a	39 b	56 a	30 a	67 a	45 a	19 a	53 ab
Clopyralid	560	36 a	16 bc	44 b	15 b	21 c	21 b	35 a	73 a	61 a	28 a	70 a
	1120	39 a	15 bc	76 a	18 b	24 c	16 b	30 a	54 a	37 ab	27 a	36 b
Aminocyclopyrachlor	140	33 a	6 c	26 b	13 b	26 bc	15 b	48 a	60 a	16 bc	27 a	53 ab
	280	40 a	30 b	41 b	30 b	34 bc	11 b	78 a	93 a	10 c	30 a	42 ab

[a] Injury was evaluated visually with 0 being no effects on the plant and 100 being complete plant death.

[b] Means followed by the same letter within the same column or variety are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[c] Rates are in g ai ha^{-1} for MAT28, g ae ha^{-1} for clopyralid, and aminopyralid.

[d] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

Table 3-6. Grass height 28 DAT in response to growth regulator herbicides applied postemergence in the greenhouse to six perennial range grasses[a].

			Run 1					Run 2				
Herbicide	Rate[b]	ELYEP[c]	AGRSP	ELYCI	ORZHY	POAAM	SITHY	AGRSP	ELYCI	ORZHY	POAAM	SITHY
	g ai ha^{-1}	cm plant^{-1}										
Control	0	23 a	21 a	30 a	22 ab	14 ab	19 a	22 a	24 b	24 c	16 ab	20 bc
Aminopyralid	123	20 b	10 d	13 b	23 ab	10 c	11 b	18 ab	29 a	25 c	14 b	19 cd
	246	19 b	13 c	14 b	17 b	11 bc	12 b	21 ab	20 b	23 c	22 a	18 d
Clopyralid	560	23 a	21 a	26 a	25 a	14 a	19 a	22 a	23 b	26 c	16 ab	21 bc
	1120	25 a	19 ab	16 b	25 a	15 a	18 a	19 ab	23 b	27 bc	19 ab	22 ab
Aminocyclopyrachlor	140	24 a	22 a	29 a	26 a	13 ab	18 a	19 ab	20 b	32 a	17 ab	23 a
	280	25 a	17 b	28 a	24 a	13 ab	17 a	15 b	22 b	30 ab	17 ab	21 bc

[a] Means followed by the same letter within a column or variety are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Rates are in g ai ha^{-1} for MAT28, g ae ha^{-1} for clopyralid aminopyralid.

[c] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

Table 3-7. Grass biomass 28 DAT in response to growth regulator herbicides applied postemergence in the greenhouse to six perennial range grasses[a].

			Run 1					Run 2				
Herbicide	Rate[b]	ELYEP[c]	AGRSP	ELYCI	ORZHY	POAAM	SITHY	AGRSP	ELYCI	ORZHY	POAAM	SITHY
	g ai ha^{-1}	mg plant^{-1}										
Control	0	308 a	255 a	325 a	340 a	173 a	275 a	140 a	137 a	85 a	120 a	70 ab
Aminopyralid	123	210 ab	45 d	93 c	195 ab	118 cd	83 c	75 b	110 ab	98 a	80 a	58 bc
	246	156 b	55 d	75 c	85 b	100 d	85 c	105 ab	70 b	85 a	140 a	50 c
Clopyralid	560	251 ab	198 ab	220 b	300 a	170 a	195 b	115 ab	77 b	100 a	93 a	68 ab
	1120	253 ab	165 bc	105 c	145 ab	158 ab	190 b	90 ab	87 b	90 a	130 a	75 ab
Aminocyclopyrachlor	140	249 ab	210 ab	245 ab	295 a	140 bc	190 b	100 ab	80 b	105 a	120 a	88 a
	280	250 ab	125 c	223 b	280 ab	115 cd	168 b	70 b	77 b	110 a	110 a	70 ab

[a] Means followed by the same letter within a column or variety are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Rates are in g ai ha^{-1} for MAT28, g ae ha^{-1} for clopyralid aminopyralid.

[c] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

Table 3-8. Grass injury[a] at two locations in Logan, UT 60 days after treatment in response to postemergence applications of growth regulator herbicides to several perennial range grass species in the summer[b].

			Evans farm			Greenville farm				
Herbicide	Rate[c]	POAAM[d]	AGRSP	ELYCI	ORZHY	AGRSP	ELYCI	ORZHY	ELYEP	SITHY
	g ai ha^{-1}	%								
Aminocyclopyrachlor	35	6 a	—	—	—	5 c	11 bc	—[e]	26 d	59 b
	70	5 a	21 c	25 bc	8 b	48 b	21 b	—	65 c	76 ab
	140	18 a	38 b	44 ab	15 ab	66 b	65 a	—	80 b	79 ab
	280	14 a	56 a	61 a	21 a	91 a	83 a	—	94 a	88 a
Aminopyralid	53	9 a	5 d	8 c	16 ab	0 c	0 c	—	4 e	0 d
	123	9 a	13 cd	20 c	18 ab	6 c	9 c	—	1 e	10 d
	246	10 a	15 cd	9 c	23 a	11 c	19 bc	—	10 e	31 c

[a] Injury was evaluated visually with 0 being no effects on the plant and 100 being complete plant death.

[b] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[c] Rates for MAT28 are in g ai ha^{-1} and g ae ha^{-1} for aminopyralid.

[d] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

[e] Indian ricegrass did not establish well at the Greenville site so means were unable to be calculated.

Table 3-9. Grass injury[a] at two locations in Logan, UT 365 days after treatment in response to postemergence applications of growth regulator herbicides to several perennial range grass species in the summer[b].

			Evans farm			Greenville farm				
Herbicide	Rate[c]	POAAM[d]	AGRSP	ELYCI	ORZHY	AGRSP	ELYCI	ORZHY	ELYEP	SITHY
	g ai ha^{-1}	%								
Aminocyclopyrachlor	35	3 a	—	—	—	10 b	9 b	56 a	6 b	69 b
	70	2 a	5 b[d]	6 b	3 a	11 b	5 b	48 a	16 b	91 ab
	140	9 a	13 b	20 ab	13 a	38 b	24 b	38 a	26 b	99 a
	280	13 a	29 a	33 a	15 a	75 a	78 a	61 a	59 a	100 a
Aminopyralid	53	7 a	1 b	8 b	5 a	18 b	24 b	49 a	8 b	0 c
	123	7 a	9 b	15 ab	9 a	20 b	28 b	58 a	14 b	0 c
	246	9 a	8 b	4 b	7 a	10 b	9 b	56 a	6 b	18 c

[a] Injury was evaluated visually with 0 being no effects on the plant and 100 being complete plant death.

[b] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[c] Rates for MAT28 are in g ai ha^{-1} and g ae ha^{-1} for aminopyralid.

[d] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

Table 3-10. Grass cover from two locations in Logan, UT 365 days after treatment in response to postemergenceapplications of growth regulator herbicides to several perennial range grass species in the summer[a].

			Evans farm			Greenville farm				
Herbicide	Rate[b]	POAAM[c]	AGRSP	ELYCI	ORZHY	AGRSP	ELYCI	ORZHY	ELYEP	SITHY
	g ai ha^{-1}	%								
Control	0	69 b	73 a	88 a	83 a	50 a	63 b	—[d]	76 ab	55 a
Aminocyclopyrachlor	35	84 a	—	—	—	59 a	70 ab	—	71 ab	6 b
	70	83 a	75 a	90 a	71 a	45 ab	73 ab	—	63 b	1 c
	140	84 a	78 a	76 a	60 a	29 b	30 c	—	36 c	0 c
	280	69 b	64 a	74 a	63 a	2 c	5 d	—	10 d	0 c
Aminopyralid	53	78 ab	82 a	89 a	65 a	64 a	80 a	—	79 ab	56 a
	123	74 ab	78 a	80 a	63 a	65 a	81 a	—	84 a	54 a
	246	78 ab	82 a	82 a	73 a	58 a	76 ab	—	76 ab	44 a

[a] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Rates for MAT28 are in g ai ha^{-1} and g ae ha^{-1} for aminopyralid.

[c] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass *(Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

[d] Indian ricegrass did not establish well at the Greenville site so means were unable to be calculated.

Table 3-11. Means for grass biomass from two locations 365 days after treatment in response to postemergence applications of growth regulator herbicides to several perennial range grass species in the summer[a].

			Evans farm			Greenville farm				
Herbicide	Rate[b]	POAAM[c]	AGRSP	ELYCI	ORZHY	AGRSP	ELYCI	ORZHY	ELYEP	SITHY
	g ai ha^{-1}	g plot^{-1}								
Control	0	324 a	531 abc	745 ab	190 a	70 abc	95 b	4 a	461 a	81 a
Aminocyclopyrachlor	35	199 a	—	—	—	136 ab	198 ab	24 a	516 a	25 b
	70	448 a	551 abc	1161 a	161 ab	147 a	227 a	32 a	609 a	6 b
	140	443 a	401 cd	673 b	83 b	60 bc	94 bc	43 a	366 a	9 b
	280	486 a	249 d	507 b	129 ab	28 c	70 c	25 a	111 b	14 b
Aminopyralid	53	364 a	639 a	896 ab	93 ab	83 abc	131 abc	24 a	478 a	69 a
	123	351 a	465 bc	825 ab	189 a	108 ab	154 abc	24 a	498 a	77 a
	246	384 a	573 ab	714 b	146 ab	67 bc	138 abc	3 a	504 a	57 a

[a] Means in the same column followed by the same letter are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

[b] Rates for MAT28 are in g ai ha^{-1} and g ae ha^{-1} for aminopyralid.

[c] Species codes are as follows: ELYEP = 'Alkar' tall wheatgrass (*Thinopyrum ponticum*); AGRSP = Anatone germplasm bluebunch wheatgrass (*Agropyron spicatum*); ELYCI = 'Magnar' great basin wildrye (*Elymus cinereus*); ORZHY = 'Rimrock' Indian ricegrass (*Oryzopsis hymenoides*); POAAM = 'Sherman' big bluegrass (*Poa ampla*); and SITHY = Toe Jam Creek germplasm bottlebrush squirreltail (*Elymus elymoides*).

CHAPTER 4

SUMMARY AND CONCLUSIONS

Russian knapweed (*Acroptilon repens*) is an invasive perennial forb that causes serious problems in range and pasturelands in the Western United States. In 2000, Skinner et al. ranked Russian knapweed as the sixth most frequently listed noxious weed in the United States. This research provides further insight into another simple yet effective management method for controlling this invasive alien species. We observed that aminopyralid was extremely effective at controlling Russian knapweed at 53 g ae ha^{-1} and that plots treated with the herbicide tended to increase in cover of both native and non-native perennial grasses. It is known that plant communities dominated by invasive weeds often require a direct management input, such as an herbicide, to suppress the invasive species and direct the community toward a more desirable native community (Krueger-Mangold et al. 2006). Data and observations from this study indicate that aminopyralid worked very well in suppressing and further facilitating the removal of Russian knapweed from the system, and by so doing, resource availability for desirable and other native species increased. Although a single grazing treatment did not produce any significant control, targeted grazing should not be ruled out as part of an integrated approach to weed control as others have been successful with its implementation. It is possible that if aminopyralid had been less effective or more frequent grazing was utilized, a response from grazing treatments may have been observed. In this study aminopyralid provided excellent control of Russian knapweed with all applied rates 8 and 20 MAT in run 1 and 8 MAT in run 2 at the Dinosaur National Monument field sites. Visual evaluations at both sites support this as aminopyralid at 53 g ha^{-1} provided nearly 99% control in spring 20 MAT in run 1 and 100% in spring 8 MAT in run 2. Russian knapweed biomass and cover were also reduced to 0 or near 0 for all rates of aminopyralid. Conversely, desirable grass cover and biomass increased across all rates. Areas recovering from the removal of an invasive species depend largely on reestablishment from seed of desirable plants (Samuel and Lym 2008). As the invasive species had likely reduced native vegetation seedbank reserves for quite some time at these plots, long term control of the invasive species is of the utmost importance in order to allow native and other desirable species to become well established once again. Aminopyralid provided effective suppression for at least 2 years after treatments were applied, however, somewhat less is known of its long-term efficacy.

Although no serious injury to the grass species present at the Dinosaur National Monument sites was observed, unwanted or “collateral” damage to desirable grasses can and does occur with some of the herbicides labeled for use on rangeland broadleaf weeds. In our grass trials, ‘Sherman’ big bluegrass appeared to be the most tolerant to both aminopyralid and amniocyclopyrachlor. In the greenhouse, clopyralid appeared to be the least injurious to all six species studied although Great Basin wildrye appeared to be the only species that was consistently sensitive to clopyralid throughout all three studies, suggesting it not be used in a management plant where clopoyralid is the main herbicide treatment of choice. The two most susceptible grass species common between the two sites in the field and also both runs in the greenhouse were ‘Magnar’ Great Basin wildrye and Anatone bluebunch wheatgrass. Each species consistently suffered high injury rates with the highest rate of aminocyclopyrachlor both in the field and in the greenhouse compared to the other speices.

Seedling or newly established grass tolerance to herbicides is critical in areas where desirables must be planted after removal of an invasive species. One advantage when applying herbicides to Russian knapweed is the timing of application. With late fall applications demonstrating maximum efficacy on Russian knapweed, herbicides applied at this time should have little effect on perennial grasses that are typically very close to dormancy at this time. However, in areas where a summer timing is necessary, these findings suggest that most of the six species evaluated would still tolerate aminopyralid, clopyralid, and aminocyclopyrachlor well up to 246 g ae ha^{-1}, 1120 g ae ha^{-1}, and 280 g ai ha^{-1} respectively and would be able to grow out of any injury sustained in a postemergence application. Toe Jam Creek germplasm bottlebrush squirreltail is the exception and was killed by the highest rate of aminocyclopyrachlor in the field trials and suffered a reduction in total plant biomass at the lowest rates of all three herbicides in the greenhouse. In pre-germination trials, all three herbicides reduced root length of all six grass species significantly. Shoot length 14 DAT was reduced by roughly half for all species by both rates of aminopyralid and by aminocyclpyrachlor at 280 g ai ha^{-1} indicating the necessity to avoid pre-emergence applications of these herbicides in areas where these grass species are to be planted for reclamation in order to maximize both the growth and competitive potential of these grasses.

These studies indicate relative tolerance between grass species used in reclamation and rehabilitation of range and pasturelands. These tolerances also differ between herbicides used on the same species. Differences in herbicide tolerance between desirable species are important to land managers seeking to maximize the ecological and economical sustainability of their management plans. Selecting desirable grass species that can establish and persist in areas being treated for reclamation or rehabilitation greatly enhances the ability of desirable grasses to compete with and control invasive species.

In conclusion, these studies provide further insight into how Russian knapweed can be effectively controlled with aminopyralid and also how a few of the native and non-native species respond to herbicides used for control of broadleaf weeds on western rangelands. Even though control data for Russian knapweed were relatively short term and only six range grasses were evaluated in these studies, with this added knowledge, managers will be closer to making more educated decisions regarding integrated weed management in areas where these species exist.

Literature Cited

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