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Biology and Control of Russian Thistle (*Salsola tragus* L.) in Bighorn Sheep (*Ovis canadensis* Shaw) Winter Ranges in Montane Grasslands of Jasper National Park, Alberta, Canada

by

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ABSTRACT

Russian thistle (*Salsola tragus* L.) invaded areas of native montane grassland important to winter survival of bighorn sheep (*Ovis canadensis* Shaw) were studied in Jasper National Park, Alberta, Canada. The biology of Russian thistle and its control in the Park were studied in the field and greenhouse. Russian thistle in grasslands were 9.1 cm tall with 37.5 seeds per plant, whereas larger plants in naturally disturbed habitats were 29.8 cm tall with 1562.4 seeds per plant. Plants travelled up to 4,180 m during dispersal. With soil seed contact, litter depth did not inhibit performance or survivability; without soil contact, thick litter reduced germination and plant performance. Russian thistle responded positively to increased greenhouse temperature and drier conditions. Seven control treatments involving herbicide, seeding mixes, hand pulling, and grazing exclusion were assessed. Grazing exclusion was the best field management option, increasing litter and biomass, while reducing Russian thistle density and biomass.

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See them tumbling down,
Pledging their love to the ground
Lonely but free I'll be found
Drifting along with the tumbling tumbleweeds.

Cares of the past are behind
Nowhere to go but I'll find
Just where the trail will wind
Drifting along with the tumbling tumbleweeds.

I know when night has gone
That a new world's born at dawn.

I'll keep rolling along
Deep in my heart is a song
Here on the range I belong
Drifting along with the tumbling tumbleweeds.

"Tumbling Tumbleweeds" composed by Bob Nolan in 1932 and recorded by the Sons of the Pioneers.

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CHAPTER I. BACKGROUND

1. INTRODUCTION

The International Union for Conservation of Nature (IUCN), currently recognizes the spread of invasive alien species as one of the greatest threats to the ecological and economic well being of the planet (McNeely et al. 2001). The impact of invasive alien species on native ecosystems, habitats, and species is severe and often irreversible. In Canada, alien species include at least 27% of all vascular plant species, 181 insect species that feed on woody plants, 55 freshwater fish species, 26 mammal species, 24 bird species, 4 amphibian species, 2 reptile species, and several fungi and mollusk species (Environment Canada 2004). Invasive alien species are often plants, which pose a heightened concern because they can alter structure, organization, or function of ecological systems (Olson 1999), resulting in reduced biodiversity, loss of habitat and food for native animals, and changes to natural ecological processes (e.g. plant community succession) (Parker et al. 1999, Booth et al. 2003, Radosevich et al. 2007). Some invaders reduce or eliminate species and communities that national parks or nature preserves were established to protect (U.S. Congress 1993).

Invasion by non native plant species is considered an ecological and economical threat to protected natural areas and adjacent surrounding lands in Canada (McPhee 2007). To protect and preserve examples of Canada's natural heritage policies, action plans must be developed to deal with invasive species in natural areas (White et al. 1993). The National Parks Act requires that national parks be managed for maintenance of ecological integrity (Mosquin 1997), which is considered the key focal point of policies and practices for Canada’s protected areas (Canadian Parks Council 2006). Restoration activities are expected to be consistent with recommendations in, ”An Invasive Alien Species Strategy for Canada” (Canadian Parks Council 2006). Environment Canada (2004) recommends that an ecosystem approach be used to manage invasive species through eradication, containment, and control.

In Jasper National Park, situated along the Rocky Mountains in western Alberta, 123 non native invasive plant species have been documented in several hundred infestations along transportation corridors and disturbed sites (McPhee 2007). The Jasper National Park Management Plan (Parks Canada 1997) recognizes that these non native species threaten the integrity of native plant species and communities. Their management is an integral component of the Park's objective to maintain or restore the integrity of Rocky Mountain ecosystems and preserve native biodiversity (McPhee 2007).

This study focused on one non native invasive species in Jasper National Park, Russian thistle (*Salsola tragus* L.). The Jasper National Park Integrated Pest Management Plan (McPhee 2007) included Russian thistle as one of the most noxious broadleaf species representing significant threats to native plant communities and ecological integrity in the park. Large areas of Russian thistle have been observed in native montane grassland communities used for winter grazing by bighorn sheep (*Ovis canadensis* Shaw) and other ungulates. There is concern these areas of invasion may be increasing in size, and appear to coincide with areas subject to sustained use by bighorn sheep, elk (*Cervus elaphus* Linnaeus), and deer (*Odocoileus* spp.). Overgrazing of critical winter range areas has diminished range condition, thus permitting Russian thistle to become established and compete with, or replace, already stressed native plant species and possibly reduce wildlife forage.

Montane grasslands of the lower Athabasca Valley and surrounding hillsides near Jasper Lake, provide a unique critical winter range habitat for ungulate species, particularly bighorn sheep. This winter range is located on exposed slopes at lower elevations providing good predator visibility and escape terrain. Due to low precipitation and wind swept conditions the area retains little snow allowing easy access to winter forage. The Athabasca Valley is an important east-west corridor through the Rocky Mountains for rail, vehicle traffic, and pipelines. Non native plant species, including Russian thistle, brought in along these transportation corridors threaten winter range areas. Invasive plant species can alter native plant communities and reduce range condition (Olson 1999). Poor range health and reduced forage availability, combined with severe winter conditions, could theoretically reduce localized ungulate populations.

This research on Russian thistle will address the extent and character of infestations in the Athabasca Valley, mechanisms of invasion, the role of wildlife grazing on establishment, and management strategies. Research results will benefit protected areas and land managers throughout the province and beyond who are involved with ungulate grazing and invasive species.

2. RUSSIAN THISTLE

2.1 Plant Origin and History

Russian thistle, colloquially referred to as tumbleweed, is an annual forb native to Central and Southwest Asia and Southeast Europe; now widely naturalized in South Africa, Asia, Australia, Europe, and North and South America (Flora of North America 2009, USDA Agricultural Research Service 2009). Russian thistle is a member of the *Chenopodiaceae* (Goosefoot) family, and related to another invasive species in the Park, kochia (*Kochia scoparia* (L.) Schrad) (Brenzil 2004).

Russian thistle nomenclature is confusing and the plant has numerous scientific synonyms including *Salsola australis* R. Br., *Salsola iberica* (Sennen & Pau) Botsch, *Salsola kali* L. and *Salsola pestifer* A. Nelson (Howard 1992, Mosyakin 1996, USDA Forest Service 2006, Orloff et al. 2008). *Salsola tragus* L. is now accepted as the correct name (Flora of North America 2009, Integrated Taxonomic Information System 2009). The correct name was used by some botanists in the 19th century, but most North American botanists chose to use a European misapplication of the name (Mosyakin 1996). Numerous field books (including Moss 1994 Flora of Alberta), government publications, and reports in Alberta refer to the plant as *Salsola kali,* or other synonyms.

According to Flora of North America (2009), *Salsola tragus* is an extremely polymorphic species consisting of several subspecies; however many of them are simply morphological variants of limited or no taxonomic value (Flora of North America 2009). Plant specimens collected from Jasper National Park were taken to the University of Alberta herbarium for expert indentification, where the plant was confirmed as *Salsola tragus* L.

Russian thistle was first introduced to North America in 1873 by Russian immigrants as a contaminant in flax (*Linum* sp.) seed in South Dakota (Brenzil 2004, Orloff et al. 2008). After its introduction Russian thistle quickly spread across the continent by contaminated seed, threshing crews, railroad cars, and by its wind blown dispersal mechanism (Orloff et al. 2008). Russian thistle first arrived in Canada in 1889, east of Morden Manitoba (Evans 2002). It was such a large concern for farmers in Manitoba that it was largely responsible for the creation and enactment of Canada's first provincial noxious weed act in 1894 (Evans 2002). By 1895 several provinces and 16 states were infested with Russian thistle (Young and Evans 1972) and it was abundant in drier parts of southern Alberta and Saskatchewan by 1909 (Evans 2002).

Agricultural practices of the late 1800s and early 1900s and the plowing of native prairie facilitated the rapid dissemination of Russian thistle. Russian thistle is not aggressive enough to compete with established native vegetation, so like many weeds, it benefits from agricultural practices designed to reduce environmental stresses (e.g. irrigation and fertilization) (Young 1991). Russian thistle has apparently had a long relationship with agriculture; Young (1991) mentions archaeologists have found carbonized seeds in excavations of some of the world's oldest agricultural sites in southern Eurasia.

Today in North America, Russian thistle occurs from British Columbia east to Labrador and south through the United States to northern Mexico (Howard 1992). It is common throughout southern and central portions of the Prairie Provinces and absent in northern Alberta (Leeson et al. 2005). Northern occurrences are rare, although Crompton and Basett (1984) found Russian thistle as far north as 55° latitude. An isolated population of Russian thistle occurs in the Peace River region near Taylor, British Columbia (Latitude: 56° 09' 08" N) (British Columbia Ministry of Agriculture, Food and Fisheries 2002). Recently Russian thistle has been observed north of Fort McMurray, Alberta, (Latitude: 57° 01' 01" N) on oil sands mining areas (Brown pers. comm. 2009).

In Jasper National Park Russian thistle is common on dry exposed or disturbed sites in the lower Athabasca Valley. It was documented near Windy Point as early as 1946 (Pfeiffer 1948). In 1980, Russian thistle was considered common on open sand dune ridges in the Jasper Lake area (Sharp 1980). In 1993 the amount of Russian thistle in open southeast facing slopes adjacent to Jasper Lake had diminished the value of the grasslands for wildlife (Biota Consultants 1993). By the early 1990s the Jasper Warden Service considered Russian thistle a serious concern due to its ability to invade and dominate overgrazed rangeland (Weerstra and Weerstra 2007).

2.1 Plant Characteristics

Russian thistle is an annual, well adapted to hot dry conditions. It can develop a deep widely branched taproot 1 m or more in length (British Columbia Ministry of Agriculture, Food and Fisheries 2002). Mature plants are 0.1 to 1.3 m in height (Morisawa 1999, British Columbia Ministry of Agriculture, Food and Fisheries 2002) and are rounded and bushy with numerous slender ascending stems (Orloff et al. 2008). In late fall and early winter, the base of the stem becomes brittle and breaks off at soil level (Orloff et al. 2008) allowing the plant to tumble in the wind, hence the name 'tumbleweed'. A specialized layer of cells in the stem allows the plant to break cleanly away from the roots; destruction of these cells coincides with seed maturity (Young 1991). The plant disperses seeds as it rolls along the ground. Seed production can vary depending on conditions (Halvorson and Guertin 2003), with a single plant producing up to 200,000 seeds (Young and Evans 1972). New infestations commonly appear as a trail of seedlings across fields (USDA Forest Service 2006).

Russian thistle only reproduces by seed. It is indeterminate, with flowering and seed production continuing until temperatures drop below -3.9 ℃ (Morisawa 1999). Individual small winged seeds are retained in the leaf axils. The seed contains no endosperm, but is comprised of a spirally coiled, fully differentiated seedling, which facilitates the seed in rapidly taking advantage of short periods of favorable conditions (Young et al. 1995). Seed germination is based primarily on an internal time clock rather than external factors, with seeds able to germinate under very specific temperature conditions in the fall (Young and Evans 1972). Over winter, temperature restrictions disappear and in spring seeds germinate under a wide range of seed bed temperatures (Howard 1992). Spring germination can occur if daytime temperatures are above freezing; however seedlings are very susceptible to frost (Morisawa 1999).

Seeds are short lived and seed viability in the soil deceases greatly within two years. Young et al. (1995) report that under irrigated conditions 99% of seeds germinated in the first year or died before germinating. Seed germination and viability vary depending on environmental factors. Brenzil (2004) found that for seeds planted in the fall, 31% germinated the following spring, 0.5% germinated the second year and 0.04% germinated the third year. The soft porous nature of the seed may allow it to germinate rapidly, contributing to its lack of longevity (Young et al. 1995).

Russian thistle is a shade intolerant, initial colonizer in primary and secondary succession (Howard 1992). It is well adapted to cultivated dryland agriculture and is found on disturbed sites, including overgrazed rangelands (Morisawa 1999, British Columbia Ministry of Agriculture, Food and Fisheries 2002, Whitson et al. 2006). Russian thistle grows along roads, railroad tracks, fields, and disturbed sites. It can invade many different disturbed plant communities, and colonize barren desert areas that cannot support other flora (Howard 1992). Young et al. (1995) considered Russian thistle one of the most efficient plants in the world at producing plant dry matter per unit of water used. Russian thistle is considered one of the most common and troublesome invasive weed species in the drier regions of the United States (Whitson et al. 2006). It grows well on uncompacted, well drained soil with a sunny exposure (British Columbia Ministry of Agriculture, Food and Fisheries 2002), does not perform well in moist environments (Brenzil 2004), and cannot tolerate saturated soils for extended periods of time (British Columbia Ministry of Agriculture, Food and Fisheries 2002).

Russian thistle exploits disturbed sites and exposed soil. However, it competes poorly with established vegetation and lacks the aggressiveness to overtake dense native populations (Young 1991). Rutledge and McLendon (1996) suggest both intra-specific and inter-specific competition can reduce set seed. During drought conditions or if competing vegetation is removed, Russian thistle will dominate (Morisawa 1999). With a C4 metabolic pathway, Russian thistle has increased germination at higher temperatures, and higher water use efficiency compared to C3 species (Crompton and Basett 1984). However, under cool conditions the attributes of C4 plants become less advantageous and they often cannot compete with native and crop C3 species (Brenzil 2004).

Russian thistle is a pioneering annual that invades disturbed sites during early successional stages but may only remain in the system for two to seven years (Lodhi 1979, Howard 1992). Even as a monoculture, it becomes stunted after colonization of a disturbed area (Lodhi 1979, Schmidt and Reeves 1989). Lodhi (1979) found that Russian thistle contained allelopathic phytotoxins and claimed the plant litter was autotoxic. However, Schmidt and Reeves (1989) later refuted Lodhi's finding, suggesting the poor growth following initial colonization was not due to phytotoxins from the litter of previous Russian thistle plants. Russian thistle does not likely have an allelopathic effect on surrounding plants as evidenced by Russian thistle material having no effect on growth of *Agropyron smithii* Rydb. (Schmidt and Reeves 1989).

Russian thistle is a non mycorrhizal species (Schmidt and Reeves 1984). On sites with vesicular arbuscular mycorrhizal (VAM) fungi in the soil, Russian thistle roots were readily invaded by the fungi to the detriment of the plant (Allen and Allen 1988, Allen et al. 1989). VAM hyphae attempted to invade the roots of Russian thistle, but were rejected causing browning and death of root segments. At the seedling stage, the VAM invasion resulted in reduced growth and survival; inoculation in field trials reduced Russian thistle density up to 30%. Halvorson and Guertin (2003) suggested as mycorrhizal fungi build up in the soil following a disturbance, Russian thistle populations decline and the fungi will be available to create associations with compatible species for the next successional stage.

Although Russian thistle is generally an undesirable species, it has nutritional value for domestic animals and wildlife. It is consumed by a number of animals including bison, cattle, elk, deer, prairie dogs, pronghorn, and sheep; the seeds are eaten by birds and small mammals (Howard 1992). Russian thistle contains more protein and carbohydrates than clover (*Trifolium* spp.) (Long 1941), and although not as palatable, it has as much mineral salt and 65% as much protein as alfalfa (*Medicago sativa* L.) (Howard 1992). During prolonged drought periods in the late 1930s, farmers in Canada and the United States harvested Russian thistle for hay and silage when agricultural crops failed (Young 1991, Evans 2002). Due to its efficient use of water, there has been interest in using Russian thistle as a forage crop in semiarid regions (Howard 1992).

2.2 Management and Control

Russian thistle must be managed by preventing seed production and depleting the soil seed bank. The British Columbia Ministry of Agriculture, Food and Fisheries (2002) recommends preventing establishment of new infestations by minimizing disturbance and seed dissemination, eliminating seed production, and maintaining healthy native plant communities.

Numerous attempts to find an effective biological control agent have been unsuccessful. A leaf mining moth (*Coleophora klimeschiella* Toll) and a stem boring moth (*Coleophora parthenica* Meyrick) were approved and released in California but were not effective at reducing Russian thistle populations (California Department of Food and Agriculture 2008). Currently a blister mite (*Aceria salsolae* de Lillo & Sobhian) from the Mediterranean Basin, a stem boring caterpillar, and two weevils are under investigation (Orloff et al. 2008).

The British Columbia Ministry of Agriculture, Food and Fisheries (2002) suggest mowing or pulling young plants can manage Russian thistle, if repeated over several years. Mowing is effective on very young plants; however older plants will recover by axial branching below the cut (California Department of Food and Agriculture 2008). Hand pulling of large plants is difficult and may cause injury from the spines (USDA Forest Service 2006). Loosening the soil during cultural control practices must be avoided because loose soil is necessary for Russian thistle germination and is likely to aggravate the situation (Orloff et al. 2008).

Planting competitive desirable species can prevent Russian thistle establishment in many non-crop environments (Orloff et al. 2008). Reestablishment of native plant species can reduce Russian thistle infestations (Rutledge and McLendon 1996). The British Columbia Ministry of Agriculture, Food and Fisheries (2002) recommends seeding disturbed areas to perennial grass.

In agricultural crop and non-crop areas herbicides can control immature Russian thistle plants to prevent seed production. Pre-emergent herbicides are applied to the soil prior to seed germination; if applied in fall they can provide season long control (California Department of Food and Agriculture 2008). According to Orloff et al. (2008) the most effective pre-emergent herbicides are atrazine (Aatrex), bromacil (Hyvar), chlorsulfuron (Telar), hexazinone (Velpar), imazpyr (Arsenal), napropamide (Devrinol), simazine (Princep), and sulfometuron (Oust). Post-emergent herbicides must be applied directly to plants in early growth stages, preferably early seedling stages before the plant hardens and produces spiny branches (Orloff et al. 2008). Post-emergent herbicides typically do not provide long term control due to repeated flushes of seed germination following application (USDA Forest Service 2006, California Department of Food and Agriculture 2008). Russian thistle is not readily controlled by any post-emergent herbicide once in the spiny stage (Orloff et al. 2008). Effective post-emergent herbicides are dicamba (2,4-D, Banvel, Vanquish), glufosinate (Finale, Liberty, Rely), glyphosate (Roundup), and paraquat (Gramoxone) (Orloff et al. 2008).

Russian thistle is prone to developing herbicide resistance (Brenzil 2004, California Department of Food and Agriculture 2008, Orloff et al. 2008), particularly to Group 2 herbicides (Brenzil 2004, Saskatchewan Ministry of Agriculture 2008) which are inhibitors of the enzyme acetolactate synthase (Hall et al. 1999). Herbicide resistant biotypes of Russian thistle have evolved in only a few years following treatment with chlorsulfuron (Telar) or sulfometuron (Oust) (Orloff et al. 2008). Herbicide resistance has been documented in California, Idaho, Montana, North Dakota, Oregon, Washington (California Department of Food and Agriculture 2008, Saskatchewan Ministry of Agriculture 2008), and Saskatchewan (Brenzil 2004, Saskatchewan Ministry of Agriculture 2008). In Alberta, two populations are resistant to sulfonylureas (Beckie pers. comm.). Repeated use of a single herbicide, or of herbicides with the same mode of action, should be avoided to prevent herbicide resistant populations (Orloff et al. 2008). Using a combination of management strategies and rotating herbicide modes of action will reduce the chances of developing herbicide resistance.

3. STUDY AREA

3.1 Location

The study area is located in Jasper National Park, in west central Alberta in the Rocky Mountains, approximately 350 km west of the city of Edmonton. The Continental Divide makes up the west boundary of the park and is the border between Alberta and British Columbia. Jasper National Park is 10,878 km^2 in size (Parks Canada 2005). The park is comprised of three primary ecoregions, montane, subalpine, and alpine. Of the three ecoregions, the montane ecoregion is the smallest in size but contains the richest diversity of flora and fauna, and provides important winter range for most of the large mammal species in Jasper National Park (Decker and Bradford 2001). A large proportion of human development in the park occurs in the montane ecoregion, including roads, railway, pipelines, and the town of Jasper.

The study area was located in the montane grassland hillsides and valley bottom in the lower Athabasca Valley from 12 Mile Bridge on Highway 16 to Brule Lake near the east gate (Figure 1-1). The area was selected with Parks Canada staff based on presence of Russian thistle and heavy grazing of winter ranges by bighorn sheep (McPhee pers. comm. 2008, Westhaver pers. comm. 2008).

3.2 Climate

Variations in Jasper National Park climate are due to a combination of elevation, rainshadow effect, and latitude. The climate of Jasper National Park is characterized by long cold winters and short cool summers, with occasional hot spells (Parks Canada 2005). The climate of the montane ecoregion is the warmest and driest of the three ecoregions in the park, with the greatest temperature fluctuations (Holland and Coen 1983a). The daily average temperature from the Environment Canada Jasper Weather Station in January is -9.8 °C; the daily average temperature in July is 15 °C. Moisture reserves in the upper soil horizons are often depleted by early July and it is not uncommon to have prolonged periods of soil water stress later in the summer (Stringer 1973). Average annual precipitation at the Environment Canada Jasper Weather Station is 399 mm, with summer precipitation greater than winter precipitation. In winter, warm Pacific air masses raise temperatures and result in the montane ecoregion being intermittently snow free (Holland and Coen 1983a). Holland and Coen (1983a) suggest winds in the montane ecoregion are more frequent and a little stronger than those in other areas because the valleys, such as the Athabasca Valley, are oriented parallel to prevailing westerly winds.

3.3 Landscape, Topography and Soils

The Athabasca River flows northward through the study area, widening and slowing to create Jasper Lake and again directly outside of the park to create Brule Lake. Both lakes are very shallow, and large portions are seasonally dry, revealing sandy lake bottoms during periods of low flow. Strong winds mobilize sand and silt from the exposed lake bed and deposit it in the surrounding area. Dune formations are located along both Jasper Lake and Brule Lake.

In the study area the Athabasca Valley is oriented in a northeast direction with large open grasslands located along hillsides on the west side of the valley, particularly from Windy Point at the base of Roche de Smet to Benson Ridge at the east edge of the park. On the east side of the valley open grasslands are located primarily on south facing slopes in areas such as Cinquefoil Mountain, Syncline Ridge, and Edna's Knoll.

In the Athabasca Valley, studies were focused in two specific ecosections, the Devona (DV) Ecosection and the Talbot (TA) Ecosection. In the Jasper Lake area, Russian thistle was primarily associated with DV1 Ecosites and TA2 Ecosites (Figure 1-2). The following ecosite information was derived from the Ecological (Biophysical) Land Classification of Banff and Jasper National Parks (Holland and Coen 1983b).

The DV1 Ecosite occurs on the Athabasca Valley floor, adjacent to Jasper Lake. It is associated with ridged dune landforms (maximum depth 25 m) of calcareous, medium textured eolian material. Soils are rapidly drained, extremely calcareous Orthic Regosols. Wind erosion and deposition is ongoing. Soil texture is very fine sandy loam to silt loam.

The TA2 Ecosite occurs on lower slopes of the Athabasca Valley from Jacques Creek to Jasper's east gate. The ecosite is typified by veneers of calcareous, medium textured eolian materials overlaying morainal till and bedrock. Eolian deposits are a result of strong winds transporting material from the Athabasca River floodplain and shores of Jasper Lake. As a result of the deposition of wind blown material, soils associated with this ecosite are rapidly to well drained, extremely calcareous Orthic and Cumulic Regosols. In localized protected areas, Orthic Eutric Bunisols may occur in minor amounts.

3.4 Vegetation

The montane ecoregion in the study area is characterized by three vegetation communities: closed forest communities dominated by Douglas fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and white spruce (*Picea glauca* (Moench) Voss); deciduous forest occurring on fluvial fans, terraces and floodplains; and open grasslands occurring on dry exposed slopes (TeraWestland 2005). This study focuses primarily on vegetation and site conditions associated with open grassland communities.

In the DV1 Ecosite, vegetation on drier sites on exposed dunes is dominated by creeping juniper (*Juniperus horizontalis* Moench), northern wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn), and rush like sedge (*Carex scirpoidea* Michx.) (L6 vegetation type). Thickets of white spruce are found in moist depressions (Holland and Coen 1983b). Occasionally, communities of june grass (*Koeleria macarantha* (Ledeb.) J.a. Schultes), fringed sage (*Artemisia frigida* Willd.), and wild blue flax (*Linum lewisii* Pursh) (H6 vegetation type) are found.

The TA2 Ecosite encompasses the majority of grassland in the valley. It is dominated by june grass, fringed sage, and wild blue flax (H6 vegetation type); and shrubby cinquefoil (*Dasiphora floribunda* (Pursh) Kartesz, comb. nov. ined.), bearberry (*Arctostaphylos uva-ursi* (L.) Spreng), and northern bedstraw (*Galium boreale* L.) (L1 vegetation type) (Holland and Coen 1983b). The H6 vegetation type occurs mainly on south and east facing erosional scarps between Jasper Lake and Jasper's east gate (Holland and Coen 1983b). The L1 vegetation type is typical of steep south exposures. Although limited in presence, gullies and northerly aspects are characterized by white spruce, juniper, and bearberry (O17 vegetation type).

According to the range plant community types for the montane subregion of Alberta (Willoughby et al. 2005) the climax community associated with south facing slopes in the study area is a fringed sage / june grass (A1) community type. The prominent species in this community (june grass, northern wheatgrass, fringed sage, pussy toes (*Antennaria* spp.), and bearberry) are typical of xerophytic and Mixed Prairie type grasslands throughout Western Canada (Willoughby et. al 2005). Grazing likley had a strong role in the development of this community type. Without heavy wildlife grazing, plains reed grass (*Calamagrostis montanensis* Scribn.) and northern wheatgrass would likely increase and fringed sage and june grass would decrease (Stringer 1973).

Tannas (1997) found that rangelands in the Athabasca Valley were unique in that they did not include expected climax species (*Festuca altaica* Trin. or *Festuca campestris* Rydb.) found in similar sites in the montane subregion outside the Park. Tannas suggested this may be due to extreme grazing pressure over an extended period of time prior to 1956. Historically, the area was used for winter grazing for large numbers of horses. Pfeiffer (1948) found that all the ranges were over utilized, mainly by elk and horses, resulting in retrogressive succession and making the ranges increasingly unproductive. Previous climax species may have been grazed to a point of elimination (Tannas 1997).

3.5 Wildlife

The lower portion of the Athabasca Valley (Jasper town site to Jasper east gate) is important to ungulates and their predators, waterfowl, and many bird species (Holroyd and Tieghem 1983). Due to low precipitation and strong winds, the open slopes provide important winter range habitat for grazing ungulates. Holroyd and Tieghem (1983) believed that the lower Athabasca Valley provides one of the most important areas for elk, bighorn sheep, deer, and possibly moose (*Alces alces* (Linnaeus, 1758)) in Jasper and Banff.

Bighorn sheep spend summers in the mountains at high elevations, moving to low elevations in the Athabasca Valley in winter. Almost half the Park's bighorn sheep population overwinters on six ranges in the lower Athabasca Valley (Stelfox 1976). Winter ranges for bighorn sheep generally occur on steep slopes with escape terrain to avoid predators. The sites are often exposed to strong winds preventing snow accumulation from burying forage. Census data indicate sheep populations on Snaring-Windy and Colin-Jacques winter ranges varied from 369 sheep in 1966, 520 in 1982, and 331 in 1987 (Bradford 1987). Sheep observations on ecosites in the lower Athabasca Valley conducted in 1978 and 1979 showed highest numbers of sheep on the TA2 Ecosite (Holroyd and Tieghem 1983). Detailed wildlife observations from 1981 to 2001 showed fluctuations in ram numbers between 11 and 23 at the Ram Pasture winter range on Devona Hill, and band sizes of ewes and lambs between 21 and 77 at the Snake-Indian Canyon winter range (Decker and Bradford 2001).

Widespread hunting in the 1800s extirpated elk from what is now Jasper National Park (Decker et al. 1985). Approximately 90 elk from Yellowstone National Park were reintroduced in 1920 and their numbers multiplied to where they had serious impact on winter range health (Beschta and Ripple 2007). Elk herds were thinned by more than 2200 animals between 1942 and 1970 (Beschta and Ripple 2007); there are now approximately 1000 elk in the Park (Beschta and Ripple 2007). Elk winter throughout the lower Athabasca Valley. Important winter range includes slopes and flats between Windy Point and Moosehorn Creek, and the river floodplain and dunes from Edna Lake to Jasper east gate (Holroyd and Tieghem 1983).

Mule deer and white-tailed deer are found in the Athabasca Valley. Major wintering areas for mule deer include the south and east facing lower slopes from the Jasper town site down the valley to the east gate (Holroyd and Tieghem 1983). The Canadian National Railway transects almost the entire length of the most important winter and spring mule deer habitat in Jasper, with deer mortality seven times greater than that along the Canadian Pacific Railway in Banff (Holroyd and Tieghem 1983). White-tailed deer are most common downstream of Jasper Lake, but can be found in the valley up to the Jasper townsite (Holroyd and Tieghem 1983).

4. GENERAL RESEARCH OBJECTIVES

Russian thistle is a non native invasive species of high priority in Jasper National Park. Large areas of infestation can be found at low elevations throughout the lower Athabasca Valley. Russian thistle has invaded areas of native montane grassland in the valley important for winter survival of bighorn sheep. Although the ecological integrity of these unique areas has been compromised by the spread of Russian thistle, the presence of Russian thistle may be a symptom of poor range health caused be intensive winter grazing.

The goal of this research is to provide improved understanding of the biology and ecology of Russian thistle and its control in the montane grasslands of Jasper National Park. The research objectives are as follows.

- To contribute to the knowledge of Russian thistle biology specific to Jasper National Park including movement during wind dispersal, seed production, germination and growth response to soil texture, litter depth, and climate.
- To assess the effect of wildlife grazing on Russian thistle establishment, spread, and persistence.
- To determine the effectiveness of integrated weed management techniques in controlling Russian thistle.

In Chapter II the biology of Russian thistle in the lower Athabasca valley of Jasper National Park is examined. This study provides an indication of the size of infestation in the study area and the movement of Russian thistle in the valley during winter of 2008-2009. Seed production based on plant size was determined along with seed germination and viability rates. To investigate the role of litter in Russian thistle germination and establishment, Russian thistle was grown in the greenhouse under various litter depths. In a separate study Russian thistle was grown in the greenhouse in different soil textures, including two soil types from the study area, to investigate influence of soil texture on plant growth. In growth chambers, plants were grown at current and predicted 2050 summer temperatures to examine possible growth trends in Russian thistle related to future temperatures.

In Chapter III the effect of wildlife grazing on Russian thistle establishment, spread and persistence is examined. Range health and grazing pressure at four winter range sites infested with Russian thistle in the study area were examined through the use of provincial grassland health assessments, pellet count transects, and paired biomass clipping plots. The effectiveness of six integrated weed management techniques for controlling Russian thistle were compared to controls at four study sites.

Chapter IV covers overall research results and how they relate to future management strategies for controlling Russian thistle. Future research needs related to the control of Russian thistle and the health of bighorn sheep winter ranges in the lower Athabasca valley in Jasper National Park are provided.

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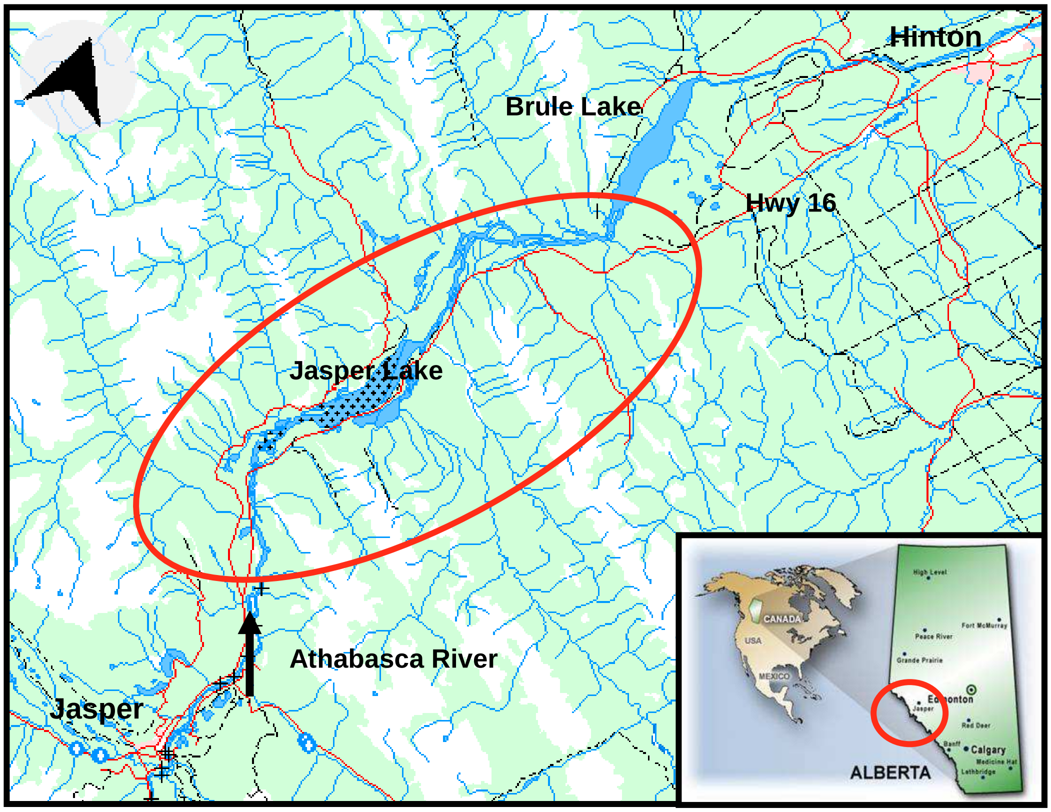

Figure 1-1. Overview map of the study area in Jasper National Park.

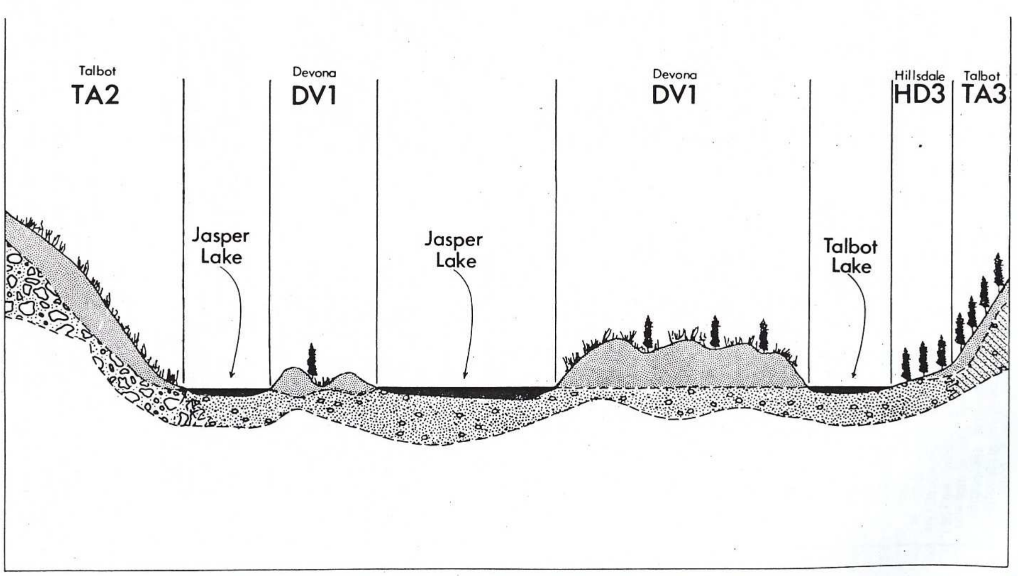

Figure 1-2. Diagram depicting the location of DV1 and TA2 Ecosites in the Athabasca River valley (Holland and Coen 1983b).

CHAPTER II. RUSSIAN THISTLE (*SALSOLA TRAGUS* L.) POPULATION BIOLOGY IN THE LOWER ATHABASCA VALLEY OF JASPER NATIONAL PARK, ALBERTA, CANADA

1. INTRODUCTION

Most research on Russian thistle (*Salsola tragus* L.) has been from an agronomic perspective. Russian thistle in natural areas has had limited study in arid to semi arid regions of the United States but none in Canada. Although a small number of isolated populations exist further north, the Russian thistle population in Jasper National Park is near the northern extent of its range in North America. In Jasper National Park, Russian thistle is common on dry exposed or disturbed sites in the lower Athabasca Valley. It has been documented in the Park, near Windy Point, as early as 1946 (Pfeiffer 1948). In 1980, it was considered common on open sand dune ridges in the Jasper Lake area (Sharp). By 1993 Russian thistle within open southeast facing slopes adjacent to Jasper Lake had diminished the value of these grasslands for wildlife (Biota Consultants 1993). By the early 1990s the Jasper Warden Service considered it a serious concern due to its ability to invade and dominate overgrazed rangeland (Weerstra and Weerstra 2007). Russian thistle currently inhabits two distinct natural habitat types in the study area, natural disturbance areas, such as sand dunes and actively eroding river banks, and native montane grassland. Russian thistle plants found on sand dunes and banks were much larger than those in native grasslands.

Russian thistle is well adapted to hot dry conditions and can develop a deep widely branched taproot 1 m or more in length (British Columbia Ministry of Agriculture, Food and Fisheries 2002). Mature plants are 0.1 to 1.3 m in height (Morisawa 1999, British Columbia Ministry of Agriculture, Food and Fisheries 2002) and are rounded and bushy with numerous slender ascending stems (Orloff et al. 2008). In late fall and early winter, the base of the stem becomes brittle and breaks off at ground level (Orloff et al. 2008) allowing the plant to tumble in the wind, hence the name tumbleweed. A specialized layer of cells in the stem allows the plant to break cleanly away from the roots; destruction of these cells coincides with seed maturity (Young 1991). The plant disperses seeds as it rolls along the ground, with a single plant producing up to 200,000 seeds (Young and Evans 1972). New infestations commonly appear as a trail of seedlings across fields (USDA Forest Service 2006).

Stallings et al. (1995) published one of the few papers on Russian thistle movement. When Russian thistle was placed in wheat fields in Washington State, the maximum distance of travel over a six week period was 4069 m, and the average seed release from plants was 66%. There have been no studies of *in-situ* Russian thistle movement in natural areas.

Russian thistle is adapted to disturbed soils and often associated with well drained alkaline or sandy areas on clay loam or sandy soils (Crompton and Bassett 1995). The seed contains no endosperm, but is comprised of a spirally coiled, fully differentiated seedling with active chloroplasts in the cotyledons (Crompton and Bassett 1995, Young et al. 1995). By uncoiling, the seedling is able to push its radical into the soil. Russian thistle germinates well on loose moist soil, but on compacted soil the seedlings are unable to push the radical into the soil and eventually die of dehydration (Wallace et al. 1968). For the seedling to survive, the seed must be covered by soil, or be in a position where it can exert enough pressure to force the radical and part of the stem into the soil (Wallace et al. 1968). Emergence is optimal at seed depths less than 2.5 cm, however if conditions are favourable seedlings can emerge from soil depths of up to 7 cm (Young et al. 1995).

Plant litter is important in rangelands. It can moderate temperature and water content at the soil surface, creating favourable microsites for germination and establishment of annual weeds (Evan and Young 1970). There have been few published papers on the role of litter on Russian thistle germination and establishment. Evan and Young (1972) found that 1 cm of litter cover improved seed germination compared to bare soil, and that if watered to field capacity the number of established seedlings were similar whether seeds were buried, placed on the soil surface and covered with litter, or placed on top of a litter layer.

Russian thistle is adapted to arid conditions, being one of the world's most efficient plants at creating biomass per unit of water (Young 1991). Wiese and

Vandiver (1970) found that Russian thistle produced twice as much biomass under dry soil conditions as under wet soil conditions. Russian thistle has a C_4 metabolic pathway, allowing for greater efficiency in CO_2 utilization and prevention of moisture loss than in C_3 species (Crompton and Basett 1984). Features of the C_4 pathway allow Russian thistle to be more competitive under hot dry conditions; however under cool conditions the C_4 attributes become less advantageous and plants often cannot compete with C_3 species (Brenzil 2004).

Emphasis has recently been placed on how climate change relates to ecological range of invasive species. Invasive plant species currently alter composition, structure, and function of ecosystems. Climate change is predicted to favour invasive species by altering seasonal temperature patterns and amount and seasonal distribution of precipitation (Tausch 2008). The range of many invasive plants is expected to expand into higher latitudes and elevations (Patterson 1995, Tausch 2008). Russian thistle thus has potential to take advantage of changing conditions and stressed native communities (Parry and Swaminathan 1992).

To better articulate current and potential impacts of Russian thistle in Jasper National Park, its biology must be better understood. Little is known of its seed production potential, movement during winter dispersal, how soil type influences germination and establishment, the role of litter depth in establishment, response to annual weather variability, and invasion of native montane grassland in the valley important for the winter survival of bighorn sheep (*Ovis canadensis* Shaw).

2 RESEARCH OBJECTIVES AND HYPOTHESES

The goal of this research is to provide an improved understanding of the biology of Russian thistle in Jasper National Park. Research objectives are as follows.

- To determine Russian thistle seed production.
- To determine Russian thistle movement during wind dispersal.
- To determine Russian thistle germination and growth response to soil texture.
- To determine the role of litter in regulating germination and establishment of Russian thistle and if there is a critical litter depth to restrict Russian thistle establishment.
- To determine how Russian thistle responds to temperature and soil water.

A number of hypotheses were made regarding Russian thistle in the lower Athabasca Valley.

- Infestation of large healthy plants along the banks of the Athabasca River and shores of Jasper Lake migrate from the valley bottom to provide seed sources for grassland infestations.
- Small Russian thistle plants on grassland sites produce enough viable seed for localized populations to persist.
- Soil textures between sand dune and grassland areas are too similar to yield a difference in germination and growth.
- Intensive winter grazing removes litter, allowing Russian thistle to establish on grassland sites.
- Increased litter cover will limit Russian thistle establishment.
- Hot summer temperatures and low precipitation may result in increased growth of Russian thistle.

3. MATERIALS AND METHODS

3.1 Extent of Infestation

A site reconnaissance survey was conducted 5 to 9 May 2008, in the lower Athabasca valley to quantify the extent of Russian thistle invasion and locate potential research sites. The survey was conducted, where access permitted, in montane grasslands from the east park boundary to the 12 Mile Bridge crossing of the Athabasca River on Highway 16. Locations of known Russian thistle sites provided by Parks Canada staff were used as a starting point. The location of each encountered Russian thistle infestation was recorded in UTMs (Datum: NAD 83) by a handheld Garmin 96 Global Positioning System (GPS) unit. At each site, observations were made on the distribution, evenness and density of Russian thistle and grazing intensity. General site conditions (slope, aspect, soil texture) and plant species composition were recorded. Photographs were taken of each site to document physical site conditions and Russian thistle infestation.

Due to the early season of the reconnaissance, Russian thistle germination had not yet occurred. Sites were located by searching for Russian thistle litter and locating areas where dead plants were still attached to the soil. Surveys were conducted throughout summer 2008 to confirm the size of sites found in May and to investigate other areas that were not documented during the reconnaissance.

3.2 Russian Thistle Movement and Seed Germination After Winter

To better understand Russian thistle dispersal patterns specific to the study area, movement of individual plants was examined during the winter of 2008-2009. Between 19 and 22 September 2008, 144 naturally growing Russian thistle plants were tagged along the Athabasca River downstream of 12 Mile Bridge and surrounding Jasper Lake. Selected plants were from various habitats, falling within the upper 25% of height range for plants in their respective area; 38 were in grasslands and 106 were in natural disturbance areas such as sand dunes and river banks. The UTM location of each selected plant was determined using a handheld Garmin Etrex GPS unit. For each plant, height was measured, a waypoint number embossed on a 20 x 20 mm aluminum tag was fastened to the stem at the plant center with small gauge wire, and florescent pink flagging tape marked with the waypoint number was tied to the stem. Care was taken to avoid shattering or release of seeds. To limit possible disruption in the natural movement of the marked Russian thistle, flagging tape length was proportional to individual plant size; large plants had longer flagging tape than small plants.

Extensive searches to relocate tagged plants were conducted 2 and 3 May and 11 to 14 May 2009 with two to five people. The search started from the original tagged locations and expanded outward. Searchers looked for tagged plants in open areas and along forest edges and other natural features that would halt plant movement. Search distance was dependant on openness of the area and potential distance the plant could move. Searches were performed around the perimeter of Jasper Lake and grassland areas where plants, although not originally tagged, had the potential to move from other locations in the valley. Location of each relocated plant was recorded in UTMs by a handheld Garmin Etrex GPS unit and physical condition of the plant noted. Metal tags and flagging tape from relocated plants were removed and collected for disposal. By comparing the starting point to the end point of individual plants, straight line distances of movement and direction of travel over winter were determined.

A linear regression was performed in SigmaPlot 11 (Systat Software Inc. 2008) to examine a possible relationship between plant height and distance traveled. A p-value of 0.05 and a coefficient of determination (R^2) of 0.95 were used to verify the existence of a significant relationship.

Thirty-nine tagged plants were relocated and collected, placed in plastic bags, and transported to the laboratory to determine seeds remaining on the plants after winter dispersal. Number of seeds remaining on each plant was counted. Percent over winter seed loss per plant was based on a regression equation related to plant height and seed number, determined during the seed production study (Section 3.3). These seeds were placed on moist paper towel in a Petri dish near an east facing window and allowed to germinate over a ten day period.

3.3 Russian Thistle Seed Production

Fifty Russian thistle plants were collected between 19 and 22 September 2008 from natural disturbance areas, such as sand dunes, and from grassland sites. A UTM waypoint was taken at each plant location with a hand held Garmin Etrex GPS unit. Seeds were used for greenhouse experiments during winter 2008-2009. Complete mature plants of a range of sizes were collected; plants < 15 cm were stored in open paper bags, plants > 15 cm were stored in cotton bags.

Plants were stored and dried in an unheated shed at the University of Alberta Ellerslie Research Station until December 2008. After drying, plant height and width were measured and biovolume estimated based on the volume of a cone. To remove seeds, a 3.8 cm diameter rubber stopper was placed in a cotton bag with a plant and vigourously shaken to cause shattering of seeds from the plant. Remaining seeds were removed by rubbing the stopper across the plant, or plant pieces, on an upside down 4 mm soil sieve. Seeds were collected from the bag and sieve for counting. For plants < 15 cm in height, seeds were removed from the chaff and counted. Due to difficulties in separating the light Russian thistle seed from the chaff for larger plants with abundant seeds an indirect method was used to determine seeds per plant. A sample of approximately 1.0 g was taken from the well mixed chaff and seed and weighed to three decimals with an Ohaus Adventurer SL AS313 digital scale, then seeds were removed from the chaff and counted. The remainder of the original sample was weighed in grams to three decimals. Using number of seeds and weight of the sample, total number of seeds per plant was estimated.

Number of seeds per plant was compared to plant height and biovolume to determine a possible mathematical relationship using a Mann-Whitney Rank Sum Test. Finally, plant height, biovolume, and seed production were compared among plants from disturbed habitats and grassland areas.

3.4 Russian Thistle Seed Viability and Germination

In January 2009 viability and germination of Russian thistle seeds were determined. For viability and germination tests, 100 seeds were selected from a composite sample collected from approximately 20 plants from a variety of habitats and a diversity of plant heights. Only large seeds with a well developed winged pericarp were selected.

Viability was examined using standard tetrazolium testing procedures outlined in the Association of Official Seed Analysts Tetrazolium Testing Handbook (Peters 2000). In each of ten petri dishes, ten seeds were placed on paper towel moistened with deionized water and allowed to imbibe for 24 hours. Once softened the winged pericarp from each seed was removed. Seeds were immersed in a 1% solution of 2,3,5-triphenyl tetrazolium chloride and distilled water solution and placed in an unlit Quincy Lab Model 21-250 oven at 30 ℃ for 24 hours. After drying, each seed was bisected using a dissecting scalpel and inspected for red staining of living tissue, an indication of respiration (Vankus 1997, Oregon State University 2002). Seeds with evidence of respiration were counted. Embryo viability was determined based on degree and pattern of staining as described in the Tetrazolium Testing Handbook (Peters 2000).

For germination tests, in each of ten petri dishes, ten seeds were placed on paper towel moistened with deionized water. Petri dishes were placed in front of an east facing window and monitored for ten days. Deionized water was added when the paper towel showed signs of dryness. The number of seeds that germinated in each petri dish was counted.

3.5 Russian Thistle Response to Greenhouse Litter Depth

The role of litter in Russian thistle germination, emergence, timing of emergence, and growth was examined. The study consisted of six treatments; four treatments with litter placement rates of 1000, 3000, 4000, and 5000 kg/ha on top of Russian thistle seeds; one treatment with seeds placed on top of 4000 kg/ha of litter; and a control treatment without litter. Each treatment was replicated ten times. The experiment was carried out using 10.2 x 15.2 cm plastic potting trays. Ten bedding trays, each with six randomly located potting trays, were placed on a single greenhouse bench in the University of Alberta greenhouse.

Each potting tray was evenly filled to a depth of approximately 4 cm with sandy loam textured topsoil collected from the study area in Jasper National Park. Soil was sieved through a 4 mm screen to provide a uniform growing medium. Ten large Russian thistle seeds from a single plant, with well developed winged pericarps, were evenly spaced in each tray. For treatments requiring seed soil contact, seeds were placed directly on the soil surface, dorsal side up. For the treatment requiring seed placement on litter, seeds were evenly spaced and placed dorsal side up on the litter surface.

Litter was collected 21 September 2008, from a grassland area near Devona Hill. Litter was hand raked from an area with thick accumulation and placed in a large plastic bag. Litter was collected from an area dominated by northern wheatgrass (*Agropyron dasystachyum* Hook. (Scribn.)), june grass (*Koeleria macrantha* (Ledeb.) J.A. Shultes f.), needle and thread grass (*Stipa comata* Trin. and Rupr.), and wild blue flax (*Linum lewisii* Prush). Russian thistle was absent from the area. The litter was damp due to rain at collection. Litter was brought to the Ellerslie Research Station, removed from the plastic bag, and air dried for two weeks in a large shed. Prior to the start of the greenhouse study the litter was dried in a Quincy Lab Model 21-250 oven at 155 ℃ f or 24 hours.

Based on area of the trays, litter application rate was converted from kg/ha to g/tray. Dried litter was weighed to two decimal places using a Mettler PC2000 scale then placed between two gardening trays and compressed to form a mat of litter similar to what would occur under natural field conditions. The compressed litter was then placed in the respective treatment tray.

The study ran for 34 days from 13 March to 16 April 2009 in a greenhouse with a temperature of 23 ℃ and a 16 hour photoperiod. An alcohol soil thermometer was used to measure soil temperature. Each tray was watered to saturation every third day. Timing of germination and developmental stage of each plant in each tray was recorded. Categories of plant development were based primarily on leaf number: germination, emergence, two leaf stage, four leaf stage, six leaf stage, and eight leaf stage. Germination was considered any protrusion of the radical from the pericarp. Cotyledons had to be free of the pericarp to be counted as emerged. Cotyledons were not counted as leaves, for example a plant in two leaf stage would have two leaves and two cotyledons. Leaves had to be over 1 mm in length to be counted. At the end of study, plant heights were measured from the soil surface to the apex meristem, and to the tip of the longest leaf when stretched vertically. On each plant live leaves (including cotyledons) were counted and longest leaf length measured. A five point ranking system was used to indicate plant vigour based on average health as follows.

- 1: very poor health; plants moribund or dead.
- 2: poor health; plants chlorotic, diminished stature.
- 3: moderate health; average growth, limited chlorosis.
- 4: healthy; above average growth and leaf development, dark green foliage, no chlorosis.
- 5: very healthy; above average growth, dark green foliage, long succulent leaves, advanced leaf development, multiple stem branching.

The Shapiro-Wilks test for normality and Levene's test for equality of variance were performed on the residuals in SAS 9.1 (SAS Institute Inc. 2002-2003). In most cases the dependant data did not meet either, or both, requirements for normality and homoscedasticity. The Box-Cox Transformation procedure in SAS was used to select the most appropriate equation to transform data. In most cases transformed data did not alter interpretation of results or complicated interpretation and presentation of results (Norman and Steiner 2000). Thus untransformed data were used in a one-way Analysis of Variance ANOVA using the Proc Mixed model in SAS with a Tukey post hoc pairwise multiple comparison procedure to determine differences in survival of Russian thistle among treatments. Data on plant height, maximum leaf length, leaf number, and number of germinants data were nonparametric. A Friedman's test using

Cochran-Mantel-Haenszel statistics (based on rank scores) was performed in SAS to determine if there was a difference in dependant variables among treatments. If a difference was detected, a post hoc pairwise multiple comparison procedure was performed using a Dunn's test on the ranks. A p-value of 0.05 was used to determine significant differences among treatments.

3.6 Russian Thistle Response to Soil Texture

A study was conducted for 44 days from 16 March to 29 April 2009 in the University of Alberta greenhouses to evaluate germination and growth of Russian thistle on five soil types. Two soils from Jasper National Park in which Russian thistle is commonly found were used; a loamy sand Devona soil and a fine sandy Jasper Lake soil. Other soil types were clay, coarse sand, and a potting mix. Five 10.2 x 15.2 cm plastic potting trays representing each treatment were randomly ordered in seven larger bedding trays and placed on a single greenhouse bench.

Each potting tray was evenly filled with 500 ml of soil to a depth of approximately 40 mm. Ten Russian thistle seeds with large well developed winged pericarps were evenly spaced in each tray. Seeds were selected from a well mixed composite sample from multiple plants. Seeds were placed directly on the soil surface, dorsal side up, and covered with 5 mm of soil.

The greenhouse was programmed to a temperature of 23 ℃ with a 16 hour photoperiod. All trays were watered to saturation every second day. Timing of germination and developmental stage of each plant was recorded. Categories of plant development were based primarily on leaf number: germination, emergence, two leaf stage, four leaf stage, six leaf stage, and eight leaf stage. Germination was considered any protrusion of the radical from the pericarp. Cotyledons had to be free of the pericarp for a plant to be counted as emerged. Cotyledons were not counted as leaves, for example a plant in the two leaf stage would have two leaves and two cotyledons. Leaves had to be over 1 mm in length to be counted. At the end of this study plant heights were measured from the soil surface to the apex meristem. Longest leaf length on each plant was measured. The five point ranking system used in the litter study was used as an indicator of plant health.

Soils were analyzed by a commercial analytical laboratory, ALS Canada Limited in Saskatoon, Saskatchewan. Available nitrate was determined by the calcium chloride method (Carter 1993). Available potassium and phosphate were determined using a modified Kelowna extraction (Qian et al. 1994).

Data were tested to determine requirements for a one way Analysis of Variance (ANOVA). The Shapiro-Wilks test for normality and Levene's test for equality of variance were performed on residuals in SAS. In all cases dependant variable data did not meet requirements for normality and homoscedasticity. The Box-Cox Transformation procedure in SAS was used to select the most appropriate equation to transform data. In most cases transformed data did not alter results interpretation, or complicated results interpretation and presentation (Norman and Steiner 2000). All untransformed nonparametric data were used in the analysis.

Non normality is a common occurrence in biological data, where normally distributed data are considered an exception (Biondini et al. 1988, Potvin and Roff 1993). Potvin and Roff (1993) maintain that nonparametric statistical methods of analysis are better able to buffer against distortion in significance testing due to non normality, and are only slightly less powerful than traditional parametric methods. A Friedman's test using Cochran-Mantel-Haenszel statistics (based on rank scores) was performed in SAS to determine if there was a difference in the dependant variable among treatments. If a difference was detected, a post hoc pairwise multiple comparison procedure was performed using a Dunn's test on the ranks. A p-value of 0.05 was used to determine significant effect among treatments.

3.7 Russian Thistle Response to Temperature and Soil Water

A growth chamber study was designed to determine the role seasonal temperature and moisture variations have on Russian thistle and how this may relate to predicted climate change where global warming is hypothesized to benefit Russian thistle. Using the climate modeling software ClimateAB v3.21 (Mbogga et al. 2008), temperature and precipitation data from 1961 to 1990 specific to the Jasper Lake area were obtained. Output from the program provided mean monthly temperatures, mean maximum monthly temperatures, mean minimum temperatures, and mean monthly precipitation. The third generation Hadley Climate Model (HADCM3) was selected because it provided a worst case scenario where conditions would be considerably hotter and drier than historically. The year 2050 was selected, as it provided enough time for sufficient changes in predicted temperature and precipitation.

An Enconaire GRB-168 growth chamber, with day temperature at 22 ^{o}C and night temperature at 8 ^{o}C was used to simulate historic climate conditions (1961 to 1990). A Conviron CMP3244 growth chamber, with day temperature at 28 ^{o}C and night temperature at 11 ^{o}C was used to study predicted 2050 climate conditions. Chambers were set for mean maximum July temperature for a 16 hour photoperiod followed by a drop to mean minimum July temperature for 8 hours. Three HOBO H8 data loggers were used to record temperature and relative humidity, at 10 minute intervals in each chamber. To accurately record ambient temperature, data loggers were shielded from direct light. A LI-COR Li188 Integrating Quantum/Radiometer/Photometer was used to record light levels in photosynthetic photon flux density. Light at bench level in the two chambers was equalized to 70 µEm-2 sec^{-1} by placing a light weight shade cloth over the lighting unit in the Conviron chamber and lowering the lighting bank in the Enconaire chamber to approximately 1.25 m above the bench surface.

In each growth chamber, 45 plants were grown in 5.1 x 5.7 cm containers. The sandy loam textured soil was collected from a single source in Jasper National Park, representative of soil found throughout the montane grassland area in the Athabasca Valley. Soil was sieved through a 1.18 mm screen for uniform consistency, then 125 g placed in each container.

Due to difficulties achieving consistent germination of Russian thistle seeds in the growth chamber during pre study activities, seeds were germinated in the greenhouse. Seeds were large with well developed winged pericarps, collected from a single plant. Three seeds were placed in each container, directly on the soil surface, dorsal side up, and covered with 5 mm of soil. Containers were watered to saturation every second day. The first plant to emerge in each container was retained; all other emergents were removed. After ten days, each container had one emergent.

Of the 45 plants in each chamber, 15 were watered at field capacity (28 ml), 15 at 25% field capacity (21 ml), and 15 at 50% field capacity (14 ml). Field capacity was determined prior to the study. Dry soil was placed in eight, 7.5 cm diameter, uhland core sleeves. Sleeve bottoms were covered with cheese cloth to promote free draining. Soil dry weight was compared to soil weight 24 and 48 hours after saturation. Volume of water per gram of soil after 24 hours was used to determine amount of water needed to reach field capacity in the containers.

Plants were moved from the greenhouse and placed in growth chambers on 21 February 2009. Plants were watered with tap water according to the specific treatments using a graduated cylinder every second day for 52 days. At the end of the study plant height to the apex meristem and root length were measured, and leaves counted. Soil from each container was placed in a sieve with a 3 mm mesh and rinsed with water to expose the roots, which were placed on a ruler and held straight for measurement. Due to the fine delicate nature of the roots it was difficult to avoid root breakage during extraction, washing, and measuring.

The growth chamber study followed a simple split-plot design. Data were analyzed using a two-way ANOVA in SigmaPlot 11 (Systat Software Inc. 2008). SigmaPlot tested data for normality using the Kolmogorov-Smirnov test. The program tests for homoscedasticity by examining the variability around group means (Systat Software Inc. 2008). A p-value of 0.05 was used to determine significance between treatments.

4. RESULTS AND DISCUSSION

4.1 Extent of Infestation

During summer 2008, 42 Russian thistle sites were identified in the lower Athabasca Valley between Mile 12 Bridge and the east park boundary. Sites included long continuous bands of thistle along sections of the Athabasca River and Jasper Lake to small isolated self perpetuating populations less than 5 m x 5 m in size. Using Google Earth Pro (Google Inc. 2009) and field GPS waypoints, the area infested with Russian thistle was estimated at 73.3 ha for the general study area.

Infestation density varied with site conditions and available habitat. Russian thistle generally occurred in areas with exposed soils from natural or anthropogenic disturbances. It was common along sandy eroding banks of the Athabasca River, sand dune areas, and Jasper Lake shore line (Plate 2-1). It was found upstream of the study area and downstream of the east park boundary near Brule lake. It was common in heavily grazed bighorn sheep winter ranges near the Athabasca River or Jasper Lake such as Bedson Ridge, Disaster Point, Edna's Knoll, Devona Hill, Little Windy Point, and Windy Point (Plate 2-2). It was often found at sites where sheep bedded and wore away the soil to create vertical walls on the upslope side which were used for rubbing off winter coats (Geist 1971). Less heavily used grasslands or those with physical landscape features such as wetlands or forest buffers that could intercept Russian thistle migration from the Athabasca River or Jasper Lake were not usually infested. Isolated pockets were found along, or in close proximity to, linear anthropogenic disturbances such as the ATCO natural gas line, Canadian National rail line, Highway 16, and Celestine Road.

4.2 Russian Thistle Size and Seed Production

The fifty Russian thistle plants collected in fall 2008 ranged in height from 3 to 50 cm, and in biovolume from 1.3 to 8,332.3 cm^3 (Table 2-1). Seed production per plant varied from two seeds on the smallest plant to approximately 7,330 seeds on a 45.9 cm plant. Seed production increased exponentially ($y = 4.0464e^{0.1523x}$) with plant height ($R^2 = 0.80$). The relationship between seed production and plant biovolume was positive linear ($y = 0.839x + 24.204$) ($R^2 = 0.83$). Plant seed number variability increased with plant size, reducing the strength of the relationships between seed production, plant height, and plant biovolume.

Habitat played a large role in size and seed production of Russian thistle. Russian thistle in native grasslands were smaller with fewer seeds than those growing along naturally disturbed areas such as the Athabasca River banks or sand dunes (Table 2-1). Of the 50 plants collected for seed yield, 31 were from areas with little disturbance in native grasslands. Grassland plants averaged 9.1 cm tall with 37 seeds per plant. With the exception of two plants collected from a road side near Devona cabin, the remaining 19 plants were from areas characterized by natural disturbances along sand dunes subjected to continual wind erosion, and steep sandy banks along the Athabasca River unravelling due to gravity and wind erosion. Plants from disturbed areas averaged 29.1 cm in height with 1,562 seeds per plant. Russian thistle from disturbed habitats had significantly greater (P = <0.001) plant height, biovolume, and seeds than plants from grassland areas. Seed viability determined from tetrazolium testing was 97%, and germination was 84%.

Russian thistle seed production in Jasper National Park was approximately 4% of plants in the United States which produced up to 200,000 seeds per plant (Young and Evans 1972). Stallings et al. (1995) reported 66,000 seeds per plant in Washington State. Lower seed production is likely related to smaller plant size in less favourable conditions at this northern latitude. Plants along the Athabasca River and Jasper Lake were larger (Plate 2-3) than those in native grasslands (Plate 2-4). Russian thistle is a poor competitor (Young 1991, Rutledge and McLendon 1996), which may explain why Russian thistle in grasslands are so much smaller than those on open dunes with no surrounding plants. Russian thistle growth and survival is also reduced when roots are invaded by VAM fungi (Allen and Allen 1989). Although not investigated during this study, higher VAM fungi associated with perennial grasses in grassland habitats may help explain the poorer performance of Russian thistle in these areas.

4.3 Russian Thistle Movement

In spring 2009, 88 of the 144 (61%) tagged plants were located, 6.7% of which remained rooted in the ground. Travel distances ranged from 1.4 to 4,180.5 m, with the median 12.8 m, and the mean 129.3 m (Table 2-2). There was no significant regression relationship between plant height and distance traveled (R^2 = 0.02). Of plants tagged in grasslands 81.7% were relocated, of those tagged in natural disturbance areas 53.8% were located. Tagged plant heights in grasslands were significantly smaller (P = <0.001) than in disturbed areas, and the median distance traveled was less (P = 0.023).

Russian thistle movement in grasslands was relatively limited, and locating tagged plants was more successful than in the valley bottom. Tagged plants along the Athabasca River and Jasper Lake moved further, and fewer were located. Plants tagged along the river banks would be prone to blowing into the water, as evidenced by the skeletons in the river and lake. However, once the waters freeze, plants can cross the valley on the ice surface. Russian thistle in the river have the potential to colonize and infest areas downstream. Russian thistle from Jasper National Park are likely a seed source for infestations outside the park in the adjacent Brule Lake area. A number of tagged plants were found partially buried in sand, attributed to blowing sand and active eroding steep cut banks. Some unlocated plants may have been completely covered by sand.

The prevailing wind direction in western Canada is from west to east (Table 2-3); however the north south orientation of the Athabasca Valley directs localized winds north down the valley. Thus, Russian thistle movement direction was greatest to the north (58%), decreasing to the east (25%), south (19.2%), and west (1.9%). In grasslands, movement to the north and east were equal (41.7%) followed by movement south (12.5%) and west (4.2%). Environment Canada Jasper Warden Weather Station wind data from 1 October 2008 to 1 May 2009 showed maximum wind gusts in winter 2008-2009 were from the south 48% of the time, and from the north 40% of the time. Highest mean maximum and single highest recorded wind gust speed occurred from north to south (Table 2-4). Thus Russian thistle movement would be expected more to the south than to the east. Environment Canada National Climate Data Archive Information only presents daily wind data as direction and speed of maximum wind gusts, where wind gusts are greater than 29 km/hr (Environment Canada 2009). Westerly winds may be more prevalent than indicated, however, wind speeds may not be as strong as north or south winds, and therefore are not recorded as maximum gusts. Russian thistle may blow back and forth in the valley, alternating between north and south as dictated by the dominant winds, but eventually become entrapped by forest edges (which generally run north south in the valley) during westerly gusts.

Seeds per tagged plant ranged from 0 to 235, with a median of 10 and a mean of 27.2. Using fall 2008 plant heights, seed production for tagged thistle was calculated using the equation $y = 4.0464e^{0.1523x}$, which best fit the relationship between plant height and seed number determined during the seed production study. Seeds remaining on plants were compared to expected number of seeds per plant. An average of 86.9% of seeds on each plant was released during winter. Additionally those seeds remaining on the plants were often small and undeveloped, with 29.9% capable of germinating.

Larger Russian thistle plants in the valley bottom were hypothesized to act as a seed source for Russian thistle invasions into grasslands. Although the potential exists, tagged plants from the valley bottom were not found in grasslands. Thus plants in grasslands were producing enough seed to infest sites year after year.

4.5 Effect of Litter Depth

Litter depth effect on plant height was small (less than 1 cm), however, significant differences were observed with taller plants generally associated with greater litter depths (Table B1). Plant height was significantly shorter (5.15 cm) with 1000 kg/ha of litter (Table 2-5), than with all greater litter treatments (3000 kg/ha, $P < 0.001$) (4000 kg/ha, $P = 0.003$) (seed on top 4000 kg/ha, $P = 0.046$) (5000 kg/ha, $P < 0.001$), but not significantly different from no litter. Plant height was significantly different between control and 3000 kg/ha ($P = 0.001$), 4000 kg/ha ($P = 0.020$), and 5000 kg/ha ($P < 0.001$) of litter. Plant height among high litter applications (3000 kg/ha, 4000 kg/ha, 5000 kg/ha) was not significant, but a trend suggests an increase with litter depth. Plants with 4000 kg/ha of litter and seeds on the litter surface were shorter than those of higher litter treatments and significantly less than those of the 5000 kg/ha treatment ($P = 0.433$).

Maximum leaf length provides an indication of plant health and photosynthetic potential. The lightest litter treatment (1000 kg/ha) had the shortest maximum leaf length (2.48 cm); the control, with no litter, had the longest (3.09 cm) (Table 2-5). Maximum leaf length with 1000 kg/ha litter was significantly less than control ($P = 0.003$), 3000 kg/ha ($P = 0.014$), 4000 kg/ha ($P = 0.048$), and 5000 kg/ha ($P < 0.001$) treatments. Maximum leaf length with 5000 kg/ha litter was significantly longer than with 4000 kg/ha ($P = 0.020$) and seed on top of 4000 kg/ha ($P = 0.017$) treatments. Maximum leaf length of the control was longer than other litter treatments, although only significantly greater than the 1000 kg/ha treatment.

Number of leaves on a plant was used as a general indication of plant health, performance, and photosynthetic potential. Plants in the seed on top 4000 kg/ha treatment had the lowest leaf number (7.0), while plants with 5000 kg/ha litter had the most (9.3), significantly more so than all other treatments (control, P = 0.036) (1000 kg/ha, P < 0.001) (3000 kg/ha P <0.001) (4000 kg/ha, P = 0.002) (4000T kg/ha, P < 0.001). The seed on top of 4000 kg/ha litter treatment produced plants with significantly fewer leaves than the control (P < 0.001), 3000 kg/ha (P = 0.027), and 4000 kg/ha (P = 0.004) treatments.

Germination and survival rates were closely linked and provided an indication of seedbed suitability and mortality. Germination refers to percent of Russian thistle seeds that germinated during the study; survival refers to percent of plants alive at the end of the study. The seed on top 4000 kg/ha litter treatment had lowest germination (60.0%) and survival (57.0%); the 3000 kg/ha litter treatment had highest germination (93.0%) and survival (91.0%) (Figure 2-1). Germination in the seed on top 4000 kg/ha litter treatment was significantly less than all other treatments (control, P = 0.019), (1000 kg/ha, P = 0.006), (3000 kg/ha P < 0.001), (4000 kg/ha, P = 0.010), (5000 kg/ha, P = 0.002). Although survival was not significantly different than the control, survival of the seed on top 4000 kg/ha litter treatment was significantly less than all remaining treatments (1000 kg/ha, P = 0.017), (3000 kg/ha P < 0.001), (4000 kg/ha, P = 0.005), (5000 kg/ha, P = 0.001). Survival in the control was poor; significantly less than for the 3000 kg/ha (P = 0.003), 4000 kg/ha (P 0.038), and 5000 kg/ha (P = 0.011) litter treatments.

Mortality occurred in all treatments; < 5% with litter and 25% in the control. Most deaths occurred during germination. Often the radical would protrude from the seed coat but could not penetrate the soil; after exhausting energy reserves it withered and died. As indicated by maximum leaf length and vigour, once established in the control plants performed well compared to litter treatments. With the exception of the seed on top 4000 kg/ha litter treatment, there was no significant difference in germination among treatments, suggesting conditions were similar in treatments with direct seed-soil contact. Litter may provide some water retention capability that limits seed desiccation or evaporation, allowing soil to remain moist and penetrable. Litter improved seed-soil contact and provided a resistant base for the seed to push from to force the radical into the soil.

Plants in the control had the highest vigour ranking (3.8); those in the 3000 kg/ha litter treatment had the lowest (2.7). Plant vigour in the control was significantly higher than that of all other treatments (1000 kg/ha, $P < 0.001$), (3000 kg/ha $P < 0.001$), (4000 kg/ha, $P < 0.001$), (4000T kg/ha, $P < 0.001$), (5000 kg/ha, $P = 0.039$). The two treatments with the highest vigour were those with the fewest plants, whereas treatments with low ratings had more plants. There is a weak inverse linear relationship ($y = -0.25x + 5.1021$) between vigour and plant survival (R^2 0.720), suggesting as plant density increases plant vigour decreases. Of the four litter treatments with seeds below the litter, vigour of the 5000 kg/ha treatment was significantly higher than that of other treatments (1000 kg/ha, $P < 0.001$), (3000 kg/ha $P = 0.008$), (4000 kg/ha, $P = 0.010$).

Thus if Russian thistle seeds have soil contact, increased litter does not inhibit plant performance or survival. Increased litter may provide improved seedbed conditions for germination and establishment. However, if Russian thistle seeds are situated on top of a thick litter layer, germination is greatly reduced and plant performance diminished. It is unlikely that litter layers less that 1000 kg/ha would have enough coverage to prevent Russian thistle seeds from migrating through interstitial spaces to the soil surface. Healthy grasslands on Devona Hill, that did not have Russian thistle, had an average litter layer of 2,332 kg/ha.

When there is adequate seed soil contact, litter improves germination and survival; however increased density associated with improved establishment reduced plant vigour compared to the control, suggesting intra specific competition. Since all treatments were regularly watered to saturation, water is not a limiting resource. In the field, dense patches of Russian thistle often consisted of a carpet of small stunted plants.

4.6 Effect of Soil Texture

Since the two soils on which Russian thistle was found in the study area are so closely related in parent material, soil forming processes, and soil texture, it is not surprising there were limited differences in Russian thistle growth in the greenhouse between grassland (Devona) and Jasper Lake area soils. There were no significant differences in Russian thistle maximum leaf length, leaf number, germination, survival, and vigour between the two soils. However, plants were significantly taller in Jasper Lake soil than in Devona soil ($P = 0.027$); a difference of 0.73 cm (Table 2-6) (P-values in Table B2). Although not statistically significant, thistle grown in Jasper Lake soil had 5.7% greater germination and 7.1% greater survival than that grown in Devona soil (Table 2-6). If the study were to continue for a longer period of time the difference in thistle heights could become more pronounced, since plants in Jasper Lake soils were much taller than those in Devona soils in the field.

When all five soil treatments were compared, Russian thistle in the potting mix had the highest mean leaf number, plant height, maximum leaf length, and vigour, followed by those in clay; Devona and Jasper Lake treatments were in the middle, and those in sand were poorest (Table 2-6). Plants in the potting mix had significantly more leaves, were taller, had longer leaves, and higher vigour than those in Devona and Jasper soils ($P < 0.001$ for all cases). Russian thistle in the sand soil had the lowest mean leaf number, plant height, maximum leaf length, and vigour. Plants in sand had significantly fewer leaves ($P = 0.006$), were shorter ($P < 0.001$), had shorter leaves ($P < 0.001$), and a lower vigour rating ($P = 0.001$) than those in the Jasper soil. Plant height and vigour in the sand treatment were not statistically different than for plants in Devona soil. Leaf number ($P = 0.001$) and length ($P < 0.001$) were significantly less in sand than Devona soil.

Jasper Lake soil had the highest germination and survival followed by Devona soil (Figure 2-2). Clay soil had the poorest germination (47.1%) and survival (45.7%). Hardening of the clay surface between waterings may have limited radical penetration and could explain poor survival, but would not fully explain poor germination. Clay had significantly poorer germination and survival than Devona ($P = 0.016$ and $P = 0.020$, respectively) and Jasper Lake soils ($P = 0.002$ and $P = 0.002$, respectively). Mortality was low (< 3%) in Devona, Jasper, clay, and potting soils, however mortality in the sand treatment was high at 32%. The quick draining nature of coarse sand may have resulted in excessive soil drying between watering, limiting available water for germinating Russian thistle.

Greater Russian thistle performance in the potting mix is explained by the presence of readily available of soil macronutrients, nitrogen, phosphorous, and potassium (Table 2-7). However soil nutrients do not account for the performance of Russian thistle in the Jasper soil in the greenhouse experiment or in the field.

4.7 Temperature and Moisture Effects

Russian thistle plants grown in warmer predicted future temperature conditions were significantly taller that in cooler current temperature conditions ($P < 0.001$) (P-values in Table B3). Plants grown under xeric conditions were significantly taller than those grown under hydric conditions ($P < 0.001$). There were no significant interaction effects of temperature and moisture treatments although plant height decreased from xeric to hydric moisture regimes under both temperature regimes (Figure 2-3). Hot xeric conditions resulted in the tallest plants (9.79 cm), cool hydric conditions resulted in the shortest plants (6.74 cm).

Plants under the higher temperature had significantly more leaves ($P < 0.001$). Plants under xeric and mesic treatments had significantly more leaves than in the hydric treatment ($P = 0.011$ and $P = 0.036$, respectively). There were no significant interactions between temperature and moisture. Russian thistle grown under hot xeric conditions had 22.3% more leaves than plants grown under cool hydric conditions (Table 2-8).

Root lengths under the cooler temperature treatment were significantly longer than those under the hotter temperature treatment ($P < 0.001$). There were no significant effects associated with moisture treatments or interaction of moisture and temperature. Plants under cool hydric conditions had the longest roots while plants grown under hot mesic conditions had the shortest (Figure 2-3), with a 27.5% difference in root length. This was unexpected, however, root development in response to temperature varies within and among species (Kaspar and Bland 1992). Kaspar and Bland (1992) maintain that in some cases when altering temperature it can be difficult to explain root growth and development, especially when other environmental or experimental factors are involved. Above optimal soil temperatures, root growth rate decrease (MacDuff et al. 1986, Kaspar and Bland 1992). The optimal soil temperature for Russian thistle is not known, but as a plant adapted to arid conditions it would likely be high compared to cool season species. Due to difficulty separating fine, delicate Russian thistle roots from soil, experimental error cannot be entirely ruled out.

Five plants under the lower temperature regime produced flower structures, while none did under the higher temperature regime. There was no relationship between flowering plants and moisture. Flowering structures were noted on two plants under xeric, one under mesic, and two under hydric conditions. Plant development and flowering response was affected by temperature in other studies (Fitter and Hay 1981, Raven et al. 1992, Larcher 2003). Southwick and Davenport (1986) found low temperature stress in trees resulted in induced flowering similar in response to that of moderate moisture stress.

Above ground indicators of plant performance (plant height, leaf number) indicated Russian thistle responded positively to increased temperature and drier conditions. The lack of statistically significant interactions between temperature and moisture suggests xeric conditions could have been drier to elicit more response. Ideally this study would have continued over a longer period of time in larger containers to monitor differences in plant growth among treatments; however growth chamber space and availability were limited.

4.8 Management Considerations

Multiple areas of native montane grasslands and naturally disturbed areas in the Athabasca Valley are infested with Russian thistle. Large plants in the river valley can move considerable distances during winter and take advantage of abundant suitable habitats. Due to the large area prone to natural disturbance and the extent of infestation, removal of Russian thistle would be difficult. Smaller plants in grassland habitats produce enough viable seed each year to perpetuate isolated populations implying that if Russian thistle establish in an area, they may remain in the community as long as site conditions are favourable.

Although, microsite conditions under litter are conducive to Russian thistle germination and growth, a thick litter layer acts as a barrier to seeds dispersed on the surface. Thus management strategies that promote litter accumulation on heavily grazed sites should inhibit Russian thistle success. Litter accumulation could be achieved by reducing grazing pressure, or applying a thin mulch.

The growth chamber study demonstrated that Russian thistle responded favourably to hot dry conditions, which has been observed in other studies (Wiese and Vandiver 1970). Russian thistle is one of only a few C_4 plants in Jasper National Park. Weed management strategies should consider the increased competitive ability and seed production of Russian thistle during hot dry summers and put more resources into controlling the plant.

5. CONCLUSIONS

Plants in naturally disturbed sites along the Athabasca River and Jasper Lake were larger and produced more seeds than those in grasslands. Seeds produced by plants in Jasper National Park were much lower than reported elsewhere. Seed viability was high, and Russian thistle in grasslands was capable of producing enough seed to continually recolonize.

Russian thistle movement distance during winter was variable and depended on habitat and physical surroundings. It did not always correspond to prevailing wind direction, with plants found in the opposite direction to prevailing winds. Plants moved as much as 4 km during winter. Larger plants in the valley bottom did not appear to act as a seed source for Russian thistle invasions into grasslands.

Increased litter depths did not inhibit Russian thistle performance or survival as long as seeds had soil contact. Increased litter may have provided improved seedbed conditions for germination and establishment; however, a thick litter layer prevented seeds from reaching the soil surface, reducing germination and plant performance. With adequate seed soil contact, litter improved germination and survival; however increased density from improved establishment resulted in reduced plant vigour.

Soil texture played a role in Russian thistle germination and growth. Russian thistle height was greater on Jasper Lake soil than on Devona soil, greatest in potting soil mix, and worst in coarse sand. Germination and establishment were reduced by drying of rapidly draining coarse sand and hardening of clay surfaces. The high germination and survival rates of Russian thistle seeds in the Jasper Lake and Devona soils indicate that this plant is well suited to the soils of the Athabasca Valley.

Russian thistle responded positively to increased temperature and drier conditions. This supports field observations and helps explain differences in plant growth between years, with Russian thistle performance poorer during cool wet years and better during hot dry years. If current climate models are correct, warmer and drier future conditions may exacerbate the Russian thistle problem in Jasper National Park.

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Table 2-1. Russian thistle height, biovolume, and seed number among plants collected in grassland and disturbed habitats.

Habitat	Parameter	Maximum	Minimum	Median	Mean
Grassland	Height (cm)	25.9	3.0	6.9	9.1 (6.2)
	Biovolume (cm^3)	369.7	1.3	10.1	41.7 (85.7)
	Seed Number	254.0	2.0	9.0	37.5 (61.1)
Disturbed	Height (cm)	50.0	9.5	29.6	29.8 (12.6)
	Biovolume (cm^3)	8332.3	32.1	1007.2	1791.1 2372.2
	Seed Number	7330.0	25.0	440.0	1562.4 (2226.3)

Standard deviations of the mean are presented in brackets

Table 2-2. Russian thistle height and distance traveled among plants collected in grassland and disturbed habitats after winter.

Habitat	Parameter	Maximum	Minimum	Median	Mean
Grassland	Height (cm)	44.0	7.5	19.0	20.2 (9.4)
	Distance Travelled (m)	135.1	0.0	7.2	20.6 (33.2)
Disturbed	Height (cm)	62.0	17.0	36.0	37.2 (11.9)
	Distance Travelled (m)	4181.9	0.0	17.5	187.1 (625.2)

Standard deviations of the mean are presented in brackets

Table 2- 3. Direction of Russian thistle movement during winter 2008-2009 in grassland and naturally disturbed habitats.

Cardinal Direction of Travel	Overall Direction of Movement (%)	Grassland Habitat Directional Movement (%)	Disturbed Habitat Directional Movement (%)
North	50.0	41.7	53.8
East	30.3	41.7	25.0
South	17.1	12.5	19.2
West	2.6	4.2	1.9

Table 2-4. Direction, occurrence, and speed of maximum wind gusts recorded at the Environment Canada Jasper Warden Weather Station between 1 October 2008 and 1 May 2009.

Direction of Maximum Gust (blowing from)	Occurrence of Maximum Gust (%)	Mean Maximum Gust Speed (km/h)	Maximum Gust Speed (km/h)
North	40.0	41.8 (8.0)	59
East	1.4	33.0 (-)[a]	33
South	48.6	36.2 (4.7)	52
West	10.0	37.0 (6.2)	50

Standard deviations of the mean are presented in brackets
[a] Single occurrence of recordable maximum wind gust from the east

Table 2-5. Litter treatment effect on leaf number, plant height, maximum leaf length, vigour, germination, and survival in the greenhouse.

Treatment	Mean Leaf Number	Mean Plant Height (cm)	Mean Maximum Leaf Length (cm)	Mean Vigour Code	Mean Germination (%)	Mean Survival (%)
1000 (kg/ha)	7.6 (1.6) [b]	5.15 (0.95) [c]	2.48 (0.54) [b]	3.1 (0.8) [d]	87.0 (14.2) [a]	82.0 (14.0) [ab]
3000 (kg/ha)	8.0 (1.1) [b]	5.76 (0.96) [ab]	2.57 (0.47) [a]	2.7 (0.7) [d]	93.0 (9.5) [a]	91.0 (12.9) [a]
4000 (kg/ha)	8.5 (2.4) [b]	5.61 (1.12) [ab]	2.63 (0.70) [a]	2.8 (1.0) [d]	87.0 (11.6) [a]	85.0 (13.5) [a]
5000 (kg/ha)	9.3 (2.4) [a]	5.86 (0.95) [a]	2.77 (0.46) [a]	3.2 (0.9) [c]	89.0 (13.7) [a]	88.0 (13.2) [a]
4000 (kg/ha)Top	7.0 (2.5) [c]	5.49 (1.17) [b]	2.56 (0.71) [ab]	3.5 (0.8) [b]	60.0 (22.1) [b]	57.0 (22.1) [b]
Control	8.2 (1.8) [b]	5.18 (1.04) [bc]	3.09 (0.75) [a]	3.8 (0.4) [a]	87.0 (8.2) [a]	62.0 (21.5) [b]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table 2-6. Soil texture effect on leaf number, plant height, maximum leaf length, vigour, germination, and survival in the greenhouse.

Treatment	Mean Leaf Number	Mean Plant Height (cm)	Mean Max Leaf Length (cm)	Mean Vigour Code	Mean Germination (%)	Mean Survival (%)
Clay	19.4 (6.0) [a]	8.28 (2.44) [b]	4.99 (1.04) [a]	4.7 (0.7) [a]	47.1 (31.5) [b]	45.7 (33.1) [b]
Devona	10.3 (3.0) [b]	5.28 (1.24 [d]	3.61 (0.74) [b]	3.2 (1.0) [bc]	85.7 (14.0) [a]	84.3 (12.7) [a]
Jasper Lake	10.4 (2.4) [b]	6.01 (1.33) [c]	3.52 (0.65) [b]	3.7 (0.5) [b]	91.4 (9.0) [a]	91.4 (9.0) [a]
Potting Mix	20.7 (5.6) [a]	11.18 (3.44) [a]	5.46 (0.97) [a]	4.8 (0.5) [a]	81.4 (14.6) [ab]	80.0 (15.3) [ab]
Sand	7.8 (2.2) [c]	4.94 (1.11) [d]	2.43 (0.57) [c]	2.7 (1.1) [c]	80.0 (15.3) [ab]	54.3 (23.7 [b]

* Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table 2-7. Available nitrate, phosphate, and potassium for clay, Devona, Jasper Lake, peat potting mix, and sand soil treatments.

Soil Name	Available Nitrate (mg/kg)	Available Phosphate (mg/kg)	Available Potassium (mg/kg)
Clay	2.0	25.0	234.0
Devona	12.9	<1.0	21.9
Jasper Lake	1.4	<1.0	20.0
Potting Mix	32.3	8.3	112.0
Sand	1.2	<1.0	20.8

Table 2-8. Least square means for plant height, number of leaves per plant, and root length associated with temperature and moisture treatments in growth chambers.

Treatment	LS Mean Plant Height (cm)	LS Mean Leaf Number Per Plant	LS Mean Root Length (cm)
Cool and Xeric	8.1 (0.36)^{ab}	13.2 (0.5) ^{b}	15.96 (0.86) ^{ab}
Cool and Mesic	7.5 (0.36) ^{ab}	13.0 (0.5) ^{b}	16.61 (0.83) ^{ab}
Cool and Hydric	6.7 (0.36) ^{b}	12.3 (0.5) ^{b}	17.79 (0.83) ^{b}
Hot and Xeric	9.8 (0.36) ^{a}	15.9 (0.5) ^{a}	13.74 (0.83) ^{a}
Hot and Mesic	8.9 (0.36) ^{ab}	15. 7 (0.5) ^{a}	12.89 (0.83) ^{a}
Hot and Hydric	8.3 (0.36) ^{ab}	14.1 (0.5) ^{a}	14.09 (0.83) ^{ab}

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

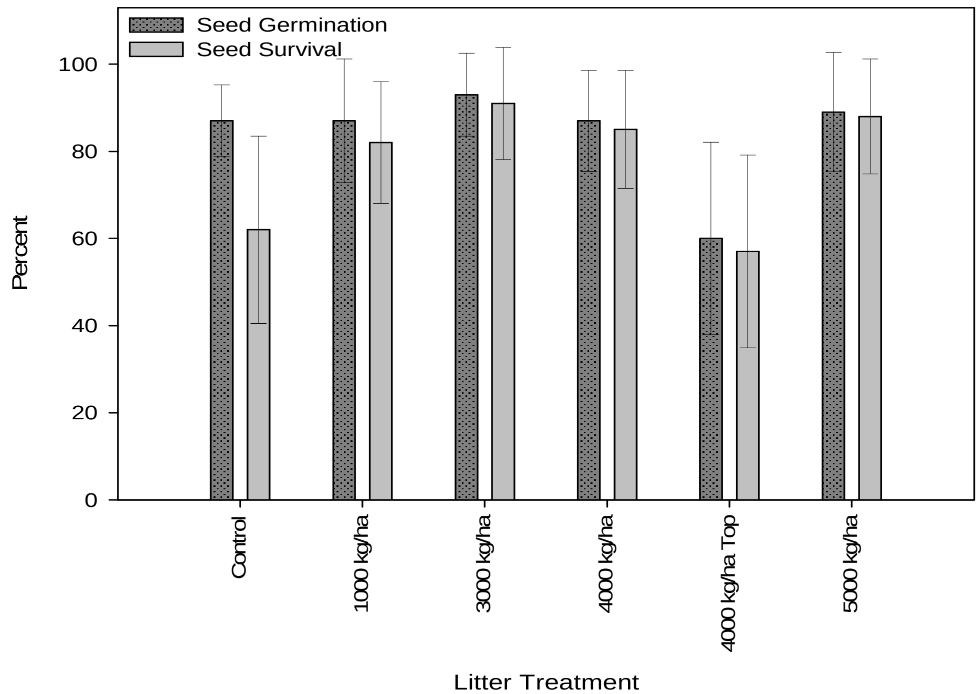

Figure 2-1. Mean (SD) percent germination and survival of Russian thistle seeds under 1000 kg/ha, 3000 kg/ha, 4000 kg/ha, and 5000 kg/ha, of litter, and for seeds on top of 4000 kg/ha of litter and a control with no litter.

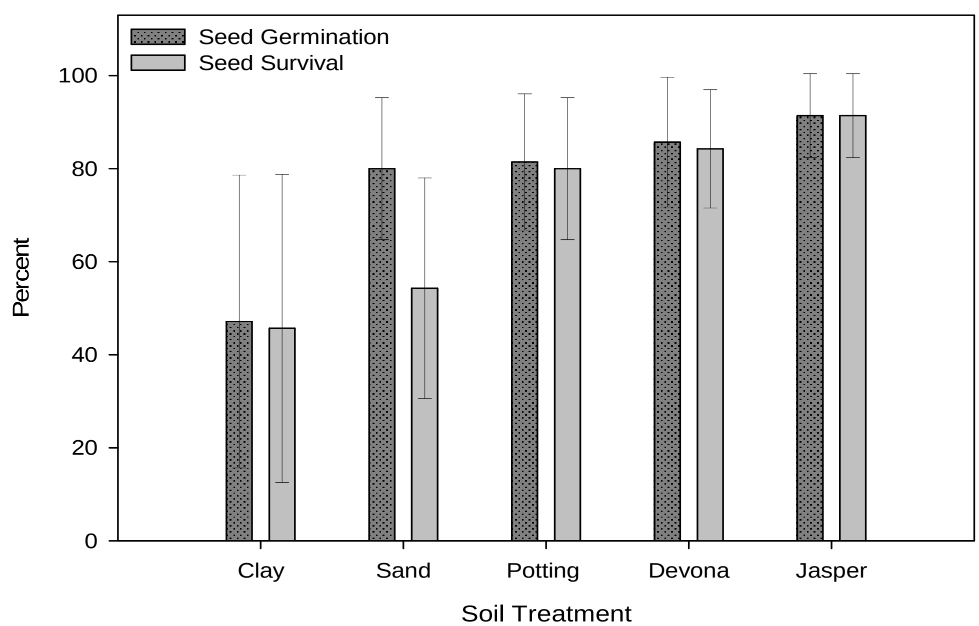

Figure 2-2. Mean (SD) percent germination and survival of Russian thistle seeds place on top of five different soil treatments.

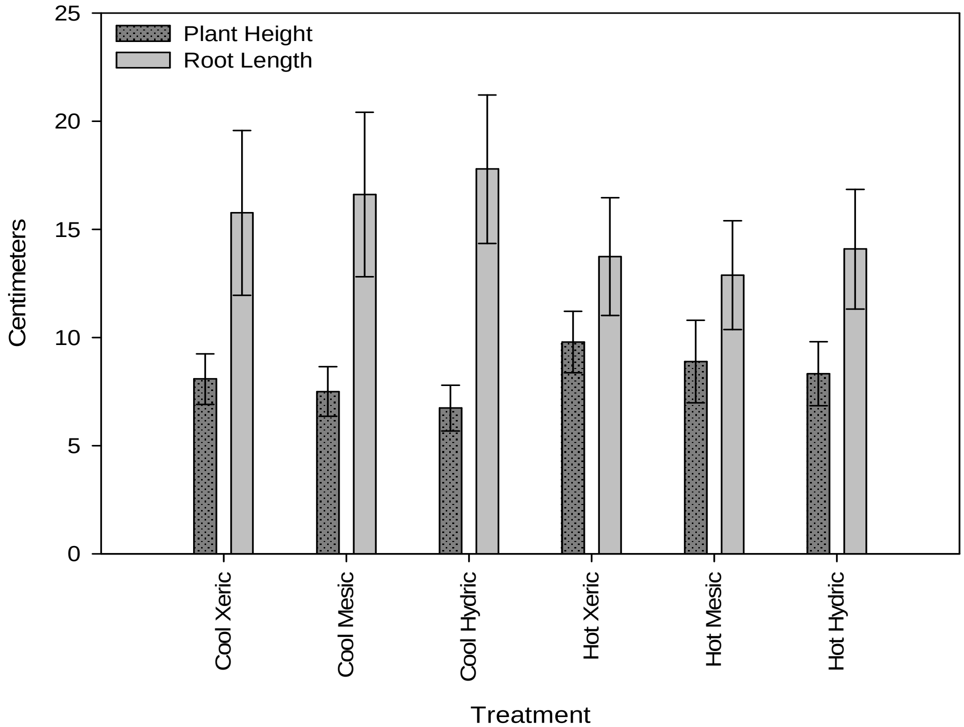

Figure 2-3. Russian thistle Mean (SD) plant height and root length under hot and cool temperatures and three moisture regimes, xeric, mesic, and hydric.

Plate 2-1. Russian thistle on naturally disturbed sandy cut banks along the east shore of Jasper Lake (15 August 2008).

Plate 2-2. Heavily grazed montane grassland infested with Russian thistle in the foreground, Jasper Lake in the background (11 April 2009).

Plate 2-3. Large Russian thistle plants growing along the north shore of Jasper Lake (12 August 2009).

Plate 2-4. Small Russian thistle plants growing in grassland habitat on Edna's Knoll (13 August 2009).

CHAPTER III. ECOLOGICAL MANAGEMENT OF RUSSIAN THISTLE (*SALSOLA TRAGUS* L.) IN BIGHORN SHEEP (*OVIS CANADENSIS* SHAW) WINTER RANGE IN THE MONTANE GRASSLANDS OF JASPER NATIONAL PARK, ALBERTA, CANADA

1. INTRODUCTION

Rangelands are one of the earth's major ecosystems and include deserts, forests, and grasslands (Holechek et al. 1995, Lund 2007). Grasslands cover approximately 40% of the earth's surface (excluding Antarctica and Greenland) and 32% of Canada's land mass (White et al. 2000). Canada ranks fifth of countries in grasslands area, with an estimated 3,167,559 km^2. Migratory herbivores are the dominant fauna in grazing ecosystems, and thus an integral component of grassland food webs that influence ecosystem functioning (Fryxell et al. 1988, Frank 1998). Native herbivores can be agents of disturbance resulting in establishment or spread of invasive plants through direct soil disturbance, intensive grazing, and seed dispersal (Hobbs and Huenneke 1992, Maron and Vila 2001). Since the arrival of European settlers and domestic livestock, grassland-herbivore dynamics in North America have shifted to more intensive livestock grazing, which can reduce plant cover, biomass, litter, and soil organic matter, and increase bare ground (Naeth et al. 1991a, Holechek et al. 1995, Vallentine 2001).

Prior to colonization, large herbivores such as bison migrated across the Great Plains, and large herds of caribou still continue annual migrations across Arctic tundra. In mountainous regions, ungulates migrate between high elevation summer habitat and low elevation winter habitat (Frank et al. 1998). Bighorn sheep (*Ovis canadensis* Shaw) move seasonally from large summer ranges with nutritious forage at high elevations to small winter ranges at low elevations where windswept grasslands have less snow and milder temperatures, allowing access to forage (Geist 1971, Stelfox 1971, Stelfox 1976, Festa-Bianchet 1988). In midwinter, when deep snow covers most slopes, sheep will rarely roam over an area more than 800 m across (Geist 1971). Winter ranges for bighorn sheep are unique and important grasslands that provide forage for concentrated numbers of sheep during a time of year when resources are scarce. Deteriorated winter range conditions and poor nutrition predispose animals to disease, possibly leading to dramatic population fluctuations (Stelfox 1971).

Winter ranges are subject to dormant and early season grazing. In Yellowstone National Park winter grazing reduced dead grass and litter, had no effect on root biomass, and increased shoot nitrogen in grasses and *Artemisia frigida* Willd. Coughenour (1991). Decreased litter on mixed prairie and fescue grasslands has been correlated with increased bare ground and decreased herbage production; litter and soil organic matter reduced soil erosion and surface evaporation by increasing infiltration rates and soil surface stability (Willims et al. 1986, Naeth et al. 1991a). However, litter and organic matter accumulations also reduced soil water through interception of precipitation and subsequent evaporation, particularly from small precipitation events (Naeth et al. 1991b).

Lower Athabasca Valley winter ranges have been in poor condition since at least the mid 1900s. In 1946 Cowan reported that most winter ranges were in a depleted condition and continuing to deteriorate due to intensive grazing by horses and game, especially elk (*Cervus elaphus* Linnaeus). Elk were culled from the Park and by 1955 Flook found winter ranges in fair condition, except for slopes such as Devona Hill and Edna's Knoll, where recovery was inhibited by trampling and grazing by bighorn sheep and elk (Flook 1955). Horse grazing was eliminated in 1962 (Trottier 1979). Assessment in 1978 suggested range condition had improved since 1957, in part due to lower stocking rates and higher precipitation (Trottier 1979).

Range condition was historically determined by comparing existing and expected climax plant communities (Wroe et al. 1988), assuming changes in plant communities are predictable and disturbed communities will revert to pre disturbance conditions once the perturbation is removed (Holechek et al. 1995). However, this may not be the case and vegetation dynamics may follow a multiple stable states and thresholds model where plant communities establish at lower stable successional states and are resistant to change (Laycock 1991). In this model, a community invaded by non native species is unlikely to return to a climax community dominated by native species (Adams et al. 2005).

Healthy rangeland communities are relatively weed resistant. If invasive species were present, removing weeds would be insufficient and a competitive plant community would need to be established to occupy available niches and limit potential for reinvasion and weed dominance (Master and Sheley 2001). In degraded rangelands with large weed infestations, revegetation with competitive species is a crucial component of successful weed management (Borman et al. 1991, Jacobs et al. 1999). Successful revegetation of weed infested rangelands with desirable grasses can be difficult, and seeding efforts often fail during establishment due to competition between weeds and desired species for suitable microsites (Jacobs et al. 1999). Carpinelli et al. (2004) suggest that for long term success, revegetation of weed infested rangeland must include active control of weeds emerging from the soil seed bank.

Management often focuses on eliminating or controlling weeds, without considering ecological processes and mechanisms promoting invasions (Hobb and Humphries 1995, Jacobs et al. 1999). Herbicides have been an integral component of rangeland weed management since the late 1940s, but rarely provide long term control when used alone and outside an integrated weed management system (Bussan and Dyer 1999). Reliance on herbicides is sometimes viewed as treating the symptom of weeds, rather than the cause of invasion (Sheley and Krueger-Mangold 2003). A concern is that decreasing forb abundance through herbicides results in loss of ecological function, increasing susceptibility to invasion, and exacerbating the weed problem (Sheley et al. 2006). In past decades there has been a shift in weed management to anticipate and manage problems rather than react to them (Singh et al. 2006). Integrated weed management systems incorporate ecological principles while combining weed control techniques, including selective herbicides (Zimdahl 2007).

In Jasper National Park, large areas of Russian thistle (*Salsola tragus* L.) have been observed in native montane grassland communities used for winter grazing by bighorn sheep and other ungulates. Park staff are concerned that these areas of invasion may be increasing in size. Invaded areas are critical winter ranges; intensive grazing over a long period of time likely reduced range health, permitting Russian thistle to become established and compete with already stressed native plant species.

2. OBJECTIVES AND HYPOTHESES

The goal of this research was to better understand the biology and ecology of Russian thistle and its control in the montane grasslands of Jasper National Park. Research objectives follow.

- To assess the effect of wildlife grazing on Russian thistle establishment, spread, and persistence.
- To determine the effectiveness of integrated weed management techniques in controlling and eliminating Russian thistle.

A number of hypotheses were made regarding Russian thistle.

- Heavy ungulate grazing and associated soil disturbances will facilitate establishment, spread, and persistence of Russian thistle.
- Grazing winter ranges will remove litter, facilitating Russian thistle invasion.
- Increased litter cover will limit Russian thistle establishment; native plant communities will then recover and displace Russian thistle once grazing pressure is reduced and range is restored to a healthy condition.
- Russian thistle, being a weak early successional competitor, will be displaced by seeding selected native grasses.
- Herbicide or manual removal will control Russian thistle in the short term but will not reduce exposed soil and therefore Russian thistle will recolonize treated sites from off site sources.
- The best method of controlling Russian thistle from an ecological perspective will involve reducing grazing pressure.

3. MATERIALS AND METHODS

3.1 Site Selection

Research plots were established at four sites in the lower Athabasca Valley (Figure 3-1). Study site criteria included: Russian thistle infestations with ungulate grazing in montane grassland, room for 28 plots, relatively uniform plant distribution, and sufficient density for multiple individual plants per plot. Of the numerous Russian thistle sites in the area, only four met the study site criteria.

The Devona Hill site was located on a large open hillside near the northwest end of Jasper Lake. The area is often referred to as Ram Pasture due to male bighorn sheep congregating on the slopes in winter (Decker and Bradford 2001). The site was approximately 200 m upslope of the CN rail line; on a macro scale it was lower slope, and on a meso scale it was middle slope. Surface shape was slightly concave on a 32% slope with a 130^{o} southeast aspect. A rock bluff used by bighorn sheep was situated 75 m south and sheep bedding areas were located near silt bluffs 50 m upslope. Decker (1997) reported concerns over abundant Russian thistle in 1995. Russian thistle was common on heavily grazed areas and steeper disturbed slopes, but absent from areas not heavily grazed.

Little Windy site was established north of Little Windy Point, on the west side of Jasper Lake. The site had open grass areas with isolated small stands of *Picea glauca* (Moench) Voss and was located approximately 300 m upslope of the CN rail line Mile 217 marker. On macro and meso scales the site was positioned mid slope with a slope gradient of 38% and a 140^{o} southeast aspect. An actively eroding sandy slope was located directly downslope and areas of exposed soils and minor slope instabilities were observed. Russian thistle distribution was less uniform and continuous than the other sites but still common on naturally disturbed slopes and where grass and litter were sparse.

Edna's Knoll is a glacio-fluvial terrace on the east side of Jasper Lake. The site was positioned on an open hillside on the west side of the knoll overlooking the Yellowhead Highway 450 m to the east. On macro and meso scales the site was positioned mid slope with a gradient of 32% and a northwest aspect of 310^{o}. Bands of bighorn sheep were commonly observed in winter and occasionally in summer. Downslope active erosion was evident. Russian thistle was widespread and uniformly distributed across the slope; height and density were greatest near actively eroding slopes adjacent to the site. The site is often very windy and Russian thistle from up wind sources in the valley bottom could migrate.

The Talbot Lake site was located on the north side of Edna's Knoll overlooking Talbot Lake, 800 m east of the Yellowhead Highway. On a macro scale the site was upper slope, on a meso scale it was mid slope with a gradient of 18% and northeast aspect of 35^{o}. Bighorn sheep congregate in the area of Edna's Knoll area in winter and are less common during summer. Sheep frequently move between the Talbot Lake and Edna's Knoll sites. Russian thistle was widespread across the slope and infested most of the area. Plant density was greatest along the western tree line where wind blown Russian thistle skeletons came to rest.

3.2 Range Use

3.2.1 Range Health Assessment

Range health was assessed from 21 to 25 June 2008 according to the Rangeland Health Assessment Field Workbook (Adams et al. 2005). A rank was assigned for five key indicators: integrity and ecological status based on plant species composition, community structure, hydrologic function, nutrient cycling, site stability, and presence of noxious weeds. The fringed sage / june grass (*Artemisia frigida* / *Koeleria macrantha* (Ledeb.) J.A. Shultes f.) community for the Montane Subregion was the reference (Willoughby et al. 2005). The general range area, not the specific study site, was assessed using a series of points that were added and converted to a percent. Range heath of < 50% is considered unhealthy, 50 and 74% is healthy with problems, and > 75% is healthy.

3.2.2 Winter Forage Consumption

Ten paired biomass clipping plots were established at each site to determine standing forage consumed during winter 2008-2009. Plots were randomly established near the control treatment; individual plots were approximately 10 m apart, consisting of two 0.25 m^2 quadrats. Plots were established by aligning a 0.5 x 0.5 m quadrat in a north-south direction. Two 15 cm steel spikes with washers marked the east edge of the fall 2008 quadrat, or plot center; the spring 2009 quadrat was located on the east side of the spikes.

Standing biomass was clipped to a height of 1 cm with hand shears. New grass was avoided during spring clipping. At each plot, plant material was separated into grasses, forbs, and Russian thistle and placed in brown paper bags. Samples were oven dried for 24 hours at 70 ℃ then weighed using an Ohaus Adventurer SL AS313 digital scale.

Dried grass, forbs, and Russian thistle biomass from each site were compared between fall 2008 and spring 2009 to provide an indication of relative grazing use between sites, quantity of forage biomass consumed over winter, and remaining biomass for litter. Biomass differences between seasons were compared as a sum of all sites and within individual sites.

3.2.3 Pellet Count Transects

In wildlife studies, fecal pellet count surveys are often used to estimate mammal populations (Freddy and Bowen 1983, Fuller 1991; Murray et al. 2002; Forsyth 2005). Pellet surveys use the frequency in which pellet groups are encountered in relation to area surveyed to estimate animal populations in an area. Pellet surveys were only used to compare relative abundance of ungulate use among sites as bighorn sheep congregate and remain in specific areas for the winter and surveys would over estimate the population.

In September 2008, three pellet count transects, each 50 m long and 1 m wide, were established in grassland areas at each site. Transects randomly fanned away from the study site to capture ungulate use in the vicinity of each site.

Due to low pellet decomposition rate and years of accumulation, it can be difficult to distinguish pellet age (Watters 2003). Thus all existing pellets were removed from along the transect to a 1.5 m width; an additional 0.25 m on each side of the transect provided a buffer to avoid potential complications during spring counts. In May 2009 all distinct pellet groups consisting of ten or more pellets were counted along each transect and identified to associated ungulate species.

3.3 Soil Sampling and Physical Properties

Volumetric soil water content was measured at the study sites 17 June 2009 with a Deta-T Devices HH2 moisture meter with a Theta Probe-Type ML2Y. Soil surface measurements were taken at the centre of each plot. Measurements were also made at the soil surface and 30 cm below the soil surface at three locations directly upslope and at three locations directly downslope of each site.

Soil penetration resistance (PR) was measured 17 June 2009. Nine PR measurements were taken upslope and 9 downslope of each site, totalling 18 measurements. Using a Soiltest Model CN973 penetrometer with a 30° cone and a 20 mm base, measurements were taken at 2.5, 5, 10, 15, and 30 cm depths.

Soil samples were obtained from the center of each study site on 20 August 2008 using a small shovel due to the loose sandy nature of the soil. At each site, approximately 750 ml of soil was collected from 0 to 10 cm and at 30 cm depths. Soil samples were sent to ALS Canada Limited, a commercial analytical laboratory in Edmonton, Alberta for analyses. Total organic carbon was determined using a wet oxidation-redox titration method (Tiessen and Moir 1993), and total nitrogen was determined by combustion (Bremmer 1996). Following standard soil sampling methods outlined by the Canadian Society of Soil Science (Carter 1993), electrical conductivity was measured by electrode in a 1:2 water extract, pH was obtained from a 1:2 water extract, and particle size was determined using a hydrometer.

3.4 Russian Thistle Management Experimental Design and Treatments

Seven Russian thistle management treatments, each replicated four times, were established at the study sites (Figure 3-2). The layout consisted of four rows; each row had seven randomly located 1.5 m x 1.5 m plots representing each treatment. Where space and distribution of plants permitted, rows and plots were separated by 1.5 m. At the Little Windy site spacing between plots and rows was altered to accommodate inconsistent distribution of Russian thistle (in isolated circumstances spacing between plots was 1 m). Russian thistle distribution affected row orientation in cardinal directions and slope between sites.

Treatments included a control (reference); exclusion of grazing by range cages (1.5 m x 1.5 m); manual pulling of Russian thistle; spraying with the herbicide metsulfuron methyl (DuPont trade name: Escort); seeding a native species mix; seeding a native species mix with 25% perennial ryegrass (*Lolium perenne* L.); and a combination of grazing exclusion, herbicide application, and seeding a native species mix. Control plots did not receive any treatment and were used as a baseline to compare the effectiveness of other treatments.

Range cages were used to examine plant response in the absence of grazing over two growing seasons. Manual pulling of Russian thistle and herbicide application were used to examine vegetation response in the absence of Russian thistle but with ungulate grazing. Seeding with a native grass mix was used to investigate whether increased grass density would reduce Russian thistle. Perennial ryegrass was added to the native seed mix to provide a quick growing grass that might out compete Russian thistle; it is known to produce abundant litter which could limit future Russian thistle establishment. The integrated pest management strategy was used to determine if establishment and persistence of Russian thistle could be managed with multiple control strategies

The 1.5 x 1.5 m grazing exclusion cages were installed 9 to 11 June 2008. Cages were constructed of 5 mm gauge wire mesh with 0.1 x 0.1 m spacing and anchored to the ground by steel pins on each side. Manual pulling of Russian thistle occurred after the pre-treatment vegetation assessment on 21 to 25 June 2008, 2 July 2008, and 19 June 2009. The number of plants pulled from each plot was recorded. Herbicide was applied with a back pack sprayer by a Parks Canada employee with an Alberta Pesticide Application Certificate. The herbicide powder was mixed with water according to manufacturer specifications to provide an application rate of 20 g/ha (0.35 ml Escort/20 L of water). Spraying occurred early in the morning of 2 July 2008 and 2 July 2009, under calm conditions with the applicator nozzle 10 cm from the ground with a coarse spray to limit drift.

Seeding occurred 12 June 2008, at a rate of 4 g per plot (18 kg/ha), with seed provided by Jasper National Park. To avoid damage to existing plants, no site preparation was conducted. Seeds were hand sprinkled evenly over each site from a height of 10 cm above the ground. The seed mix consisted of six native grass species (Table 3-1) and the augmented mix included 25% perennial ryegrass (Table 3-2).

3.5 Vegetation Assessments

Vegetation was assessed each summer over two field seasons on 21 to 24 June and 18 to 21 August 2008, and 15 to 17 June and 4 to 7 August 2009. The June 2008 assessment was to determine homogeneity among treatment plots prior to start of the study. The June 2009 assessment was to examine Russian thistle reestablishment after winter dispersal. The August 2008 and 2009 assessments were used to determine treatment effectiveness at the end of the first and second growing seasons, respectively.

Three randomly placed 0.1 m^2 (0.2 x 0.5 m) quadrats were used to assess vegetation in each plot. A 0.25 m buffer around the plots was not sampled to reduce edge effects. During the pre-treatment assessment, canopy cover for each plant species, total canopy cover, litter cover, bare ground, fecal pellets, moss, and lichen, were estimated and total Russian thistle plants were counted. The same parameters were assessed post-treatment along with Russian thistle performance characteristics including number of plants flowering, producing seed, at six leaf stage or greater, and dead. Total biovolume in cm^3 was estimated for all Russian thistle plants, and minimum, maximum, and average height of Russian thistle plants recorded. Prominence values (PV) were calculated for each species during the pre-treatment assessment using the following equation: PV = $\sqrt{}$ (% frequency) x mean % canopy cover.

3.6 Above Ground Biomass

Above ground plant biomass was collected from each plot at the end of the second growing season between 8 and 13 August 2009. A metal 0.25 m^2 (0.5 x 0.5 m) quadrat was placed in the northwest corner of each plot, offset from the plot corner to the south and east by 0.25 m to avoid edge effects. Standing biomass in the quadrat was clipped to a height of 1 cm with hand shears. Biomass was separated into grass and carex (graminoids), forbs, shrubs, and Russian thistle. Litter consisted of standing litter separated from current seasonal growth and litter that could be hand raked from the ground (plant material > 2 cm in length). Collected plant material did not include tree debris (twigs, spruce cones), as this material did not originate in the plots. Biomass samples were placed in labeled paper bags and dried at the University of Alberta in a Napco Model 420 laboratory oven at 70 ℃ for 48 hours, then weighed using an Ohaus Adventurer SL AS313 digital scale.

3.7 Statistical Analyses

Data analyses of winter forage consumption were performed using SigmaPlot 11 (Systat Software Inc. 2008). Where data were normally distributed as determined by a Kolmogorov-Smirnov test, a t-test was used to compare 2008 and 2009 mean biomass. Where data were not normally distributed a Mann-Whitney Rank Sum Test was used to compare 2008 and 2009 means.

Treatment effects were analyzed across and within sites for each of the four vegetation assessments and the biomass clipping. Data were tested for normality and homoscedasticity. SigmaPlot 11 tested data for normality using the Kolmogorov-Smirnov test, and equality of variances by examining variability around group means (Systat Software Inc. 2008). Using SAS 9.1 (SAS Institute Inc. 2002-2003), biomass data were tested for normality and homoscedasticity using Shapiro-Wilks test for normality and Levene's test for equality of variance. Where dependant variables did not meet normality and homoscedasticity requirements the Box-Cox transformation procedure in SAS 9.1 was used to select the most appropriate equation to transform the data. Transformed data were compared to original data; in most cases transformed data did not alter or would have complicated results interpretation and presentation (Norman and Steiner 2000), thus untransformed data were used in all analyses.

Non normality is a common occurrence in biological data, where normally distributed data are considered an exception (Biondini et al. 1988, Potvin and Roff 1993). Potvin and Roff (1993) maintain that nonparametric statistical methods of analysis are better able to buffer against distortion in significance testing due to non normality, and are only slightly less powerful than traditional parametric methods. In this study, where assumptions of normality and equality of variances were met, a one-way ANOVA using the Proc Mixed model in SAS was used with a Tukey post hoc pairwise multiple comparison procedure. When general assumptions required for ANOVA were not met, a Kruskal-Wallis one way ANVOA on ranks was conducted to determine differences in dependant variables among treatments. If a difference between treatments was detected, a post hoc pairwise multiple comparison was performed using Dunn's test on the ranks. A p-value of 0.05 was used to determine significance.

For biomass data, direct pairwise comparisons among treatments were made using t-tests for normal data and Mann-Whitney rank sum tests for non normal data. Direct pairwise comparisons among treatments prevented a loss of significant differences that would otherwise occur during multiple comparison procedures. This method reduced the chances of making a Type I error.

4. RESULTS AND DISCUSSION

4.1 Range Health

Devona Hill rated “healthy with problems” at 58.3%. The native plant community had minor alterations from the reference community, with lower *Koeleria macrantha*, greater *Agropyron dasystachyum* Hook. (Scribn.) and lower forb cover. Litter was moderately reduced and patchy. Site instability associated with grazing, soil movement, and plant pedestalling were evident. Russian thistle were present at < 1% cover. The study area had greater soil erosion and less litter than the surrounding area and was considered unhealthy.

Edna’s Knoll rated “unhealthy” at 48.3%. *Agropyron dasystachyum* was the dominant grass with minor alterations from the reference community. Forbs and moss were reduced and litter was greatly reduced across the site, with little to no standing or fallen litter. Soil movement and plant pedastalling were observed. Russian thistle were present at < 1% cover. Continuous uniform occurrences of Russian thistle across the site indicated a high level of infestation.

Little Windy rated “healthy with problems” at 63.3%. The native plant community had minor alterations from the reference community, with lower *Koeleria macrantha*, greater *Agropyron dasystachyum* and *Stipa comata* Trin. & Rupr., and lower forb cover. Litter was moderately lower and patchy. There was soil movement and plant pedestalling. Russian thistle was present at < 1% cover.

Talbot Lake rated “healthy with problems” at 51.7%. *Agropyron dasystachyum* was the dominant grass with minor alterations from the reference community. Expected plant layers were present. Litter was greatly reduced and there was little to no standing or fallen litter. The area had soil movement and plant pedestalling. Russian thistle was present at < 1% cover. Continuous uniform occurrences of Russian thistle across the site indicated a high level of infestation.

4.2 Wildlife Observations

On Devona Hill rams were observed on numerous occasions, especially in May 2008 and 2009. The largest band of 13 rams was seen on 12 May 2009. No ewes were observed. White-tailed (*Odocoileus virginianus* Zimmermann) and mule deer (*Odocoileus hemionus* Rafinesque) were observed in the vicinity throughout the summer. An elk antler was found near the base in spring 2009, but elk were never observed. Elk were frequently witnessed in spring at Devona Flats, near the Snake Indian River, approximately 2.5 km north of Devona Hill.

Bighorn sheep on Edna's Knoll were frequently observed during winter and early spring, and occasionally throughout the summer. Edna's Knoll and Talbot Lake sites are physically on Edna's Knoll and sheep move between the sites. Bands of males and females tended to keep separate. The largest number of sheep observed occurred 7 May 2008, and consisted of 2 rams, 18 ewes, and 15 lambs. The largest band of 18 rams was sighted on 13 May 2009. Bighorn sheep were often seen near the Talbot Lake site on the lee side of the knoll offering protection from prevailing winds. The steep rocky slopes in close proximity provide escape terrain. There were no signs of deer or elk, however they were occasionally seen in the valley bottom.

Although there was evidence of bighorn sheep use near Little Windy, they were not observed. Ewes with lambs were seen south near Windy Point and Little Windy Point. White-tailed and mule deer were observed in the vicinity during summer. There was no evidence of elk on the hillside near the site; however in May 2009 a wolf (*Canis lupus* Linnaeus) was seen scavenging on an elk carcass at the base of Little Windy Point. Due to the proximity of the carcass to the railway tracks it was assumed the elk was killed by a train.

4.3 Winter Forage Consumption

Most grazing occurred during the winter when bighorn sheep were confined to winter ranges as indicated by a significant across site decrease in biomass over winter 2008-2009 ($P < 0.001$). The greatest biomass reduction occurred at Talbot Lake (99.2%) suggesting heavy winter grazing (Figure 3-3), and was further supported by common observations of bighorn sheep grazing. Little Windy had the lowest biomass reduction (63.8%), indicating less grazing than the other sites. Although Devona Hill did not have the greatest biomass reduction (85.4%), it had the most material removed (885.2 kg/ha) (Table 3-3). Edna's Knoll had a

96.1% reduction in biomass, but the least material removed (392.6 kg/ha) due to low fall biomass.

Devona Hill had the most Russian thistle biomass (20.0 kg/ha) and Little Windy had the lowest (7.6 kg/ha) in fall 2008 (Table 3-3). There was a 99 to 100% over winter reduction in Russian thistle biomass at all sites, partly attributed to the plant's dispersal mechanism. Plants were 2 to 6 cm tall and unlikely to receive the force necessary to break free. Some plants were likely consumed by sheep and some dry fragile plants may have been crushed or trampled by sheep congregating on the sites.

4.4 Pellet Evidence of Winter Ungulate Use

All pellet groups encountered belonged to bighorn sheep, with the exception of one elk pellet group at Devona Hill. Assuming high pellet group counts equate to high ungulate use, Talbot Lake had highest ungulate use (105 pellet groups) followed by Devona Hill (99), Enda's Knoll (53), and Little Windy (14), as expected from winter biomass removal and observations. Bighorn sheep congregated frequently at Talbot Lake and Devona Hill, which had protection from strong winter winds and proximity to escape terrain. The same sheep graze Talbot Lake and Edna's Knoll, but the latter is more exposed and does not offer much protection from weather. Little Windy is likely a transition site for ungulates moving to and from more desirable locations, with less winter grazing use as indicated from pellet count and biomass clipping data.

4.5 Soil Properties

Soils were similar among sites; generally rapidly draining and sandy loam to loamy sand textured (Tables A2 to A5). Penetration resistance ranged from 23.6 to 164.4 psi, lowest at Little Windy and highest at Talbot Lake. Volumetric soil water ranged from 1.1% to 2.4% at the surface and from 3.1% to 3.9% at 30 cm. Soil pH ranged from 7.9 to 8.0; electrical conductivity ranged from 13 dS/m at Edna's Knoll to 22 dS/m at Talbot Lake. Organic matter was lowest at Edna's Knoll (1.4% at surface, 1.0% at 30 cm) and highest at Talbot Lake (3.9% at surface, 2.5% at 30 cm). Carbon to nitrogen (C:N) ratio ranged from 12 at Little

Windy to 20 at Devona at the surface, and from 14 at Talbot Lake to 33 at Devona at 30 cm. Only Devona soil at 30 cm was considered nitrogen deficient. Stevenson (1986) suggests soils with C/N ratios over 30 are limited in nitrogen, as microorganisms remove available ammonium and nitrate leaving insufficient concentrations for plant use.

4.6 Plant Species Composition Prior To Treatment Implementation

Plant species composition was similar among sites prior to treatment implementation (Tables A7 to A10). Grasses comprised the majority of vegetation cover ranging from 51.6% at Devona to 72.5% at Talbot Lake. Except at Little Windy, *Agropyron* dasystachyum was the dominant grass (17.5% to 29.1% prominence). At Little Windy *Stipa comata* (24.8% prominence) dominated followed by *Agropyron dasystachyum. Koeleria macrantha* and *Stipa comata* were subdominants. *Bromus inermis* var. *pumpellianus* Leyss. (northern awnless brome), *Calamagrostis montanensis* (Scribn.) (plains reedgrass), and *Poa interior* Rydb. (inland bluegrass) contributed less cover and did not occur at all sites. Forbs comprised 27.1 (Talbot Lake) to 48.4% (Devona) of cover. *Artemisia frigida* was the dominant forb; prominence ranged from 10.4% at Talbot Lake to 46.4% at Devona. Russian thistle prominence varied from 1.6% at Devona to 4.8% at Little Windy.

There were 30 plant species recorded in the plots (Table A6). Devona had the lowest species richness (10). Talbot Lake had the highest (29). There were no significant differences among sites in number and cover of Russian thistle, and cover of graminoids, forbs, total vegetation, litter, and exposed soil (Tables 4 and B4). However, due to heterogeneity in vegetation and physical characteristics some significant differences were found on individual sites among the treatment locations. These differences were considered during interpretation and discussion of the vegetation assessments.

At Devona Hill and Edna’s Knoll, large numbers of Russian thistle plants in the rye grass and control treatments (Edna’s Knoll only) and low numbers in the herbicide treatment resulted in significant differences in density and cover among treatment locations (Tables B5 to B12). At Little Windy, graminoid cover in the native seeding treatment was lower than all other treatments, while in herbicide treatments it was greater; this was reflected in significant differences among treatments at that site in graminoid cover, total vegetation cover, and exposed soils. At Talbot Lake, uneven forb distribution resulted in significant differences in forb cover among treatments; forb cover was greatest in herbicide plots and lowest in hand pulling plots.

4.7 Vegetation Response to Grazing Exclusion

At the end of the first growing season Russian thistle parameters, graminoid cover, litter, and exposed soil did not differ between ungrazed and control treatments across sites (Tables 3-5, 3-6, B13 to B29). *Artemisia frigida* was the dominant forb and contributed 78.7% of forb cover. Forb cover in the control was 34.7% higher than in ungrazed treatments ($P = 0.005$) (Tables 6 and B29). Since little grazing occurred during summer, grazing exclusion would not be expected to reduce forb cover in two months. Differences in forb cover were likely related to site variability and high forb cover in the control, particularly at Edna's Knoll ($P = 0.010$) and Talbot Lake (Tables B15 and B19). These differences in forb cover were not observed in later assessments.

At the end of the second growing season, grazing exclusion negatively impacted Russian thistle across sites (Table 3-5). There were significantly fewer Russian thistle plants ($P = 0.002$), number of flowering plants ($P < 0.001$), lower cover ($P = 0.002$), and lower biovolume ($P = 0.002$) in ungrazed treatments than in the control. Russian thistle was short (3.2 cm) with no significant treatment differences. Trends were the same within sites as across sites, with density and cover differences significant at Edna's Knoll ($P = 0.043$) ($P = 0.023$) and Talbot Lake ($P = 0.001$) ($P = 0.005$), respectively; flowering differences significant at Devona Hill ($P = 0.030$) and Talbot Lake ($P = 0.004$), and biovolume differences significant at Talbot Lake ($P = 0.007$).

After two growing seasons there was 31.9% more vegetation cover and 58.5% more litter in ungrazed treatments than in the control (Table 3-6). Ungrazed treatments had significantly higher graminoid ($P = 0.023$), total vegetation ($P = 0.011$), and litter ($P < 0.001$) cover, and significantly less exposed soil ($P =$

0.014) than the control. Similar significant trends occurred within sites for litter cover and exposed soil at Devona Hill (P = 0.006) (P = 0.002), Edna's Knoll (P < 0.001) (P = 0.016), and Talbot Lake (P < 0.001) (P = 0.002), respectively.

Grass and forb biomass did not differ significantly between ungrazed and control treatments due to site variability, although grass biomass was 36.1% higher in ungrazed treatments than in the control (Tables 3-7 and B31 to B36). These differences were significant at Edna's Knoll (P = 0.048) and Talbot Lake (P = 0.046). Russian thistle biomass was significantly lower (P = 0.030) with grazing exclusion than in the control across sites but not within sites. After two growing seasons and a winter without grazing there was significantly more litter (P < 0.001) and biomass (P = 0.003) in ungrazed treatments than the control. Ungrazed treatments had the greatest total biomass (1195.5 kg/ha) of all treatments (Table 3-7).

4.8 Vegetation Response to Herbicide

After the first growing season it was clear across sites that herbicide was an effective control for Russian thistle (Tables 3-5 and B9 to B30). There were no live Russian thistle plants in the herbicide treatment in August 2008. There were no significant differences in graminoid, total vegetation, litter and exposed soil cover between the herbicide treatment and the control. Herbicide damaged or killed forbs, and forb cover was significantly lower in the herbicide treatment than the control (P = 0.028). With the exception of Talbot Lake, all sites had lower forb cover in the herbicide treatment than the control; Edna's Knoll significantly so (P = 0.024). Although the herbicide plots at Talbot Lake had higher forb cover than the control pre treatment in June 2008, there was a 35.3% decrease in forb cover in the herbicide plots between June 2008 and August 2008 (Tables B8 and B19).

Herbicide continued to control Russian thistle at the end of the second growing season. There was a 98.1% reduction relative to the control, with only 12 Russian thistle plants recorded (Table 3-5). Across sites, herbicide significantly increased graminoid cover (P = 0.015), and significantly decreased forb (P < 0.001) and total vegetation cover (P < 0.001). The increased graminoid cover is likely a response to increased habitat associated with forb loss. *Artemisia frigida* comprised a large proportion of the total vegetation cover at each site and with its loss, total vegetation cover decreased and exposed soil increased.

Within sites, graminoid cover was significantly higher in herbicide treatments than the control at Devona (P = 0.027) and Little Windy (P = 0.050). At all sites herbicide significantly reduced forb (P < 0.001) and total vegetation cover at Devona (P = 0.001), Edna's Knoll (P < 0.001), and Talbot Lake (P < 0.001). With the exception of Little Windy, exposed soil was greater in herbicide treatments than the control; significantly at Edna's Knoll (P < 0.001) and Talbot Lake (P = 0.047). Except for Talbot Lake, forbs we absent from herbicide treatments.

Forb removal from herbicide likely provided more habitat for grasses. Grass biomass in the herbicide treatment was 35.1% greater than in the control across sites (P = 0.009), although there was no significant difference in litter and total biomass (Tables 3-7 and B31 to B36). Increases in grass biomass in the herbicide treatment were likely offset by forb biomass loss, resulting in similar total biomass. Across sites there was 14.4% more biomass in the control than in the herbicide treatment (Table 3-7).

4.9 Vegetation Response to Hand Pulling

A total of 24,308 Russian thistle plants were pulled from the sites in 2008 (Tables 3-8 and B9 to B30). Talbot Lake had the greatest number pulled (6,684 plants in 2008), with one 1.5 x 1.5 m plot containing 3,800 plants in June 2008. Across sites, hand pulling significantly reduced density (P < 0.001), flowering plants (P = 0.001), biovolume (P < 0.001), and cover (P < 0.001) relative to the control (Table 3-5). There was no significant difference in average Russian thistle height. Within sites the same trend was observed.

Across sites pulling Russian thistle appeared to reduce forb (P = 0.008) and total vegetation cover (P = 0.006). However, this trend was not consistent within sites. At pre treatment and in August 2008 and 2009, forb cover in the pulling plots was much lower than in control plots at Edna's Knoll and Talbot Lake. Pulling Russian thistle is unlikely to have reduced forb or total vegetation cover.

In June 2009, 4,862 Russian thistle plants were pulled from the sites, the largest number from Talbot Lake (Table 3-8). There was a 73.8% difference in number of Russian thistle between the pulling treatment and the control. By August 2009 there was a significant across site reduction in Russian thistle number ($P < 0.001$), flowering thistle ($P < 0.001$), thistle cover ($P < 0.001$), biovolume ($P < 0.001$), and thistle height ($P = 0.046$) between the pulling treatment and the control. The same trend was observed within sites.

Across sites, there were no significant differences in graminoid, forb, total vegetation, litter, or exposed soil cover between the pulling treatment and the control. Within sites there were some significant differences in forb cover, total vegetation, and exposed soil, however no discernable trends. Differences were likely due to site variability and often reflected pre treatment conditions.

Grass, forb, Russian thistle, litter, and total biomass did not differ significantly between the pulling treatment and the control across sites, although Russian thistle biomass was 52.0% lower with pulling (Tables 3-7 and B31 to B36). The same trend was observed within sites. At Edna's Knoll grass biomass was significantly greater ($P = 0.028$) and forb biomass was significantly less ($P = 0.028$) than the control. Biomass differences may result from site variability and small sample size per treatment ($n = 4$). Trends at other sites were inconsistent.

4.10 Vegetation Response to Native Seeding

At the end of the first growing season emergence of the native seed mix was poor. Only *Agropyron dasystachum* and *Koeleria macrantha*, dominant species to the study area, were found in August 2008. Across sites, no significant differences in Russian thistle number, flowering, cover, biovolume, or height were detected between the native seeding treatment and the control (Tables B9 to B30). There were also no significant differences in graminoid, total vegetation, litter and exposed soil either. However, forb cover for the native seeding treatment was significantly less than that of the control across ($P = 0.001$) and within sites (significant at Talbot Lake $P < 0.001$).

Emergence of the native seed mix remained poor in the second growing season. With the exception of *Agropyron dasystachum* and *Koeleria macrantha*, grass species in the seed mix were not found in any of the study plots in August 2009. Across sites native species seeding did not affect Russian thistle performance or cover of graminoids, total vegetation, litter, or exposed soil realtive to the control. Forb cover for the native seed treatment was significantly less than for the control (P = 0.028). Within sites, forb cover for the native seed treatment was either the lowest or second lowest of any of the non herbicide treatments. Forb cover at Talbot Lake was significantly less than that of the control (P = 0.034) and graminoid cover was significantly greater than the control (P = 0.014). This trend was also observed at Talbot Lake in August 2008, and is considered a site characteristic rather than a treatment response.

Across sites the native seeding treatment and the control were not significantly different in grass, forb, Russian thistle, litter or total biomass. Within sites, grass biomass was significantly greater in the native seeding treatment than in the control at Devona (P = 0.041) and Talbot Lake (P = 0.031) (Tables B31 to B36). At Edna's Knoll and Little Windy grass biomass was greater in the control than in the native seeding treatment. Since seed germination and emergence were poor, the difference in grass biomass is likely due to site variability and small sample size. Forb biomass was less in the native seeding treatment than in the control, although, only significant at Talbot Lake (P= 0.035).

4.11 Vegetation Response to Rye Grass Seeding

Emergence of the perennial rye grass seed mix was poor. *Agropyron dasystachum* and *Koeleria macrantha* were the only species from the seed mix found in August 2008 or 2009. Across sites, and relative to the control there were no significant differences in Russian thistle number, flowering, cover, biovolume, or height, or in the cover of total vegetation, litter, and exposed soil or biomass between the rye grass treatment and the control in 2008 or 2009. In 2008 there was significantly less forb cover (P = 0.044) in the rye grass treatment, related to high forb cover in the control. By the end of the second growing season one *Lolium perenne* plant was observed on the edge of a rye grass treatment plot at Devona. Graminoid cover for the rye grass treatment was significantly greater (P = 0.038) than that for the control in August 2009, due in part to a rye grass treatment plot at Talbot Lake and at Little Windy with high cover of *Stipa comata* (10 to 20%). *Stipa comata* was not in the ryegrass seed mix and it is unlikely that seeding was responsible for the difference in graminoid cover.

4.12 Vegetation Response to Mixed Treatments

Herbicide was also effective in the mixed treatment and responsible for a 99.8% reduction in Russian thistle density in the control by the end of the first growing season (Tables 3-5 and B9 to B30). Vegetation cover, graminoid cover, litter cover and exposed soil did not differ between the mixed treatment and the control. The herbicide also killed many forbs; *Artemisia frigida* showed signs of physical distress but was still alive in August 2008. Forb cover was significantly less (51.3%) ($P<0.001$) in the mixed treatment than in the control (Table 3-6). Trends were similar at individual sites with the mixed treatment having significantly fewer (98 to 100% reduction) Russian thistle plants ($P < 0.001$) than the control. Forb cover was less in the mixed treatment, significantly at Devona ($P < 0.001$), Edna's Knoll ($P < 0.001$), and Talbot Lake ($P = 0.011$).

At the end of the second growing season, all Russian thistle parameters were significantly different ($P < 0.001$) in the mixed treatment and the control at all sites. Graminoids ($P < 0.001$) and litter cover ($P < 0.001$) increased, and forb cover decreased ($P < 0.001$) with an overall decrease in vegetation cover ($P < 0.001$) in the mixed treatment relative to the control. This is not likely a result of seeding, as no significant differences occurred in graminoid cover between the mixed (included grazing exclusion) and grazing exclusion treatments, suggesting graminoid cover increase is a plant response to the absence of grazing.

Although only Devona had a significant difference ($P = 0.003$) in graminoid cover between the mixed treatment and control, all sites had numerically greater graminoid cover in the mixed treatment. Devona, Edna's Knoll, and Talbot Lake had significantly greater litter cover in the mixed treatment than the control ($P < 0.001$, $P = 0.001$, and $P < 0.001$, respectively); Little Windy had 38.2% more than the control (not significant). Herbicide killed forbs in the mixed treatment relative to the control (each site $P < 0.001$). Forb loss, particularly *Artemisia frigida,* which accounted for 41.4% of cover in the control, helps explain why vegetation cover in the mixed treatment was less than in the control. Differences were significant at Devona ($P = 0.010$), Edna's Knoll ($P = 0.001$), and Little Windy ($P = 0.011$).

Grass biomass in the mixed treatment (601.5 kg/ha), for all sites, was significantly greater ($P = 0.009$) than in the control (263.3 kg/ha) (Tables 3-7 and

B31 to B36). Herbicide killed all forbs and Russian thistle. Absence of grazing and death of forbs resulted in significantly (71.1%) greater ($P < 0.001$) litter biomass in the mixed treatment than in the control. At individual sites, litter biomass was greater in the mixed treatment than the control, but remained significant only at Talbot Lake ($P = 0.029$). Thus total biomass (all sites) in the mixed treatment was significantly greater (37.0%) ($P = 0.040$) than the control.

4.13 Treatment Comparisons

Understanding how the treatments relate to the control and compare to each other is important from a management perspective. August 2009 data across sites were used to compare treatment effectiveness (Figures 3-3 and 3-4).

4.13.1 Russian thistle control

The mixed and herbicide treatments were successful at removing almost all Russian thistle plants, thus differences in Russian thistle variables were significant compared to other treatments. Grazing exclusion and hand pulling were similar with no significant differences in Russian thistle number, flowering, cover, and biovolume. Russian thistle biomass with grazing exclusion was similar to that of hand pulling; 57.1% less than with rye grass seeding and significantly less (58.1%) than with native seeding ($P = 0.048$). Grazing exclusion resulted in significantly fewer Russian thistle plants and consequently less flowering, biovolume, and cover than native seeding and rye grass seeding (Tables 3-5 and 3-6). The hand pulling treatment had significantly fewer Russian thistle than native seeding ($P < 0.001$) and ryegrass ($P < 0.001$) treatments. Russian thistle parameters were similar in native seeding, rye grass seeding, and control treatments. There were no significant differences in Russian thistle height among non herbicide treatments.

4.13.2 Ecological range response

The cessation of grazing increased forbs, total vegetation, and litter cover and reduced exposed soil relative to other treatments. The grazing exclusion treatment had the highest forb (15.6%) and total vegetation cover (28.3%), the lowest exposed soil (44.7%), and the largest total biomass (1195.5 kg/ha)

(Tables 3-6 and 3-7). Although forb biomass was high, there was no significant difference among other non herbicide treatments (Table B37). There was no significant difference in litter cover between grazing exclusion and mixed treatments, which also excluded grazing; however, with grazing exclusion there was significantly more litter cover than with grazing. There were no significant differences in graminoid cover between grazing exclusion and other treatments, as confirmed with no significant differences in grass biomass between these treatments.

The herbicide treatment eliminated Russian thistle and other broad leaf species. There was no significant difference in litter and total biomass between the herbicide treatment and other grazed treatments. The herbicide treatment had less grass biomass than mixed and grazing exclusion treatments, but more grass biomass than other treatments. The herbicide treatment had significantly more grass biomass than the native seeding treatment ($P = 0.048$). However, graminoid cover did not differ among herbicide and control treatments. The herbicide treatment had the lowest vegetation cover (10.1%) and greatest exposed soil (66.9%). There were no significant differences in total vegetation cover between herbicide and mixed treatments.

Herbicide in the mixed treatment removed almost all forbs, which combined with seeding promoted grass growth, while the grazing exclusion part of the treatment led to litter accumulation. The mixed treatment had the highest graminoid (12.7%) and litter cover (27.9%), and was second only to grazing exclusion in lowest exposed soil (50.8%) (Table 3-6). The mixed treatment had highest grass (601.5 kg/ha) and litter biomass (531.2 kg/ha), and next to grazing exclusion the second highest total biomass (1144.4 kg/ha) (Table 3-7). The mixed treatment had significantly more grass biomass than grazed non herbicide treatments (hand pulling $P = 0.050$, native seeding $P = 0.010$, rye grass seeding $P = 0.045$). The mixed treatment had significantly more litter biomass than grazed treatments (hand pulling $P < 0.001$; herbicide $P < 0.001$; native seeding $P < 0.001$; rye grass $P < 0.001$); 21.8% more than the grazing exclusion treatment. The greater litter biomass in the mixed treatment was likely due to dead forb material from the herbicide. The loss of forb cover in the mixed treatment resulted in less total vegetation cover than other treatments. The mixed treatment had significantly less total vegetation cover than grazing exclusion ($P < 0.001$), hand pulling ($P = 0.001$), native seeding ($P = 0.008$) and rye grass ($P < 0.001$) treatments.

Hand pulling, native seeding, and rye grass treatments were all similar in grass, forb, litter, and total biomass. The three treatments did not differ in graminoid, forb, litter, total vegetation cover, and exposed soil cover, but differed from treatments with herbicide and grazing exclusion. Due to forb removal by herbicide, hand pulling, native seeding, and rye grass seeding had significantly more forb biomass than mixed or herbicide treatments. Biomass removal was consistent across grazed treatments. There were no significant differences in litter or total biomass among any grazed treatments. The three treatments had significantly less litter than grazing exclusion and mixed treatments, and significantly less total biomass than the grazing exclusion treatment. There was no significant difference in exposed soil among the three treatments.

4.14 Winter Seed Dispersal Within Treatments

Russian thistle is an annual, therefore all Russian thistle growing on sites in 2008 would have died and dispersed their seeds during the following winter. June 2009 thistle numbers provide insight into the role of treatments on seed dispersal and recruitment (Table 9). Grazing cages inhibit outside Russian thistle from reseeding areas inside mixed and grazing exclusion plots, but due to the small size of Russian thistle plants in the grassland areas it is possible for outside plants to enter grazing cages. Russian thistle skeletons were observed clinging to the outside of a number of cages, seeds from plants caught on the cages may have been released and blown into the enclosed treatment area. However, seeds from outside sources likely did not contribute much to the seed bank in the grazing cages, due to the small stature (2 to 4 cm in height) of most plants in the study area, small seed production, and limited distance the small plants can travel.

Across sites, there was no significant difference in number of Russian thistle between grazing exclusion and control treatments; however there were 19.7% fewer Russian thistle plants in the grazing exclusion treatment. Russian thistle in the grazing exclusion treatment are from seed produced in the plot the previous year and the soil seed bank, but less likely to have originated from plants outside the exclosure. This suggests mature plants in grazing cages produced viable seed and reestablished in the cages.

The mixed treatment, which included grazing exclusion and herbicide, had significantly fewer (87.7%) Russian thistle ($P < 0.001$) than the control. This suggests herbicide removed mature plants prior to seed set in 2008, inhibiting reestablishment of Russian thistle in the cages. The majority of the remaining 12.3% of plants likely originated from the soil seed bank, and were not derived from an outside source or seed from in the treatment the previous year.

The herbicide treatment, which did not have grazing cages, also had significantly fewer (36%) Russian thistle plants ($P = 0.010$) than the control, but significantly more Russian thistle plants ($P < 0.001$) then the mixed treatment. Plants in the herbicide treatment originated from the soil seed bank and dispersal from outside sources. Herbicide, therefore, prevented Russian thistles from producing and dropping seed in the plots; however since the physical structure of the cage was absent, there would have been unrestricted Russian thistle movement and dispersal of seed across the surface of the herbicide plots.

There were no significant differences in number of Russian thistle between the control and native seeding, hand pulling, or rye grass treatments. Without effective treatment Russian thistle are capable of repopulating winter range sites in montane grasslands year after year.

4.15 Annual Comparison of Russian Thistle Performance

Russian thistle growth from August 2008 to August 2009 were compared within treatments to investigate selected treatment effectiveness, and to examine possible annual differences in growth. Russian thistle variables between years were compared for control, grazing exclusion, hand pulling, native seeding, and rye grass treatments. Due to the effectiveness of the herbicide at eliminating Russian thistle, comparisons between years were not made for the herbicide and mixed treatments.

There were significantly more Russian thistle in 2008 in grazing exclusion ($P < 0.001$) and native seeding treatments ($P < 0.001$) than in 2009 (Table B38).

Across sites there was no significant differences in Russian thistle numbers in the control between 2008 and 2009; however there were twice as many in 2008 (n = 1137) as in 2009 (n = 573). The same trend was observed in the rye grass treatment, with over twice the number of Russian thistle plants in 2008 (n = 1334 plants) as in 2009 (n = 564). These higher plant numbers in 2008 are similar to the greater biovolumes in 2008. Typically, Russian thistle in 2009 was statistically taller than those in 2008, and number of plants with flowers was greater. Russian thistle in the grassland sites was relatively small both years, with average height in the control 2.9 cm in 2008 and 3.2 cm in 2009.

Field observations support the data. Visually there were fewer Russian thistle in the grassland areas in 2009, however, the plants were larger and more robust than plants in 2008. Differences in height and numbers were less obvious at the study sites where grasses dominated. Differences in height and numbers were most noticeable in transition zones between grassland and natural disturbance areas where loose exposed soil was more pronounced.

Environment Canada National Climate Data from the Jasper Warden Weather Station was examined for summer months 2008 and 2009 to determine if weather variation explained differences in Russian thistle height and numbers (Figures 3-6 and 3-7). Mean monthly summer temperatures (May to August) between years were similar. Summer 2008 was wetter than summer 2009. There was 84.8 mm more precipitation during summer 2008 than summer 2009. June and August 2009 were particularly dry months. There was only 6.9 mm of rain in June 2009, 88.7% less than June 2008. Rain in August 2009 was 8.8 mm, 74.1% less than August 2008. The growth chamber study (Chapter II) suggested Russian thistle grew better under drier conditions. However, it is uncertain whether smaller Russian thistle in 2008 was due to increased summer precipitation.

Based on observations of numerous large Russian thistle skeletons from the 2007 growing season, 2007 was a good year for seed production. July 2007 was hotter and drier than normal (Figures 3-6 and 3-7). Seeds dispersed during winter 2007/2008 would have germinated during spring 2008 and may account for the larger number of Russian thistle throughout the study area. Plants grown in 2008 were not as large as those in previous years, and would not likely have produced as many seeds. If fewer seed were produced in 2008, this would translate into fewer plants in 2009.

4.16 Management Considerations

Of the treatments studied, grazing exclusion holds the most promise from an ecological management perspective. After only two growing seasons without grazing, Russian thistle numbers and biomass were reduced. During the same period there were significant increases in graminoid, total vegetation, and litter cover, and a reduction in exposed soil. To exclude grazing from critical winter range areas may not be a practical management strategy, however results from this study suggest reduced grazing pressure would make these areas more resilient to Russian thistle invasion. The results are supported by observations of healthy range areas in the valley that receive less grazing pressure and are free of Russian thistle.

Although both mixed and herbicide treatments were effective at eliminating Russian thistle, widespread use of Escort in infested grassland sites would damage or remove the forbs and increase bare soil, which would make sites more susceptible to future invasions by non native species. Spraying earlier in the season would reduce some forb damage, but would likely still result in harm to *Artemisia frigida*, the dominant forb on all sites.

Hand pulling reduced number and cover of Russian thistle. However, manual removal of Russian thistle did not result in changes in graminoid and forb cover or biomass. Hand pulling small Russian thistle in the grassland sites would not be a pragmatic management strategy. Russian thistle in the plots during August were either missed or germinated after earlier hand pulling activities. Hand pulling small Russian thistle was tedious and would need to be repeated during the summer to effectively remove Russian thistle from the sites. The number of Russian thistle and size of the infestations, in combination with the difficulty in visually spotting and removing the diminutive plant from the native vegetation does not make this a feasible management option in montane grassland habitats.

Both native grass and the rye grass seeding were unsuccessful. Germination and emergence of the two grass mixes in the field was very poor. An observational trial in the greenhouse showed that the seeds germinated readily, suggesting that field conditions were likely responsible for poor germination. To avoid damage to existing plants there was no seedbed preparation prior to seeding and seeds were not watered following sowing. The seeding rate may have been too low; if attempting to reseed in the future a higher seeding application rate is recommended.

5. CONCLUSIONS

Winter ranges associated with the four study sites had diminished range health. Almost all standing biomass was removed during winter months, resulting in limited litter cover and increased soil erosion potential on intensely grazed bighorn sheep winter ranges. As little as two growing seasons without grazing led to an increase in graminoid, total vegetation, and litter cover, and significantly less exposed soil. Without grazing, Russian thistle numbers, cover, and biomass decreased, indicating that improved range condition reduced establishment and persistence of Russian thistle; conversely, continued overgrazing by bighorn sheep perpetuates the Russian thistle in heavily utilized winter ranges.

Of the treatments studied, grazing exclusion was preferred from an ecological management perspective for Russian thistle control. After only two growing seasons without grazing, there was a significant increase in total vegetation and litter cover, and a significant reduction in Russian thistle numbers, cover, and biomass. Mixed and herbicide treatments were the most effective at eliminating Russian thistle, but they also removed forbs. Hand pulling reduced Russian thistle number but would not be practical in grasslands at the scale of the infestation. Seeding treatments failed to germinate and therefore were ineffective.

Russian thistle during the two years of study in the Athabasca Valley were small in the overgrazed grasslands and did not appear to be negatively impacting the native plant community. Russian thistle was typically much smaller than the surrounding native plants and often occupied sites with available exposed soil. This species is highly responsive to annual variations in summer weather patterns, and will increase growth and vigour under hot dry conditions. During summers with drought like conditions Russian thistle may be more competitive to stressed native species.

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Table 3-1. Native grass species seed mix for the treatment sites in Jasper National Park.

Scientific Name	Common Name	Percent of Seed Mix
Agropyron dasystachyum (Hook) Schribn.	Northern Wheatgrass	25
Agropyron subsecundum (Link) Hitchc.	Awned Wheatgrass	25
Agropyron trachycaulum (Link) Malte	Slender Wheatgrass	25
Koeleria macrantha (Ledeb.) Schult.	June Grass	5
Poa alpina L.	Alpine Bluegrass	5
Stipa viridula Trin.	Green Needle Grass	15

Table 3-2. Perennial ryegrass seed mix for the treatment sites in Jasper National Park.

Scientific Name	Common Name	Percent of Seed Mix
Agropyron dasystachyum (Hook) Schribn.	Northern Wheatgrass	18.5
Agropyron subsecundum (Link) Hitchc.	Awned Wheatgrass	18.5
Agropyron trachycaulum (Link) Malte	Slender Wheatgrass	18.5
Koeleria macrantha (Ledeb.) Schult.	June Grass	4.0
Lolium perenne L	Perennial Ryegrass	25.0
Poa alpine L.	Alpine Bluegrass	4.0
Stipa viridula Trin.	Green Needle Grass	11.5

Table 3-3. Mean total standing biomass and mean Russian thistle biomass for fall 2008 and spring 2009.

Study Site	Mean Total Biomass 2008 (kg/ha)	Mean Total Biomass 2009 (kg/ha)	Mean Russian Thistle Biomass 2008 (kg/ha)	Mean Russian Thistle Biomass 2009 (kg/ha)	Reduction in Total Biomass (kg/ha)
Devona Hill	1036.0 (317.0)	150.8 (160.4)	20.0 (26.4)	0.0	885.2
Edna's Knoll	408.4 (86.7)	15.8 (7.0)	16.0 (16.2)	0.0	392.6
Little Windy	812.0 (289.4)	294.0 (265.4)	7.6 (10.1)	0.0	518.0
Talbot Lake	690.4 (253.0)	5.3 (3.6)	14.8 (19.9)	0.1 (0.2)	685.1

Standard deviations of the mean are presented in brackets

Table 3-4. Mean pre treatment ground cover (%) and Russian thistle density in June 2008.

Treatment	Number of Russian Thistle (0.1 m^{-2})	Russian Thistle	Graminoid	Forb	Total Vegetation	Litter	Exposed Soil
Control	41.5 (49.5) [a]	1.5 (1.7) [a]	21.7 (10.0) [a]	13.0 (8.8) [a]	33.5 (12.3) [a]	19.9 (11.2) [a]	38.9 (21.2) [a]
Grazing Exclusion	35.5 (29.1) [a]	1.0 (1.0) [a]	22.8 (12.8) [a]	13.0 (9.8) [a]	34.2 (13.9) [a]	22.9 (12.2) [a]	36.7 (19.8) [a]
Hand Pulling	41.7 (89.6) [a]	1.3 (3.0) [a]	25.4 (12.7) [a]	11.9 (10.5) [a]	34.2 (13.6) [a]	24.4 (15.7) [a]	37.4 (22.1) [a]
Herbicide	26.6 (30.3) [a]	1.2 (1.9) [a]	27.5 (12.1) [a]	14.2 (10.1) [a]	38.4 (14.2) [a]	23.4 (12.7) [a]	33.3 (21.8) [a]
Mixed Approach	41.7 (59.0) [a]	1.6 (2.5) [a]	22.5 (12.1) [a]	10.2 (10.1) [a]	32.7 (15.1) [a]	21.1 (13.0) [a]	39.6 (257) [a]
Native Seeding	39.6 (48.0) [a]	1.3 (1.7) [a]	22.5 (12.3) [a]	11.3 (9.5) [a]	31.8 (14.1) [a]	20.6 (10.8) [a]	40.6 (22.9) [a]
Rye Grass	49.2 (44.0) [a]	1.8 (2.0) [a]	23.6 (11.9) [a]	13.0 (9.9) [a]	36.1 (11.3) [a]	21.8 (12.2) [a]	35.8 (19.2) [a]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table 3-5. Mean Russian thistle parameters in August 2008 and 2009.

Treatment	Number of Russian Thistle per 0.1m^2	Number of Flowering Russian Thistle per 0.1m^2	Russian Thistle Biovolume (cm^3)	Russian Thistle Height (cm)
2008				
Control	30.9 (32.2) [a]	4.6 (6.0) [a]	17.3 (24.2) [a]	2.9 (0.9) [a]
Grazing Exclusion	34.9 (34.5) [a]	3.8 (5.4) [a]	9.7 (12.0) [a]	2.8 (0.8) [a]
Hand Pulling	5.9 (7.9) [b]	0.9 (1.8) [b]	1.9 (1.7) [b]	2.3 (0.9) [b]
Herbicide	0.0 [c]	0.0 [c]	0.0 [c]	0.0 [c]
Mixed Approach	0.0 (0.3) [c]	0.0 [bc]	0.0 (0.3) [c]	2.0 [c]
Native Seeding	34.5 (34.4) [a]	2.8 (4.7) [a]	16.8 (29.8) [a]	2.8 (0.7) [a]
Rye Grass	36.8 (38.6) [a]	3.5 (4.7) [a]	26.9 (44.9) [a]	2.9 (0.8) [a]
2009				
Control	13.0 (9.9) [a]	7.0 (7.6) [a]	4.2 (3.3) [a]	3.2 (0.7) [a]
Grazing Exclusion	6.6 (5.7) [b]	2.7 (3.5) [b]	2.5 (3.5) [b]	3.2 (0.9) [a]
Hand Pulling	3.4 (2.5) [b]	1.2 (1.6) [b]	1.5 (1.9) [b]	3.0 (0.9) [a]
Herbicide	0.3 (0.9) [c]	0.0 [c]	0.0 [c]	2.0 [b]
Mixed Approach	0.0 (0.1) [c]	0.0 [c]	0.0 [c]	1.8 [b]
Native Seeding	12.9 (11.3) [a]	5.4 (6.4) [a]	4.6 (4.7) [a]	3.3 (1.2) [a]
Rye Grass	15.3 (13.4) [a]	8.4 (11.0) [a]	4.7 (4.1) [a]	3.3 (0.7) [a]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table 3-6. Mean ground cover (%) in August 2008 and 2009.

Treatment	Russian Thistle Cover	Graminoid Cover	Forb Cover	Total Vegetation Cover	Litter Cover	Exposed Soil
2008						
Control	3.6 (3.8) ^{a}	14.7 (5.5) ^{a}	13.8 (9.1) ^{a}	28.3 (10.7) ^{a}	13.1 (9.2) ^{a}	46.3 (23.1) ^{a}
Grazing Exclusion	2.7 (2.2) ^{a}	14.3 (8.1) ^{a}	9.0 (8.1) ^{bc}	22.3 (9.3) ^{b}	14.0 (12.8) ^{a}	49.9 (27.7) ^{a}
Hand Pulling	0.6 (0.8) ^{b}	14.0 (9.0) ^{a}	9.7 (9.9) ^{bc}	22.7 (10.6) ^{b}	15.6 (16.8) ^{a}	51.3 (26.6) ^{a}
Herbicide	0.0 ^{c}	15.7 (6.8) ^{a}	9.3 (6.8) ^{bc}	23.3 (9.2) ^{b}	17.9 (14.8) ^{a}	47.3 (23.3) ^{a}
Mixed Approach	0.1 (0.4) ^{c}	15.6 (10.2) ^{a}	6.7 (5.7) ^{c}	22.3 (11.0) ^{b}	13.5 (9.6) ^{a}	50.3 (27.6) ^{a}
Native Seeding	3.7 (4.8) ^{a}	16.2 (9.1) ^{a}	8.5 (8.1) ^{bc}	25.8 (10.5) ^{ab}	13.8 (10.7) ^{a}	48.7 (26.4) ^{a}
Rye Grass	3.3 (3.6) ^{a}	14.3 (7.1) ^{a}	10.5 (9.5) ^{b}	25.7 (10.2) ^{ab}	12.9 (11.0) ^{a}	49.5 (24.3) ^{a}
2009						
Control	2.3 (1.9) ^{a}	7.8 (3.5) ^{b}	9.3 (6.1) ^{a}	19.2 (7.6) ^{b}	8.2 (7.2) ^{b}	59.8 (25.0) ^{ab}
Grazing Exclusion	1.2 (1.3) ^{b}	11.5 (8.5) ^{ab}	15.6 (15.6 ^{a})	28.3 (15.3) ^{a}	19.8 (13.4) ^{a}	44.7 (29.5) ^{b}
Hand Pulling	0.7 (0.7) ^{b}	10.1 (6.8) ^{b}	8.5 (9.8) ^{ab}	19.3 (10.3) ^{b}	9.8 (11.9) ^{b}	61.5 (23.8) ^{ab}
Herbicide	0.0 ^{c}	10.1 (4.2) ^{ab}	0.0 ^{c}	10.1 (4.1) ^{c}	11.8 (13.2) ^{b}	66.4 (24.1) ^{a}
Mixed Approach	0.0 ^{c}	12.7 (8.3) ^{a}	0.0 ^{c}	12.6 (8.4) ^{c}	27.9 (21.6) ^{a}	50.8 (32.1) ^{b}
Native Seeding	2.4 (2.1) ^{a}	8.9 (5.3) ^{b}	6.1 (7.0) ^{b}	17.1 (7.8) ^{b}	7.1 (6.1) ^{b}	62.7 (27.4) ^{ab}
Rye Grass	2.4 (2.5) ^{a}	10.3 (5.4) ^{ab}	8.4 (6.8) ^{ab}	21.2 (7.5) ^{ab}	10.5 (10.8) ^{b}	55.6 (25.2) ^{b}

Standard deviations of the mean are presented in brackets

^{a} Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table 3-7. Mean treatment biomass derived from data across sites.

Treatment	Grass Biomass (kg/ha)	Forb Biomass (kg/ha)	Russian Thistle Biomass (kg/ha)	Litter Biomass (kg/ha)	Shrub Biomass (kg/ha)	Total Biomass (kg/ha)
Control	263.3 (122.6) [b]	216.8 (149.1) [a]	55.5 (57.8) [ab]	153.3 (146.0) [b]	31.6 (126.6)	720.5 (240.9) [b]
Grazing Exclusion	412.1 (265.9) [ab]	344.9 (264.3) [a]	23.7 (36.2) [b]	414.8 (198.3) [a]	0.0	1195.5 (484.6) [a]
Hand Pulling	322.2 (156.9) [b]	244.8 (219.9) [a]	26.7 (30.7) [ab]	228.9 (291.9) [b]	0.0	822.7 (383.5) [b]
Herbicide	405.9 (162.1) [ab]	0.3 (1.4) [b]	0.0 [c]	210.7 (218.4) [b]	0.0	617.0 (267.6) [b]
Mixed Approach	601.5 (390.1) [a]	0.0 [b]	0.0 [c]	531.2 (389.7) [a]	11.7 (46.6)	1144.4 (629.1) [ab]
Native Seeding	280.6 (162.1) [b]	146.4 (137.6) [a]	56.6 (49.9) [a]	139.3 (127.1) [b]	2.7 (10.6)	625.5 (237.9) [b]
Rye Grass	333.3 (182.7) [b]	171.8 (133.3) [a]	55.2 (47.5) [ab]	202.5 (251.4) [b]	0.0	762.8 (227.8) [b]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table 3-8. Number of Russian thistle hand pulled across sites in 2008 and 2009.

Site	Number of Russian Thistle Pulled			
	June 2008	July 2008	June 2009	Total
Devona Hill	1,527	72	466	2,065
Edna's Knoll	1,319	137	477	1,933
Little Windy	2,032	183	259	2,474
Talbot Lake	6,120	764	1,229	8,113
Total	21,996	2,312	4,862	29,170

Table 3-9. Mean Russian thistle density and height from June 2009 vegetation assessment across sites.

Treatment	Russian Thistle per $0.1m^2$	Russian Thistle Height (cm)
Control	9.0 (8.2) [a]	2.9 (0.6) [a]
Grazing Exclusion	7.2 (7.5) [ab]	2.8 (1.0) [a]
Hand Pulling	8.0 (10.4) [ab]	2.8 (0.8) [a]
Herbicide	5.7 (8.5) [b]	2.4 (1.0) [a]
Mixed Approach	1.1 (2.7) [c]	2.4 (0.6) [a]
Native Seeding	8.5 (9.5) [a]	2.8 (1.1) [a]
Rye Grass	11.0 (13.5) [a]	2.7 (0.9) [a]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

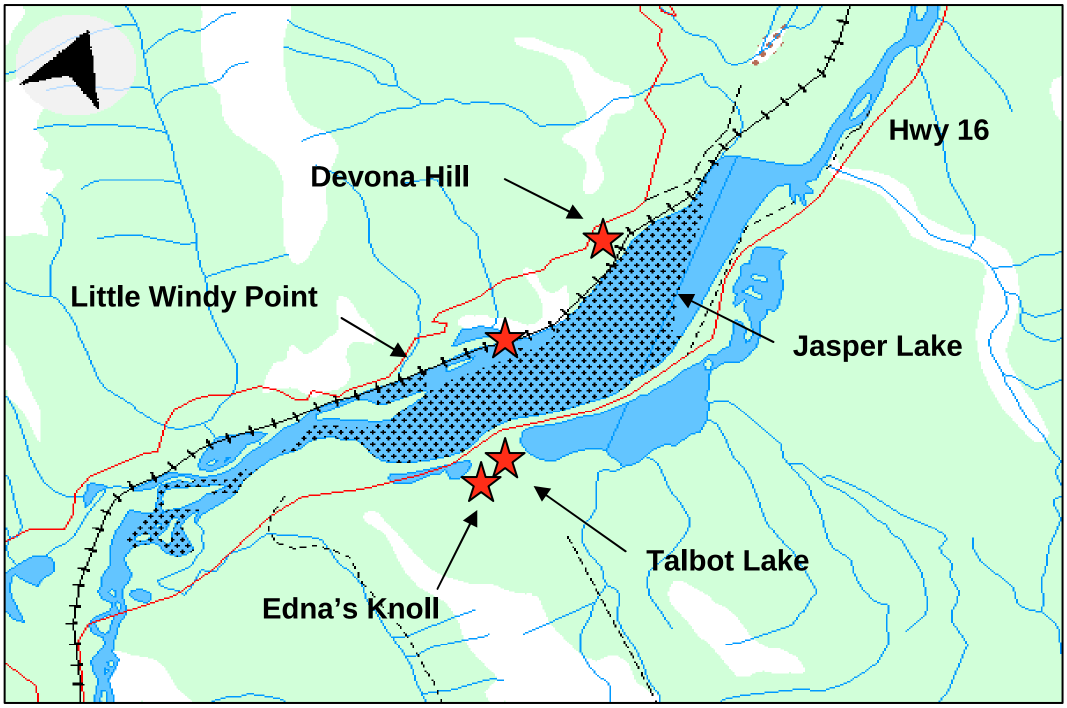

Figure 3-1. Location map of study sites in Jasper National Park.

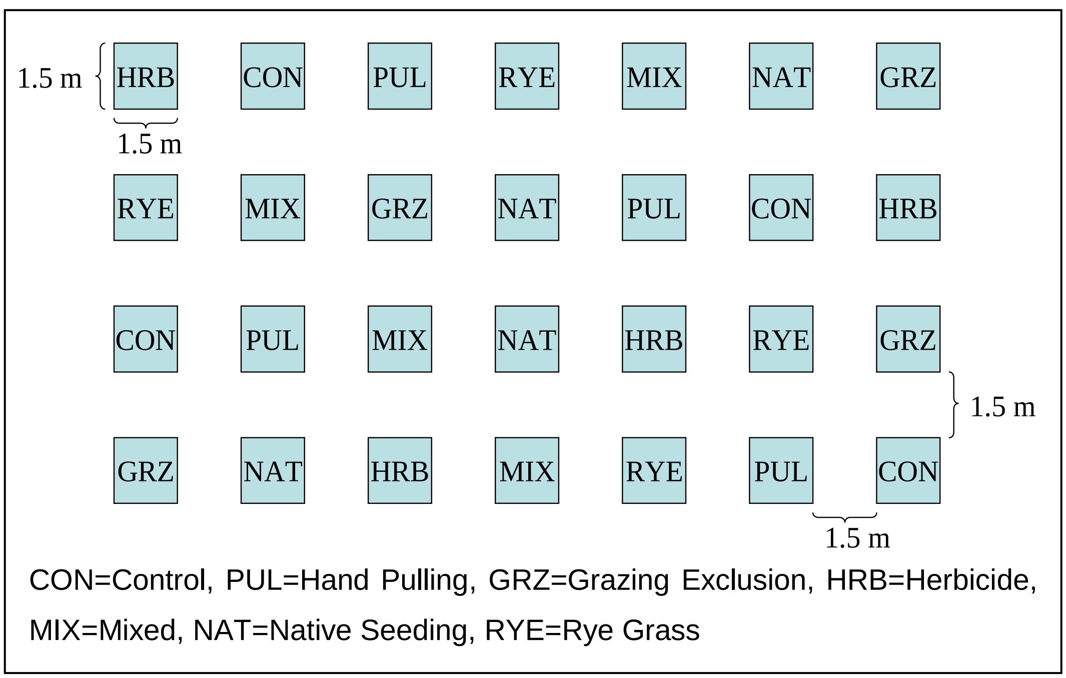

Figure 3-2. Diagram illustrating general treatment plot layout; seven treatments randomly assigned a location along each of four rows.

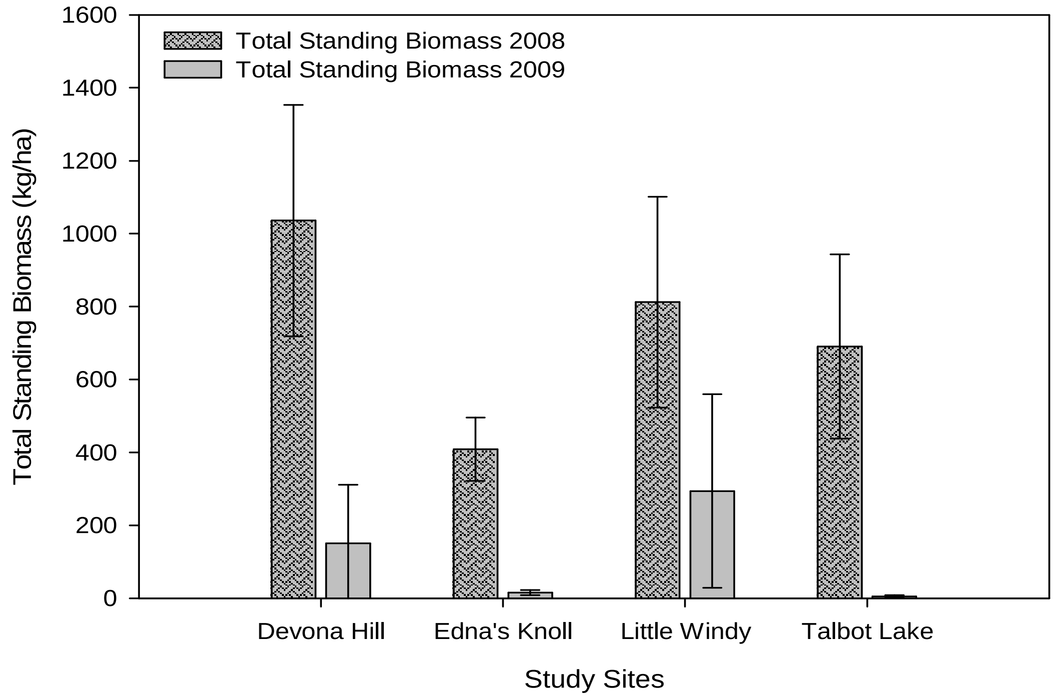

Figure 3-3. Total standing biomass in fall 2008 and spring 2009 at the study sites.

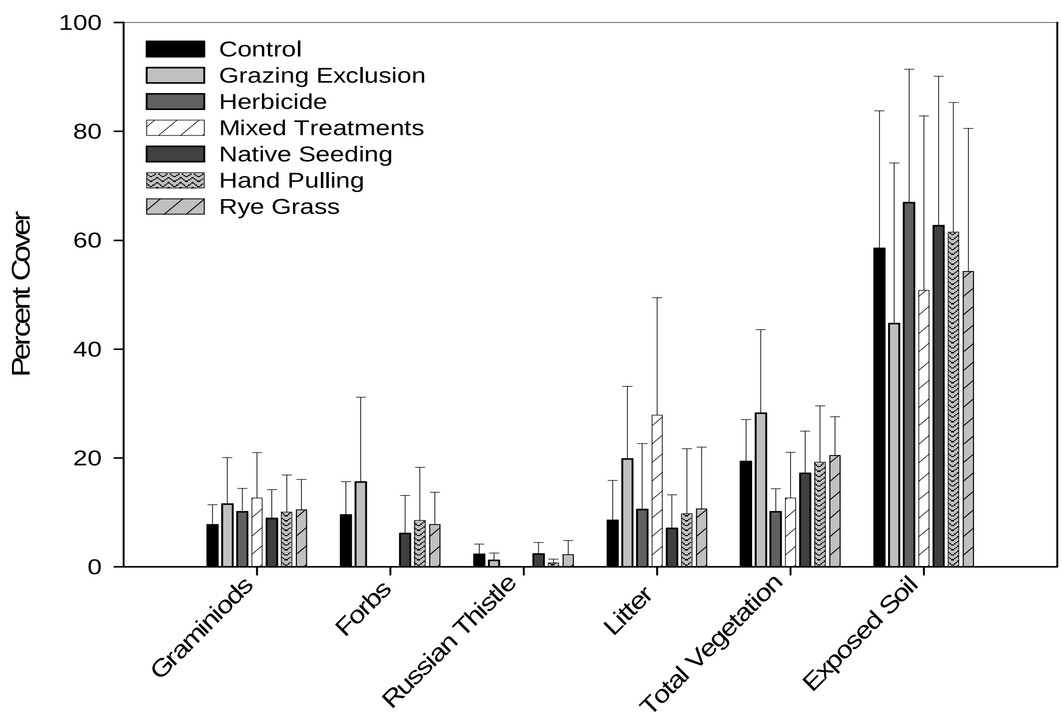

Figure 3-4. August 2009, percent cover of graminoids, forbs, Russian thistle, litter, total vegetation, and exposed soil by treatment type.

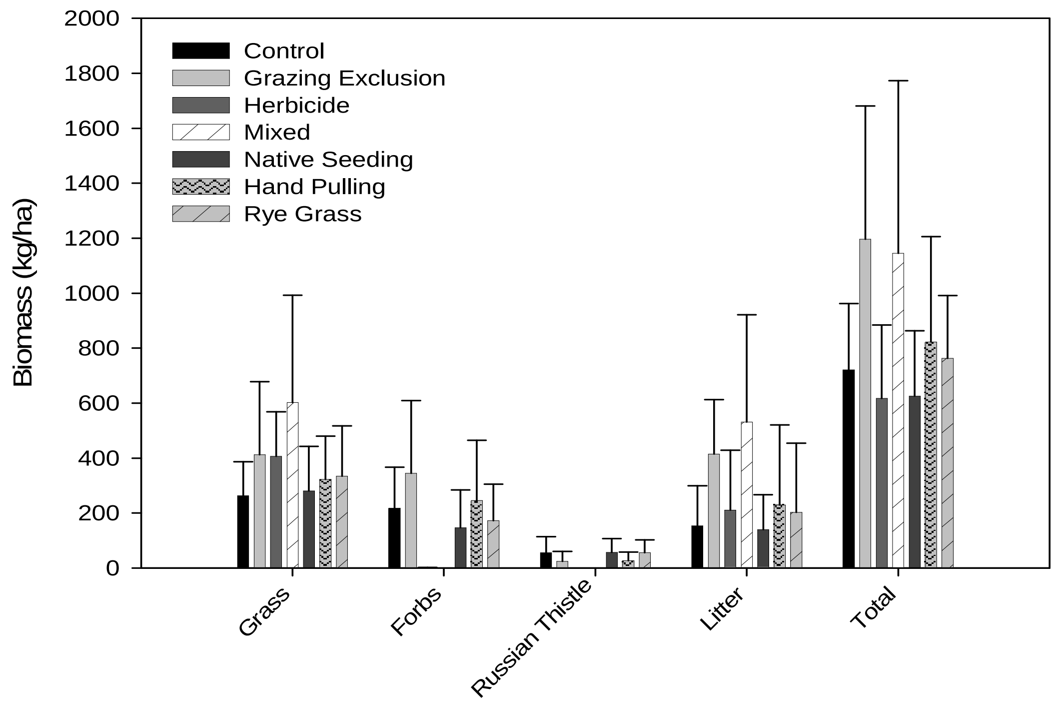

Figure 3-5. Grass, forb, Russian thistle, litter, and total biomass (kg/ha) by treatment.

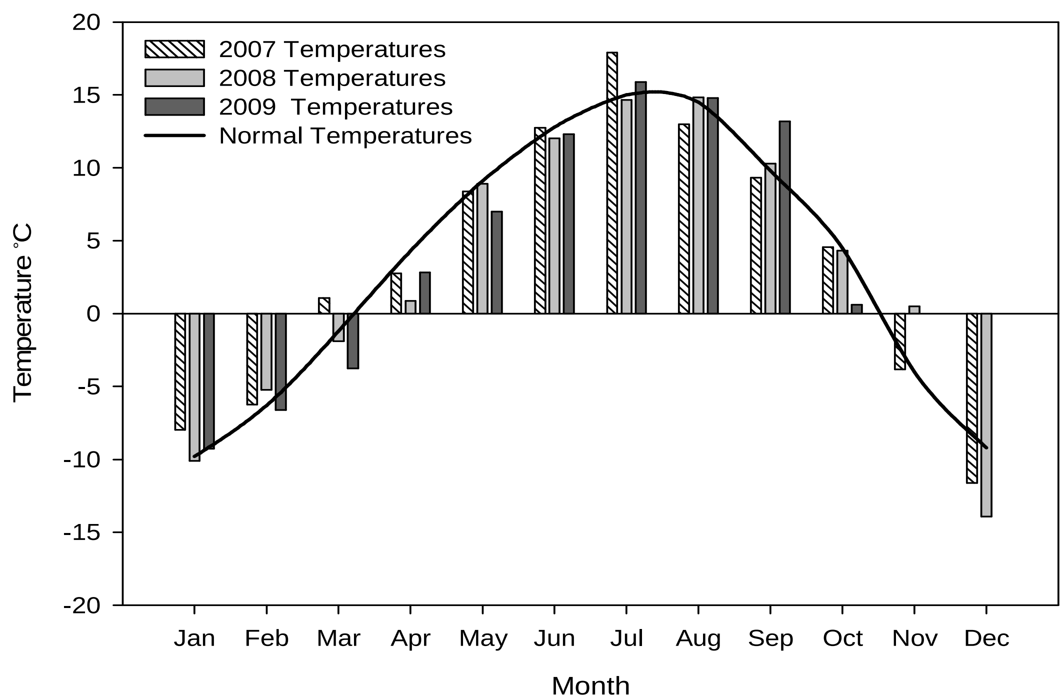

Figure 3-6. Jasper Mean monthly temperatures from 2007 to 2009 relative to the normal mean monthly temperature based on Environment Canada weather data from 1971 to 2000.

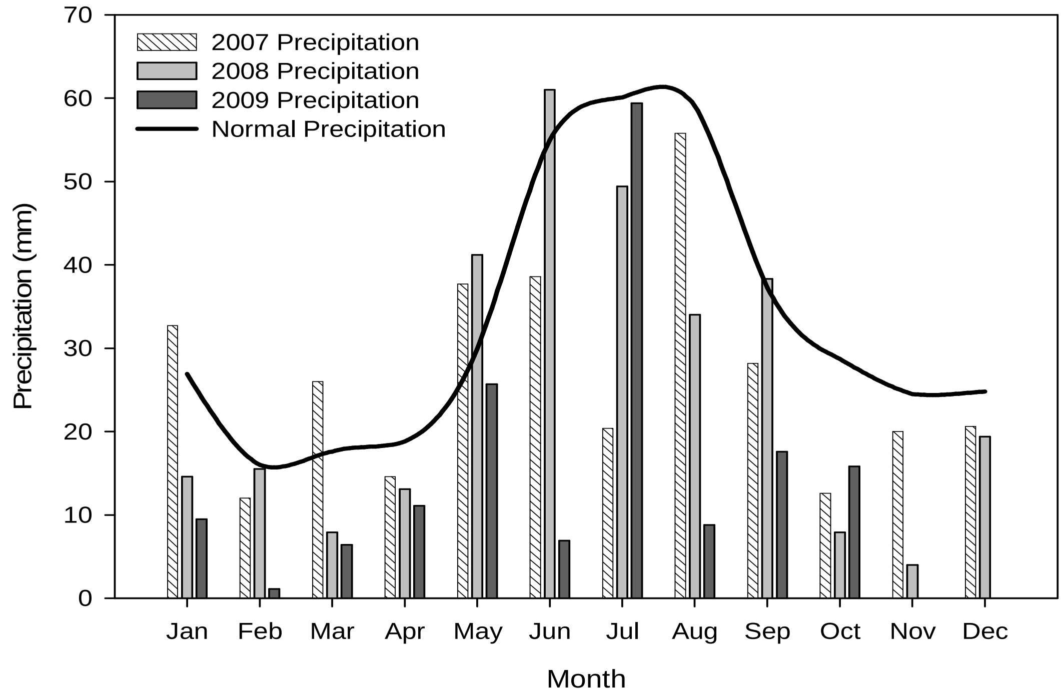

Figure 3-7. Jasper mean monthly precipitation from 2007 to 2009 relative to the normal mean monthly temperature based on Environment Canada weather data from 1971 to 2000.

CHAPTER IV. SYNTHESIS AND FUTURE RESEARCH

1. RESEARCH SUMMARY

In Jasper National Park, Russian thistle (*Salsola tragus* L.) is widespread throughout the lower Athabasca Valley along sandy river banks, lake shores, and dunes. Russian thistle occurs on heavily grazed bighorn sheep winter range sites in native montane grasslands. Plants along the Athabasca River and Jasper Lake were larger and produced more seeds per plant, than those occupying native grassland areas. Seed viability was high, and even though Russian thistle in the grassland sites had limited seed production they were capable of producing enough seed to continually recolonize sites year after year.

Distance and direction of Russian thistle travel during winter was variable and depended on habitat and physical surroundings. Plants in the valley bottom typically moved much further than those in grasslands. Although the average distance was much less, plants moved up to 4 km during winter. Large plants tagged in the valley bottom were not found in grassland sites, suggesting that they do not act as much of a seed source for grassland invasions.

As long as Russian thistle seeds had soil contact, litter thickness did not inhibit plant performance or survival. Litter cover provided improved seedbed conditions for germination, emergence, and establishment of Russian thistle. However, it a thick layer of litter could inhibit Russian thistle seeds from reaching the soil surface, reducing germination and plant performance.

Soil type affected germination and growth of Russian thistle. Russian thistle height was greater on Jasper Lake than Devona soil; however other indicators of plant performance were similar between the two soils. Overall, Russian thistle growth and establishment was greatest in potting soil and poorest in coarse sand. Germination and establishment success was reduced by drying of the rapidly draining coarse sand and hardening of the clay surface. The high germination and survival rates of Russian thistle seeds in the Jasper Lake and Devona soils indicate that this plant is well suited to the soils of the Athabasca Valley.

In growth chambers, above ground Russian thistle growth was greatest under hot and dry treatment conditions. The inverse was found for root length, where root length was longest under cool hydric conditions; this finding could not be fully explained. Based on above ground growth, Russian thistle performance is expected to be better during hot dry summers than during cool wet summers. Comparison of the size of observed Russian thistle skeletons and Environment Canada weather data suggests there is likely a difference in plant growth between years based on summer temperatures and precipitation. If current climate models are correct, then warmer and drier conditions in the future may exacerbate the Russian thistle problem in Jasper National Park.

Range health assessments indicated that winter ranges associated with the four study sites had diminished range health. Overgrazing in the general area has been reported since the mid 1940s. Almost all standing biomass was removed during the winter, limiting litter cover and increasing soil erosion potential.

Of the treatments to manage Russian thistle that were studied, the grazing exclusion treatment was preferred from an ecological management perspective. After only two growing seasons without grazing, there was a significant increase in total vegetation and litter cover, and a significant reduction in Russian thistle numbers, cover, and biomass. The mixed and herbicide treatments were the most effective at eliminating Russian thistle, but they also removed forbs. Hand pulling reduced the number of Russian thistle but would not be practical in grasslands at the scale of the infestation. The seeding treatments failed to germinate and therefore were ineffective.

Results from this study suggest that reduced grazing pressure would make heavily grazed winter range areas more resilient to Russian thistle invasion. The findings are supported by observations of healthy range areas in the valley that receive much less grazing pressure and are free of Russian thistle.

Russian thistle plants during the two years of study in the Athabasca Valley were very small in the overgrazed grassland areas (approximately 3 to 4cm). These plants did not appear to be negatively impacting the native plant community. Russian thistle were typically much smaller than the surrounding native plants and often occupied sites with available exposed soil. This species was highly responsive to annual variation in summer weather, and will exhibit increased growth and vigour under hot dry conditions. During summers with drought like conditions Russian thistle may be more competitive to stressed native species.

2. MANAGEMENT APPLICATIONS

From a management perspective, this study demonstrates that Russian thistle on average do not move far from their original location, however if conditions are favourable they can move far to infest new areas. Seed production in Jasper is limited compared to numbers reported elsewhere, particularly in the grassland habitats. Russian thistle in grassland sites were typically small and did not appear to compete well with native species. These findings, in combination with short lived seed bank viability (2 to 3 years) (Young et al. 1995, Brenzil 2004), should theoretically make controlling this annual species easier than many other weed species (e.g. aggressive perennial species with spreading rhizomes such as Canada thistle (*Cirsium arvense* (L.) Scop.)).

A number of factors make effectively controlling Russian thistle in Jasper National Park difficult. The size and extent of existing Russian thistle infestations, often in difficult to access areas within the lower Athabasca Valley, poses a considerable challenge. Large areas of unvegetated loose sandy soil along the river banks, lake shores, and dunes provide an abundance of ideal habitat for Russian thistle. Strong winter winds in the valley facilitate seed dispersal to new and existing sites. Russian thistle occupies two distinct habitats and thus complicates management by potentially requiring two different strategies.

One of the most effective measures to reduce weed invasion is the proactive management of weed dispersal (Larson et al. 1997). In the valley bottom along the dunes and lake shore, with little native vegetation and large Russian thistle plants, there is an opportunity to use an aggressive hand pulling program in combination with select herbicide use to control the species. An intense program, repeated over a number of consecutive years would greatly reduce the available seed source, and ultimately the number and size of Russian thistle infestations.

Often weed management is reactive, focusing on controlling weed species without addressing the underlying causes of the infestation (Jacobs et al. 1999). In the case of Russian thistle infestations of bighorn sheep winter ranges, overgrazing and poor range condition has allowed this plant to invade areas of native montane grassland. The use of range cages to exclude grazing, even over a period just greater than a year, has demonstrated a reduction in Russian thistle numbers and biomass and an increase in litter cover and biomass. In the greenhouse, a layer of litter covering the soil reduced germination and establishment of Russian thistle. Although not surprising, the findings of this study suggest that reduced winter grazing pressure would promote litter accumulation and improve range health, thus minimizing the potential establishment and persistence Russian thistle.

Even though overgrazing by bighorn sheep has permitted Russian thistle to invade critical winter range areas, management of sheep grazing intensity from Parks Canada's perspective would be difficult. Heavily used winter ranges have unique features that concentrate sheep use and provide important habitat for winter survival. Bighorn sheep numbers and population trends are not currently monitored by Parks Canada, so basic information on range use and changes in stocking rates are not available for consideration in management decision making. Reducing herd size is not a recommended approach to managing overgrazing of specific winter range areas, particularly when basic background population information is not known. With the reintroduction of fire into the Park and progressive prescribed burning programs new winter range areas may become available, thus taking pressure off existing heavily used areas. Rhemtulla et al. (2002) have shown that changes to the natural fire regime in the Park during much of the 1900s have resulted in forest encroachment into montane grasslands. There was an approximate reduction in grassland habitat of 50% between 1949 and 1997 (Rhemtulla et al. 2002).

During summers 2008 and 2009, Russian thistle in the heavily grazed winter range areas were small. In most cases plants did not appear to be aggressively competing with native species for light or other resources. So the question could be asked, "are Russian thistle actually, or enough of, a threat to native grassland communities to warrant active management?" Russian thistle has been in the

Park for at least 65 years and is almost to the point where it could be considered naturalized. However, allowing Russian thistle to remain would go against the Parks' mandate to protect and maintain ecological integrity of its natural areas. If given an opportunity, Russian thistle would take advantage of new disturbances in the Park, such as the Terasen TMX Anchor Loop Pipeline project, and possibly spread to new areas. Although plants in the grassland habitats were small and benign during the study period, it is speculated that during prolonged periods of drought, Russian thistle could pose much more of a threat to stressed native communities.

3. FUTURE RESEARCH

The treatment plots have been left in place at the request of Parks Canada. If future work was to continue, monitoring the time required for forb species to recolonize the treatment plots with herbicide applications and documenting effects of continued rest from grazing in the range cages would be beneficial. Future work should include attempting to successfully seed areas with native grass species and rye grass to determine seeding effectiveness on controlling Russian thistle. It would be valuable to know if seeding efforts would be defeated by winter grazing, and whether widespread seeding of overgrazed areas would result in increased winter sheep survival and ultimately an increase in population.

Russian thistle plants were noticeably smaller in grassland habitats than in sand dune areas. This could be due in part to direct competition with perennial grass species. Past studies found that vesicular-arbuscular mycorrhizal (VAM) fungi in the soil readily invaded the roots of Russian thistle, resulting in reduced growth and survival (Allen and Allen 1988, and Allen et al. 1989). Future research of Russian thistle in Jasper National Park should investigate whether VAM fungi are present in grassland and sand dune soils, and if they are limiting Russian thistle growth on grassland sites.

Further research should be conducted to verify and document the extent that trends in summer weather conditions influence Russian thistle growth and seed production.

Accurate bighorn sheep numbers within the Athabasca Valley are not currently known and fluctuations in population numbers are not regularly monitored. Improved census data of bighorn sheep use on winter range areas would be beneficial in managing grazing pressure and range use. Research should be conducted to determine if recent fires in the valley have increased bighorn winter range, and if opportunities exist to create or improve critical winter ranges areas through prescribed burning.

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APPENDIX A

Study Site Descriptions

1. INTRODUCTION

Four study sites were selected in the lower Athabasca Valley to establish experimental Russian thistle treatment plots (coordinates in Table A1). Locations were based on Russian thistle infestation in an area with ungulate grazing in the montane grassland ecotype; Russian thistle infestation large enough for 28 plots; Russian thistle infestation with a relatively uniform distribution of plants; and sufficient density of Russian thistle plants for multiple individuals in each plot. This section provides additional site descriptions of soil and vegetation details. Photographs of each site are provided in plates 1 through 4.

2. SOILS

Soil texture at Devona Hill was sandy loam at the surface and loamy sand at a depth of 30 cm (Table A2). Soils were rapidly draining, slightly basic with a pH of 7.9 to 8.0, and an electrical conductivity of 0.16 dS/m. Organic matter was 2.0% at the surface and 1.7% at 30 cm. The ratio of carbon to nitrogen (C/N) was 20 at the surface and 33 at 30 cm (Table A3). Stevenson (1986) suggested soils with C/N ratios over 30 are limited in nitrogen, as microorganisms remove available ammonium and nitrate in the soil leaving insufficient quantities for plant use. Penetration resistance (PR) was highest at a depth of 5 cm (149.2 PSI) (Table A4) and uniform at 10 to 30 cm (127.2 PSI). Volumetric soil water at the surface was 1.2% and 3.1% at 30 cm (Table A5). According to the Environment Canada Jasper Warden Station there was no measurable precipitation for 20 days prior to soil water measurements.

Soils at Edna's Knoll were rapidly drained, with a loamy sand texture at the surface and a sandy loam texture at 30 cm depth. Soil was slightly basic with a pH of 7.9 to 8.0, and electrical conductivity was 0.15 dS/m at the surface and 0.13 dS/m at 30 cm. Soil organic matter was the lowest of the four sites; 1.4% at the surface and 1.0% at 30 cm. The soils were not nitrogen deficient. The C/N ratio was 16 at the surface and 20 at 30 cm (Table A3). PR steadily increased from 26.7 PSI at 2.5 cm to 119.2 PSI at 30 cm (Table A4). It rained lightly during the night prior to taking soil water measurements; according the Environment

Canada Jasper Warden Station there was 0.3 mm of precipitation June 16, 2009. Volumetric soil water at the surface (2.4%) was wetter than the other sites; however at 30 cm soil water (3.6%) was similar to that of other sites (Table A5).

Soils at Little Windy were sandy loam textured at the surface and loamy sand textured at 30 cm. Soils were rapidly draining, slightly basic with a pH of 7.9 to 8.0, and an electrical conductivity of 0.18 dS/m at the surface and 0.15 dS/m at 30 cm. Organic matter was 1.8% at the surface and 1.3% at 30 cm. The C/N ratio at the surface was 12, and 18 at 30 cm (Table A3). Based on the C/N ratio, soils were not nitrogen deficient. PR was lowest of the four sites, steadily increasing from 23.6 PSI at 2.5 cm to 111.7 PSI at 30 cm. Soil was dry at the time of soil water measurements; volumetric soil water at the surface was 1.1% and 3.2% at 30 cm (Table A5). According the Environment Canada Jasper Warden Station there was no measurable precipitation for 20 days prior to soil water measurements.

The rapidly draining soils at Talbot Lake were sandy loam textured at the surface and silty loam textured at 30 cm. Soil was slightly basic with a pH of 7.9, and electrical conductivity was 0.22 dS/m at the surface and 0.17 dS/m at 30 cm. Organic matter was highest at this site; 3.9% at the surface and 3.5% at 30 cm. C/N ratio was relatively low compared to that of the other sites; 14 at the soil surface and 30 cm (Table A3). The site generally had higher PR than the other sites; 100.6 PSI at 2.5 cm, increasing to a maximum of 164.4 PSI at 10 cm, before decreasing to 127.4 PSI at 30 cm. It rained lightly during the night prior to taking soil water measurements; 0.3 mm of precipitation 16 June 2009, according the Environment Canada Jasper Warden Station. Volumetric soil water at the surface was 1.8% and 3.9% at 30 cm, similar to soil water measurements taken the previous day at Devona Hill and Little Windy (Table A5).

3.0 VEGETATION

Devona Hill had the lowest vascular plant species diversity of the four study sites. There were 10 species in the treatment area; 3 graminoids and 7 forbs (Table A6). Prior to treatment implementation grasses comprised 51.6% of the vegetation cover. *Agropyron dasystachyum* had the greatest prominence value of the grass species (24.2%), followed by *Stipa comata* (13.6%), and *Koeleria macrantha* (9.0%). Forbs comprised 48.4% of the cover composition, *Artemisia frigida* was most dominant (46.4% prominence). Russian thistle had a prominence value of 1.6%. Total vegetation cover was 39.6%, litter cover was 28.7%, and exposed soil was 25.4% (Table A7).

Edna's Knoll had 19 plant species, 7 graminoids and 12 forbs. Graminoid species comprised 62.7% of the pre treatment vegetation cover. The dominant grass was *Agropyron dasystachyum* (28.8% prominence), followed by *Koeleria macrantha* (18.5%), and *Stipa comata* (10.3%). *Bromus pumpellianus, Calamagrostis montanensis* (Scribn.)*,* and *Poa interior* Rydb. were present in trace amounts. Forbs made up 37.3 % of the cover; *Artemisia frigida* was the dominant forb with a prominence value of 23.2%, Russian thistle was second (4.1%). Total vegetation cover was 32.0% (±8.7 SD), litter cover was 9.7%, and exposed soil was 58.1% (Table A8).

At Little Windy there were 18 plant species, 6 graminoids, 11 forbs, and 1 shrub. Pre treatment graminoid species comprised 65.2 % of the vegetation cover. *Stipa comata* (24.8% prominence) was the dominant grass followed by *Agropyron dasystachyum* (17.5%), *Koeleria macrantha* (5.1%), and *Bromus pumpellianus* Leyss (4.9%). Forbs made up 34.1 % of the cover; *Artemisia frigida* was the dominant forb (10.4% prominence). Other common forbs included *Lithospermum incisum* Lehm (4.8%) and *Commandra umbellata* (L.) Nutt. (2.9%). Russian thistle had a prominence of (4.8%). *Rosa woodsii* Lindl. was the only shrub (0.7% cover composition). Although not in the plots, *Juniperus communis* L. and *Juniperus horizontalis* Moench were common in the general area. Total vegetation cover was 21.5%, litter cover was 29.2%, and exposed soil was 48.0% (Table A9).

Talbot Lake had the greatest species richness of the four study sites. There were 29 species, 7 graminoids, 19 forbs and 2 shrubs. *Agropyron dasystachyum* was the dominant pre treatment grass (29.1% prominence), followed by *Koeleria macrantha* (15.0%), *Stipa comata* (15.0%), and *Calamagrostis montanensis* (7.4%). Trace amounts of *Bromus pumpellianus,* and *Poa interior* were present. Talbot Lake had the highest graminiod cover of the study sites (72.5% of vegetation cover). Forb species made up 27.1% of the cover. *Artemisia frigida* was the dominant forb (13.3% prominence), followed by Russian thistle (4.5%). The only other non native species was *Lappula squarrosa* (retz.) Dumort (blue-bur) (0.1% prominence). *Juniperus horizontalis* made up the 0.7% shrub cover. Total vegetation cover was 43.6%, litter cover was 17.6%, and exposed soil was 16.0% (±9.6 SD). This site was unique, with a moss and lichen cover of 26.7% compared to < 1.5% at the other sites (Table A10). Cover of fecal pellets (2.6%) was also highest.

Table A1. Study site UTM coordinates and elevations (UTM Zone 11, Datum NAD 83)

Site	Easting	Northing	Elevation (m)
Devona Hill	432483	5887283	1,029
Edna’s Knoll	431428	588241	1,043
Little Windy	431613	5885473	1,041
Talbot Lake	431529	5882424	1,049

Table A2. Soil particles size and texture for the study sites.

Site	Soil Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Devona Hill	0 to 10	72.2	24.8	3.0	loamy sand
	30	61.8	31.4	6.8	sandy loam
Edna's Knoll	0 to 10	75.4	22.6	2.0	loamy sand
	30	58.2	39.8	2.0	sandy loam
Little Windy	0 to 10	74.0	23.6	2.4	loamy sand
	30	58.2	37.8	4.0	sandy loam
Talbot Lake	0 to 10	59.0	38.2	2.8	sandy loam
	30	44.0	52.6	3.4	silty loam

Table A3. Mean penetration resistance to 30 cm depth at the study sites in June 2009.

Site	Mean pounds per inch^2 at Depth (cm)				
	2.5	5	10	15	30
Devona Hill	90.0 (25.8)	149.2 (32.2)	127.2 (32.0)	127.2 (32.5)	127.2 (34.3)
Edna's Knoll	26.7 (22.7)	79.7 (27.6)	103.1 (18.8)	112.5 (24.0)	119.2 (34.5)
Little Windy	23.6 (15.8)	54.7 (48.8)	93.3 (35.8)	101.4 (41.4)	111.7 (39.3)
Talbot Lake	100.6 (25.5)	158.1 (44.6)	164.4 (46.4)	163.3 (75.6)	124.7 (56.1)

Standard deviations of the mean are presented in brackets

Table A4. Mean volumetric soil water at the soil surface and 30 cm at the study sites in June 2009.

Site	Volumetric Soil Water at the Surface (%)	Volumetric Soil Water at 30 cm Below Surface (%)
Devona Hill	1.2 (0.4)	3.1 (0.3)
Edna's Knoll	2.4 (3.5)	3.6 (1.0)
Little Windy	1.1 (0.4)	3.2 (0.6)
Talbot Lake	1.8 (0.8)	3.9 (0.8)

Standard deviations of the mean are presented in brackets

Table A5. Soil chemical and physical properties at the study sites at the surface and at a depth of 30 cm.

Site	Soil Depth (cm)	Organic Matter (%)	Organic Carbon (%)	Total Nitrogen (%)	Carbon/Nitrogen Ratio	Electrical Conductivity (dS/m)	pH
Devona Hill	0 to 10	2.0	1.2	0.06	20:1	0.16	7.9
	30	1.7	1.0	0.03	33:1	0.16	8.0
Edna's Knoll	0 to 10	1.4	0.8	0.05	16:1	0.15	7.8
	30	1.0	0.6	0.03	20:1	0.13	8.0
Little Windy	0 to 10	1.8	1.0	0.08	12:1	0.18	7.9
	30	1.3	0.7	0.04	18:1	0.15	8.0
Talbot Lake	0 to 10	3.9	2.3	0.16	14:1	0.22	7.9
	30	2.5	1.4	0.10	14:1	0.17	7.9

Table A6. Plant species recorded at the study sites in 2008 and 2009.

Scientific Name	Common Name	Grazing Response	Devona Hill	Edna's Knoll	Little Windy	Talbot Lake
Agropyron dasystachyum Hook. (Scribn.)	Northern Wheatgrass	Increaser	+	+	+	+
Bromus inermis var. *pumpellianus* Leyss.	Northern Awnless Brome	Decreaser		+	+	+
Calamagrostis montanensis (Scribn.)	Plains Reedgrass	Increaser		+		+
Carex filifolia Nutt.	Thread Leaved Sedge	Decreaser			+	
Carex scirpoidea Michx.	Rush Like Sedge	Decreaser		+	+	+
Koeleria macrantha (Ledeb.) J.A. Shultes f.	June Grass	Increaser	+	+	+	+
Poa interior Rydb.	Inland Bluegrass	Decreaser		+		+
Stipa comata Trin. & Rupr.	Needle and Thread Grass	Decreaser	+	+	+	+
Total Graminoids			3	7	6	7
Arabis hirsuta (L.) Scop.	Hairy Rockcrest	Increaser				+
Artemisia campestris L.	Northern Wormwood	Increaser		+	+	+
Artemisia frigida Willd.	Fringed Sage	Increaser	+	+	+	+
Campanula rotundifolia L.	Common Harebell	Increaser	+	+	+	+
Comandra umbellata (L.) Nutt.	Bastard Toadflax	Increaser	+	+	+	+
Erigeron caespitosus Nutt.	Tufted Fleabane	Increaser	+	+	+	+
Gaillardia aristata Prush	Brown Eyed Susan	Increaser		+	+	+
Galium boreale L.	Northern Bedstraw	Increaser			+	+
Lappula squarrosa (retz.) Dumort	Blue Bur	Invader	+	+		+
Linum lewisii Prush	Wild Blue Flax	Increaser		+	+	+
Lithospermum incisum Lehm.	Puccoon	Increaser	+	+	+	+
Orobanche fasciculata Nutt.	Clustered Broomrape	Increaser		+	+	+

Table A6. Plant species recorded at the study sites in 2008 and 2009. Continued…

Scientific Name	Common Name	Grazing Response	Devona Hill	Edna's Knoll	Little Windy	Talbot Lake
Oxytropis sericea Nutt.	Silky Locoweed	Increaser				+
Potentilla diversifolia Lehm.	Diverse Leaved Cinquefoil	Increaser				+
Potentilla pensylvanica L.	Prairie Cinquefoil	Increaser				+
Salsola targus L.	Russian Thistle	Invader	+	+	+	+
Senecio streptanthifolius Greene	Rocky Mountain Groundsel	Increaser		+		+
Sisyrinchium montanum Greene	Blue Eyed Grass	Increaser				+
Taraxaum ceratophorum (Ledeb.) DC.	Horned Dandelion	Increaser				+
Total Forbs			7	12	11	19
Juniperus communis L.	Common Juniper	Increaser				+
Juniperus horizontalis Moench	Creeping Juniper	Increaser				+
Rosa woodsii Lindl.	Wild Rose	Increaser			+	
Total Shrubs					1	2
Total Species			10	19	18	28

Table A7. Devona Hill mean canopy cover, composition, and prominence (June 2008).

Species	Canopy Cover (%)	Composition (%)	Prominence (%)
Agropyron dasystachyum	10.7 (8.7)	24.5	24.2
Bromus pumpellianus			
Calamagrostis montanensis			
Carex filifolia			
Carex scirpoidea			
Koeleria macrantha	4.5 (4.7)	10.4	9.0
Poa interior			
Stipa comata	7.1 (10.1)	16.3	13.6
Total Graminoids	22.3	51.6	51.6
Arabis hirsuta			
Artemisia campestris			
Artemisia frigida	20.2 (11.3)	46.7	46.4
Campanula rotundifolia			
Commandra umbellata			
Erigeron caespitosus			
Gaillardia aristata			
Galium boreale			
Linum lewisii			
Lithospermum incisum			
Lappula squarrosa	0.1 (0.2)	0.1	0.1
Orobanche fasciculata			
Potentilla pensylvanica			
Salsola targus	0.7 (1.1)	1.6	1.6
Senecio pauciflorus			
Sisyrinchium montanum			
Taraxaum ceratophorum			
Total Forbs	20.9	48.4	48.4
Juniperus horizontalis			
Rosa woodsii			
Total Shrubs			
Total Vegetation	39.6 (14.4)		
Litter	28.7 (13.3)		
Exposed Soil	25.4 (17.4)		
Moss and Lichen	1.4 (2.5)		
Pellets	0.6 (1.3)		

Standard deviations of the mean are presented in brackets

Table A8. Edna's Knoll mean canopy cover, composition, and prominence (June 2008).

Species	Canopy Cover (%)	Composition (%)	Prominence (%)
Agropyron dasystachyum	9.8 (4.6)	28.7	28.8
Bromus pumpellianus	0.1 (0.5)	0.2	0.0
Calamagrostis montanensis	0.3 (1.0)	0.8	0.2
Carex filifolia			
Carex scirpoidea			
Koeleria macrantha	6.4 (4.5)	18.9	18.5
Poa interior	0.6 (1.0)	1.8	1.1
Stipa comata	4.2 (4.2)	12.3	10.3
Total Graminoids	21.4	62.7	62.7
Arabis hirsuta			
Artemisia campestris	0.2 (0.8)	0.6	0.1
Artemisia frigida	8.3 (7.9)	24.2	23.2
Campanula rotundifolia	0.2 (7.9)	0.5	0.1
Commandra umbellata	1.6 (2.2)	4.8	3.3
Erigeron caespitosus	0.1 (0.8)	0.4	0.1
Gaillardia aristata	0.1 (0.7)	0.3	0.1
Galium boreale			
Linum lewisii	0.5 (1.0)	1.4	0.7
Lithospermum incisum			
Lappula squarrosa	0.0 (0.0)	0.0	0.0
Orobanche fasciculata			
Potentilla pensylvanica			
Salsola targus	1.4 (1.6)	4.1	4.1
Senecio pauciflorus	0.3 (0.9)	0.9	0.3
Sisyrinchium montanum			
Taraxaum ceratophorum			
Total Forbs	12.7	37.3	37.3
Juniperus horizontalis			
Rosa woodsii			
Total Shrubs			
Total Vegetation	32.0 (8.7)		
Litter	9.7 (6.0)		
Exposed Soil	58.1 (12.0)		
Moss and Lichen	0.2 (0.6)		
Pellets	0.4 (0.9)		

Standard deviations of the mean are presented in brackets

Table A9. Little Windy mean canopy cover, composition, and prominence (June 2008).

Species	Canopy Cover (%)	Composition (%)	Prominence (%)
Agropyron dasystachyum	4.6 (4.1)	19.4	17.5
Bromus pumpellianus	1.9 (3.4)	7.8	4.9
Calamagrostis montanensis			
Carex filifolia	0.1 (0.5)	0.2	0.0
Carex scirpoidea	0.2 (0.9)	1.0	0.4
Koeleria macrantha	1.8 (2.7)	7.5	5.1
Poa interior			
Stipa comata	7.0 (9.1)	29.4	24.8
Total Graminoids	15.6	65.3	65.2
Arabis hirsuta			
Artemisia campestris	0.0 (0.3)	0.2	0.0
Artemisia frigida	3.2 (5)	13.5	10.4
Campanula rotundifolia			
Commandra umbellata	1.2 (2.3)	5.1	2.9
Erigeron caespitosus	0.3 (1.1)	1.4	0.5
Gaillardia aristata	0.1 (0.4)	0.3	0.1
Galium boreale			
Linum lewisii	0.0 (0.1)	0.0	0.0
Lithospermum incisum	2.0 (4.0)	8.5	4.8
Lappula squarrosa			
Orobanche fasciculata	0.0 (0.0)	0.0	0.0
Potentilla pensylvanica			
Salsola targus	1.2 (1.8)	4.9	4.8
Senecio pauciflorus			
Sisyrinchium montanum			
Taraxaum ceratophorum			
Total Forbs	8.2	34.2	34.1
Juniperus horizontalis			
Rosa woodsii	0.2 (0.8	0.7	0.2
Total Shrubs	0.2	0.7	0.2
Total Vegetation	21.5 (10.1)		
Litter	29.2 (11.6)		
Exposed Soil	48.0 (17.1)		
Moss and Lichen	1.5 (2.5)		
Pellets	0.2 (0.9)		

Standard deviations of the mean are presented in brackets

Table A10. Talbot Lake mean canopy cover, composition, and prominence (June 2008).

Species	Canopy Cover (%)	Composition (%)	Prominence (%)
Agropyron dasystachyum	14.4 (8.5)	0.3	29.1
Bromus pumpellianus	0.0 (0.2)	0.0	0.0
Calamagrostis montanensis	4.7 (5.2)	0.1	7.4
Carex filifolia			
Carex scirpoidea	0.1 (0.4)	0.0	0.0
Koeleria macrantha	7.5 (4.7)	0.2	15.0
Poa interior	0.1 (0.6)	0.0	0.1
Stipa comata	8.9 (11.6)	0.2	15.0
Total Graminoids	35.7	72.5	72.5
Arabis hirsuta	0.0 (0.1)	0.0	0.0
Artemisia campestris	0.0 (0.1)	0.0	0.0
Artemisia frigida	6.8 (6.8)	0.1	13.3
Campanula rotundifolia	1.0 (2.2)	0.0	1.3
Commandra umbellata	0.1 (0.7)	0.0	0.1
Erigeron caespitosus	0.4 (1.3)	0.0	0.4
Gaillardia aristata	0.2 (1.0)	0.0	0.0
Galium boreale	0.1 (0.7)	0.0	0.1
Linum lewisii	1.0 (2.4)	0.0	1.2
Lithospermum incisum	1.0 (3.0)	0.0	1.1
Lappula squarrosa	0.1 (0.4)	0.0	0.1
Orobanche fasciculata			
Potentilla pensylvanica	0.0 (0.2)	0.0	0.0
Salsola targus	2.2 (2.9)	0.0	4.5
Senecio pauciflorus	0.0 (0.2)	0.0	0.0
Sisyrinchium montanum	0.0 (0.3)	0.0	0.0
Taraxaum ceratophorum	0.2 (1.4)	0.0	0.1
Total Forbs	13.3	27.0	27.1
Juniperus horizontalis	0.2 (2.1)	0.0	0.1
Rosa woodsii			
Total Shrubs	0.2	0.5	0.1
Total Vegetation	43.6 (9.4)		
Litter	17.6 (5.4)		
Exposed Soil	16.0 (9.6)		
Moss and Lichen	26.7 (13.8)		
Pellets	2.6 (3.0)		

Standard deviations of the mean are presented in brackets

Plate A1. Overview of the Devona Hill site (12 August 2009).

Plate A2. Overview of the Edna's Knoll site (15 August 2009).

Plate A3. Overview of the Little Windy site (22 August 2008).

Plate A4. Overview of the Talbot Lake site (24 June 2008).

APPENDIX B

P-Values and Site Means

Table B1. P-values for multiple comparisons of litter treatments in the greenhouse on Russian thistle plant height, leaf number, maximum leaf length, plant vigour, germination, and survival.

Treatment Comparison	Plant Height	Leaf Number	Maximum Leaf Length	Vigour	Germination	Survival
1000 vs. 3000	<0.001	0.341	0.014	0.189	0.350	0.832
1000 vs. 4000	0.003	0.085	0.048	0.187	0.868	0.999
1000 vs. 4000T	0.046	0.185	0.142	0.661	0.006	0.018
1000 vs. 5000	<0.001	<0.001	<0.001	<0.001	0.730	0.966
1000 vs. Control	0.703	0.023	0.003	<0.001	0.701	0.096
3000 vs. 4000	0.338	0.421	0.644	0.979	0.271	0.966
3000 vs. 4000T	0.133	0.027	0.470	0.461	<0.001	<0.001
3000 vs. 5000	0.547	<0.001	0.058	0.008	0.556	0.999
3000 vs. Control	0.001	0.148	0.440	<0.001	0.187	0.004
4000 vs. 4000T	0.524	0.004	0.760	0.453	0.010	0.006
4000 vs. 5000	0.123	0.002	0.020	0.010	0.609	0.999
4000 vs. Control	0.020	0.485	0.238	<0.001	0.828	0.036
4000T vs. 5000	0.043	<0.001	0.017	0.002	0.002	0.002
4000T vs. Control	0.127	0.001	0.174	<0.001	0.019	0.985
5000 vs. Control	<0.001	0.036	0.345	0.039	0.466	0.012

Table B2. P-values for multiple comparisons of soil texture treatments in the greenhouse on Russian thistle plant height, leaf number, maximum leaf length, plant vigour, germination, and survival.

Treatment Comparison	Plant Height	Leaf Number	Maximum Leaf Length	Vigour	Germination	Survival
Clay vs. Devona	< 0.001	< 0.001	< 0.001	< 0.001	0.016	0.020
Clay vs. Jasper	< 0.001	< 0.001	< 0.001	< 0.001	0.002	0.002
Clay vs.Potting	0.003	0.345	0.116	0.617	0.054	0.052
Clay vs. Sand	< 0.001	< 0.001	< 0.001	< 0.001	0.098	0.825
Devona vs. Jasper	0.027	0.901	0.572	0.055	0.514	0.426
Devona vs. Potting	< 0.001	< 0.001	< 0.001	< 0.001	0.629	0.696
Devona vs. Sand	0.425	0.001	< 0.001	0.095	0.449	0.035
Jasper vs. Potting	< 0.001	< 0.001	< 0.001	< 0.001	0.257	0.235
Jasper vs. Sand	0.006	< 0.001	< 0.001	0.001	0.159	0.004
Potting vs. Sand	< 0.001	< 0.001	< 0.001	< 0.001	0.784	0.085

Table B3. P-values for growth chamber temperature and moisture treatments.

Parameter	Treatment	Treatment Comparison	P-Value
Plant Height	Temperature	Hot vs. Cool	<0.001
	Moisture	Xeric vs. Hydric	<0.001
		Xeric vs. Mesic	0.105
		Mesic vs. Hydric	0.162
	Interaction of temperature and moisture		0.896
Root Length	Temperature	Hot vs. Cool	<0.001
	Moisture	Xeric vs. Hydric	0.293
		Xeric vs. Mesic	0.293
		Mesic vs. Hydric	0.293
	Interaction of temperature and moisture		0.593
Leaf Number	Temperature	Hot vs. Cool	<0.001
	Moisture	Xeric vs. Hydric	0.011
		Xeric vs. Mesic	0.897
		Mesic vs. Hydric	0.036
	Interaction of temperature and moisture		0.489

Table B4. June 2008 vegetation assessment Kruskal-Wallis chi square values for number of Russian thistle and selected cover parameters.

	Number of Russian Thistle	Russian Thistle Cover	Graminoid Cover	Forb Cover	Total Vegetation Cover	Litter Cover	Exposed Soil
Chi Square Value	0.091	0.053	0.270	0.191	0.339	0.779	0.740

The absence of significant differences between study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B5. Devona Hill, June 2008 mean Russian thistle density and mean percent covers.

Treatment	Number of Russian Thistle per 0.1m^2	Russian Thistle	Graminoid	Forb	Total Vegetation	Litter	Exposed Soil
Control	21.5 (21.8) [b]	0.3 (0.4) [b]	20.3 (10.8) [a]	16.8 (11.7) [a]	34.2 (13.2) [a]	26.6 (10.6) [a]	38.2 (18.6) [a]
Grazing Exclusion	38.3 (32.9) [ab]	0.8 (0.8) [ab]	19.7 (8.9) [a]	20.0 (8.9) [a]	40.3 (11.4) [a]	35.8 (7.5) [a]	21.3 (11.4) [a]
Hand Pulling	28.8 (17.2) [b]	0.6 (0.6) [b]	25.4 (12.9) [a]	18.0 (12.2) [a]	39.1 (14.5) [a]	30.5 (10.4) [a]	30.8 (16.7) [a]
Herbicide	14.4 (18.9) [b]	0.3 (0.6) [b]	30.8 (15.3) [a]	19.3 (10.7) [a]	45.7 (11.5) [a]	31.6 (8.7) [a]	22.2 (12.2) [a]
Mixed Approach	41.1 (41.5) [ab]	0.7 (1.0) [ab]	19.2 (10.9) [a]	18.8 (14.5) [a]	38.3 (20.6) [a]	27.8 (12.9) [a]	33.5 (27.3) [a]
Native Seeding	28.8 (17.2) [ab]	0.6 (0.6) [ab]	25.4 (12.9) [a]	18.0 (12.2) [a]	39.1 (14.5) [a]	30.5 (10.4) [a]	30.8 (16.7) [a]
Rye Grass	59.5 (40.8) [a]	1.8 (2.2) [a]	18.0 (6.6) [a]	24.8 (6.1) [a]	42.2 (6.1) [a]	26.6 (8.8) [a]	30.4 (8.3) [a]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B6. Edna's Knoll, June 2008 mean number of Russian thistle and mean percent covers.

Treatment	Number of Russian Thistle per 0.1m^2	Russian Thistle	Graminoid	Forb	Total Vegetation	Litter	Exposed Soil
Control	67.6 (41.4) [a]	3.1 (2.1) [a]	18.4 (5.2) [a]	15.6 (8.1) [a]	36.3 (9.6) [a]	7.9 (5.1) [a]	55.9 (12.9) [a]
Grazing Exclusion	31.1 (26.8) [ab]	0.7 (0.8) [b]	24.8 (8.8) [a]	12.8 (12.6) [a]	37.0 (9.0) [a]	11.2 (5.5) [a]	51.4 (10.7) [a]
Hand Pulling	21.3 (29.2) [b]	0.7 (1.2) [b]	24.3 (6.4) [a]	8.7 (5.8) [a]	29.9 (9.2) [a]	10.7 (7.9) [a]	59.2 (15.6) [a]
Herbicide	34.6 (25.9) [ab]	1.4 (1.0) [ab]	20.9 (9.3) [a]	10.3 (6.8) [a]	30.3 (9.8) [a]	8.6 (5.2) [a]	62.0 (12.0) [a]
Mixed Approach	33.9 (22.6) [ab]	1.2 (1.1) [b]	19.5 (5.2) [a]	8.9 (4.9) [a]	27.7 (5.6) [a]	8.3 (4.7) [a]	63.4 (5.1) [a]
Native Seeding	24.4 (18.4) [b]	0.4 (0.4) [b]	20.8 (3.4) [a]	12.3 (7.0) [a]	31.1 (8.6) [a]	12.8 (6.8) [a]	55.9 (12.9) [a]
Rye Grass	69.9 (46.9) [a]	2.4 (1.6) [ab]	20.8 (8.4) [a]	10.7 (7.6) [a]	32.8 (7.5) [a]	9.3 (4.3) [a]	57.5 (9.0) [a]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B7. Little Windy, June 2008 mean number of Russian thistle and mean percent covers.

Treatment	Number of Russian Thistle per 0.1m^2	Russian Thistle	Graminoid	Forb	Total Vegetation	Litter	Exposed Soil
Control	9.5 (7.9) [a]	0.9 (1.4) [a]	15.8 (8.8) [ab]	7.8 (5.0) [a]	28.3 (9.3) [ab]	21.3 (9.8) [a]	48.1 (15.3) [ab]
Grazing Exclusion	26.2 (25.1) [a]	1.1 (1.2) [a]	11.5 (6.2) [b]	6.5 (5.5) [a]	28.0 (10.0) [ab]	16.5 (5.2) [a]	54.6 (11.3) [ab]
Hand Pulling	19.5 (26.4) [a]	0.7 (1.2) [a]	14.7 (6.1) [ab]	9.8 (6.0) [a]	28.9 (12.9) [a]	22.6 (7.0) [a]	48.7 (13.2) [ab]
Herbicide	11.9 (17.4) [a]	2.1 (3.2) [a]	23.3 (10.4) [a]	7.4 (7.3) [a]	33.4 (9.9) [a]	28.6 (9.9) [a]	35.8 (13.9) [b]
Mixed Approach	6.2 (7.3) [a]	1.0 (1.3) [a]	16.0 (11.0) [b]	4.2 (4.6) [a]	29.6 (13.8) [a]	23.3 (14.3) [a]	46.5 (24.9) [ab]
Native Seeding	26.7 (34.2) [a]	1.9 (2.0) [a]	8.9 (4.7) [b]	6.7 (7.8) [a]	22.8 (11.6) [b]	15.1 (6.7) [a]	61.5 (11.9) [a]
Rye Grass	15.9 (12.6) [a]	0.6 (0.8) [a]	18.2 (10.3) [ab]	6.7 (8.1) [a]	34.4 (11.4) [a]	24.1 (10.5) [a]	41.0 (15.2) [b]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B8. Talbot Lake, June 2008 mean number of Russian thistle and mean percent covers.

Treatment	Number of Russian Thistle per 0.1m^2	Russian Thistle	Graminoid	Forb	Total Vegetation	Litter	Exposed Soil
Control	67.3 (72.4) [a]	1.8 (1.2) [a]	32.3 (5.6) [a]	11.9 (7.1) [ab]	16.9 (5.0) [a]	42.2 (5.8) [a]	13.3 (7.7) [a]
Grazing Exclusion	46.5 (30.6) [a]	1.4 (1.0) [a]	35.0 (13.9) [a]	12.8 (6.2) [ab]	16.6 (6.9) [a]	42.8 (10.6) [a]	19.6 (11.5) [a]
Hand Pulling	105.2 (163.3) [a]	3.2 (5.4) [a]	40.2 (13.1) [a]	5.6 (4.5) [b]	17.8 (4.7) [a]	43.4 (12.3) [a]	23.7 (11.3) [a]
Herbicide	45.3 (41.8) [a]	1.1 (1.2) [a]	35.1 (7.6) [a]	19.8 (9.7) [a]	19.8 (7.1) [a]	49.2 (13.0) [a]	13.1 (7.5) [a]
Mixed Approach	85.4 (95.3) [a]	3.6 (4.0) [a]	35.1 (11.0) [a]	8.8 (7.6) [b]	18.9 (6.0) [a]	41.4 (8.6) [a]	15.1 (8.0) [a]
Native Seeding	78.4 (76.3) [a]	2.6 (2.2) [a]	37.4 (8.4) [a]	7.9 (6.4) [b]	16.9 (2.7) [a]	43.6 (6.2) [a]	17.3 (7.6) [a]
Rye Grass	51.6 (49.6) [a]	2.3 (2.5) [a]	37.3 (10.2) [a]	9.8 (6.4) [b]	16.7 (4.1) [a]	45.3 (6.0) [a]	14.1 (10.2) [a]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B9. Devona Hill, June 2008 P-values for multiple treatment comparisons of number of Russian thistle and mean percent cover.

Treatment	Number of Russian Thistle per 0.1m^2	Russian Thistle	Graminoid*	Forb	Total Vegetation	Litter*	Exposed Soil*
Control vs. Grazing Exclusion	0.134	0.129	0.253	0.992	0.925	0.061	0.062
Control vs. Herbicide	0.301	0.923	0.253	0.998	0.386	0.061	0.062
Control vs. Mixed	0.188	0.321	0.253	1.000	0.989	0.061	0.062
Control vs. Native Seeding	0.193	0.323	0.253	1.000	0.974	0.061	0.062
Control vs. Hand Pulling	0.900	0.719	0.253	0.749	0.883	0.061	0.062
Control vs. Rye Grass	0.002	0.006	0.253	0.590	0.782	0.061	0.062
Grazing Exclusion vs. Herbicide	0.011	0.106	0.253	1.000	0.962	0.061	0.062
Grazing Exclusion vs. Mixed	0.857	0.598	0.253	1.000	1.000	0.061	0.062
Grazing Exclusion vs. Native Seeding	0.844	0.595	0.253	1.000	1.000	0.061	0.062
Grazing Exclusion vs. Hand Pulling	0.170	0.246	0.253	0.985	1.000	0.061	0.062
Grazing Exclusion vs. Rye Grass	0.099	0.222	0.253	0.942	1.000	0.061	0.062
Herbicide vs. Mixed	0.019	0.277	0.253	1.000	0.843	0.061	0.062
Herbicide vs. Native Seeding	0.020	0.279	0.253	1.000	0.900	0.061	0.062
Herbicide vs. Hand Pulling	0.246	0.648	0.253	0.966	0.980	0.061	0.062
Herbicide vs. Rye Grass	0.000	0.005	0.253	0.897	0.996	0.061	0.062
Mixed vs. Native Seeding	0.987	0.997	0.253	1.000	1.000	0.061	0.062
Mixed vs. Hand Pulling	0.233	0.528	0.253	0.938	0.999	0.061	0.062
Mixed vs. Rye Grass	0.067	0.080	0.253	0.844	0.993	0.061	0.062
Native Seeding vs. Hand Pulling	0.240	0.530	0.253	0.884	1.000	0.061	0.062
Native Seeding vs. Rye Grass	0.065	0.080	0.253	0.759	0.998	0.061	0.062
Hand Pulling vs. Rye Grass	0.003	0.017	0.253	1.000	1.000	0.061	0.062

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B10. Edna's Knoll, June 2008 P-values for multiple treatment comparisons of number of Russian thistle and mean percent cover.

Treatment	Number of Russian Thistle per 0.1m^2	Russian Thistle	Graminoid*	Forb*	Total Vegetation	Litter*	Exposed Soil*
Control vs. Grazing Exclusion	0.032	0.002	0.194	0.334	1.000	0.399	0.167
Control vs. Herbicide	0.055	0.075	0.194	0.334	0.594	0.399	0.167
Control vs. Mixed	0.050	0.033	0.194	0.334	0.183	0.399	0.167
Control vs. Native Seeding	0.007	0.000	0.194	0.334	0.745	0.399	0.167
Control vs. Hand Pulling	0.000	0.000	0.194	0.334	0.531	0.399	0.167
Control vs. Rye Grass	0.685	0.552	0.194	0.334	0.953	0.399	0.167
Grazing Exclusion vs. Herbicide	0.821	0.200	0.194	0.334	0.469	0.399	0.167
Grazing Exclusion vs. Mixed	0.851	0.355	0.194	0.334	0.122	0.399	0.167
Grazing Exclusion vs. Native Seeding	0.584	0.506	0.194	0.334	0.625	0.399	0.167
Grazing Exclusion vs. Hand Pulling	0.142	0.630	0.194	0.334	0.409	0.399	0.167
Grazing Exclusion vs. Rye Grass	0.082	0.014	0.194	0.334	0.896	0.399	0.167
Herbicide vs. Mixed	0.970	0.722	0.194	0.334	0.990	0.399	0.167
Herbicide vs. Native Seeding	0.439	0.052	0.194	0.334	1.000	0.399	0.167
Herbicide vs. Hand Pulling	0.090	0.078	0.194	0.334	1.000	0.399	0.167
Herbicide vs. Rye Grass	0.130	0.235	0.194	0.334	0.990	0.399	0.167
Mixed vs. Native Seeding	0.461	0.112	0.194	0.334	0.958	0.399	0.167
Mixed vs. Hand Pulling	0.098	0.160	0.194	0.334	0.995	0.399	0.167
Mixed vs. Rye Grass	0.121	0.123	0.194	0.334	0.758	0.399	0.167
Native Seeding vs. Hand Pulling	0.357	0.854	0.194	0.334	1.000	0.399	0.167
Native Seeding vs. Rye Grass	0.022	0.002	0.194	0.334	0.999	0.399	0.167
Hand Pulling vs. Rye Grass	0.001	0.003	0.194	0.334	0.981	0.399	0.167

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B11. Little Windy, June 2008 P-values for multiple treatment comparisons of number of Russian thistle and mean percent cover.

Treatment	Number of Russian Thistle per $0.1m^2$ *	Russian Thistle*	Graminoid	Forb*	Total Vegetation	Litter	Exposed Soil
Control vs. Grazing Exclusion	0.502	0.184	0.252	0.331	0.149	1.000	0.949
Control vs. Herbicide	0.502	0.184	0.098	0.331	0.093	0.922	0.469
Control vs. Mixed	0.502	0.184	0.757	0.331	0.897	1.000	1.000
Control vs. Native Seeding	0.502	0.184	0.032	0.331	0.077	0.905	0.365
Control vs. Hand Pulling	0.502	0.184	0.913	0.331	0.782	1.000	1.000
Control vs. Rye Grass	0.502	0.184	0.578	0.331	0.716	0.837	0.924
Grazing Exclusion vs. Herbicide	0.502	0.184	0.005	0.331	0.002	0.905	0.062
Grazing Exclusion vs. Mixed	0.502	0.184	0.403	0.331	0.189	1.000	0.866
Grazing Exclusion vs. Native Seeding	0.502	0.184	0.319	0.331	0.744	0.922	0.932
Grazing Exclusion vs. Hand Pulling	0.502	0.184	0.299	0.331	0.085	1.000	0.968
Grazing Exclusion vs. Rye Grass	0.502	0.184	0.089	0.331	0.071	0.810	0.350
Herbicide vs. Mixed	0.502	0.184	0.049	0.331	0.071	0.982	0.631
Herbicide vs. Native Seeding	0.502	0.184	<0.001	0.331	0.001	0.268	0.002
Herbicide vs. Hand Pulling	0.502	0.184	0.077	0.331	0.161	0.959	0.412
Herbicide vs. Rye Grass	0.502	0.184	0.271	0.331	0.189	1.000	0.982
Mixed vs. Native Seeding	0.502	0.184	0.067	0.331	0.101	0.771	0.237
Mixed vs. Hand Pulling	0.502	0.184	0.841	0.331	0.685	1.000	1.000
Mixed vs. Rye Grass	0.502	0.184	0.386	0.331	0.622	0.943	0.977
Native Seeding vs. Hand Pulling	0.502	0.184	0.042	0.331	0.041	0.845	0.420
Native Seeding vs. Rye Grass	0.502	0.184	0.007	0.331	0.033	0.176	0.031
Hand Pulling vs. Rye Grass	0.502	0.184	0.506	0.331	0.930	0.898	0.893

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B12. Talbot Lake, June 2008 P-values for multiple treatment comparisons of number of Russian thistle and mean percent cover.

Treatment	Number of Russian Thistle per 0.1m^2 *	Russian Thistle*	Graminoid*	Forb	Total Vegetation	Litter	Exposed Soil*
Control vs. Grazing Exclusion	0.868	0.591	0.774	0.722	1.000	1.000	0.131
Control vs. Herbicide	0.868	0.591	0.774	0.086	0.533	0.841	0.131
Control vs. Mixed	0.868	0.591	0.774	0.209	1.000	0.971	0.131
Control vs. Native Seeding	0.868	0.591	0.774	0.167	1.000	1.000	0.131
Control vs. Hand Pulling	0.868	0.591	0.774	0.019	1.000	1.000	0.131
Control vs. Rye Grass	0.868	0.591	0.774	0.398	0.981	1.000	0.131
Grazing Exclusion vs. Herbicide	0.868	0.591	0.774	0.174	0.648	0.762	0.131
Grazing Exclusion vs. Mixed	0.868	0.591	0.774	0.107	1.000	0.939	0.131
Grazing Exclusion vs. Native Seeding	0.868	0.591	0.774	0.082	1.000	1.000	0.131
Grazing Exclusion vs. Hand Pulling	0.868	0.591	0.774	0.007	1.000	0.998	0.131
Grazing Exclusion vs. Rye Grass	0.868	0.591	0.774	0.230	0.995	1.000	0.131
Herbicide vs. Mixed	0.868	0.591	0.774	0.003	0.408	1.000	0.131
Herbicide vs. Native Seeding	0.868	0.591	0.774	0.002	0.519	0.621	0.131
Herbicide vs. Hand Pulling	0.868	0.591	0.774	<0.001	0.743	0.971	0.131
Herbicide vs. Rye Grass	0.868	0.591	0.774	0.010	0.952	0.783	0.131
Mixed vs. Native Seeding	0.868	0.591	0.774	0.900	1.000	0.859	0.131
Mixed vs. Hand Pulling	0.868	0.591	0.774	0.279	0.998	0.999	0.131
Mixed vs. Rye Grass	0.868	0.591	0.774	0.682	0.947	0.949	0.131
Native Seeding vs. Hand Pulling	0.868	0.591	0.774	0.338	1.000	0.985	0.131
Native Seeding vs. Rye Grass	0.868	0.591	0.774	0.592	0.979	1.000	0.131
Hand Pulling vs. Rye Grass	0.868	0.591	0.774	0.135	0.999	0.998	0.131

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B13. Devona Hill, August 2008 and 2009 mean percent covers.

Treatment	Russian Thistle	Graminoid	Forb	Total Vegetation	Litter	Exposed Soil
2008						
Control	1.5 (1.3) [a]	13.8 (6.2) [a]	16.6 (8.5) [ab]	27.3 (10.0) [ab]	18.3 (12.7) [a]	55.9 (21.3) [a]
Grazing Exclusion	2.8 (3.8) [a]	16.4 (8.5) [a]	15.0 (7.2) [ab]	29.8 (7.2) [ab]	31.0 (13.6) [a]	34.3 (18.6) [b]
Hand Pulling	0.2 (0.4) [b]	11.4 (6.7) [a]	20.0 (13.2) [a]	31.4 (13.5) [a]	32.6 (19.3) [a]	36.1 (19.1) [b]
Herbicide	0.0 [c]	14.8 (6.4) [a]	10.3 (6.3) [b]	23.5 (5.6) [ab]	26.9 (16.7) [a]	45.2 (22.5) [ab]
Mixed Approach	0.1 (0.4) [bc]	10.3 (5.8) [a]	6.6 (6.8) [b]	17.6 (11.4) [b]	20.2 (12.1) [a]	61.0 (24.2) [a]
Native Seeding	1.7 (1.8) [a]	16.5 (8.1) [a]	14.5 (8.7) [ab]	29.7 (11.0) [ab]	24.8 (13.8) [a]	44.4 (22.7) [ab]
Rye Grass	2.9 (2.6) [a]	10.6 (4.5) [a]	16.4 (12.3) [ab]	26.4 (13.5) [ab]	17.5 (12.2) [a]	54.4 (19.9) [ab]
2009						
Control	1.6 (0.9) [a]	7.6 (3.0) [a]	12.3 (6.3) [a]	21.3 (6.9) [b]	9.8 (5.7) [b]	67.8 (10.3) [a]
Grazing Exclusion	0.9 (0.8) [ab]	12.5 (10.5 [a])	20.7 (16.5) [a]	34.0 (11.7) [a]	25.3 (16.4 [ab])	40.4 (19.8) [b]
Hand Pulling	0.5 (0.5) [b]	8.3 (2.1) [a]	19.3 (12.4) [a]	27.7 (11.3) [ab]	22.5 (17.2) [ab]	48.5 (20.7) [b]
Herbicide	0.0 [c]	10.2 (1.6) [ab]	0.0 [b]	10.3 (1.5) [c]	19.5 (13.2) [b]	69.3 (12.9) [a]
Mixed Approach	0.0 [c]	12.1 (4.0) [b]	0.0 [b]	12.1 (4.1) [c]	46.7 (26.3) [a]	41.7 (28.1) [b]
Native Seeding	1.8 (1.6) [a]	8.4 (1.8) [a]	10.3 (9.0) [a]	20.3 (9.0) [b]	13.2 (8.9) [b]	65.3 (16.7) [a]
Rye Grass	2.3 (1.5) [a]	8.2 (2.6) [a]	14.3 (7.2) [a]	24.8 (7.5) [ab]	13.3 (6.3) [b]	61.3 (11.3) [ab]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B14. Devona Hill, August 2008 and 2009 mean Russian thistle parameters.

Treatment	Number of Russian Thistle per $0.1m^2$	Number of Flowering Russian Thistle per $0.1m^2$	Russian Thistle Biovolume (cm^3)	Russian Thistle Height (cm)
2008				
Control	9.5 (8.4) [a]	2.2 (3.6) [a]	4.4 (3.4) [a]	2.6 (1.0) [a]
Grazing Exclusion	28.1 (34.4) [a]	2.9 (4.9) [a]	10.0 (14.2) [a]	2.9 (1.0) [a]
Hand Pulling	1.7 (2.5) [b]	0.0 [b]	0.8 (0.5) [b]	2.1 (0.7) [a]
Herbicide	0.0 [b]	0.0 [b]	0.0 [b]	0.0 [b]
Mixed Approach	0.2 (0.6) [b]	0.0 [b]	0.2 (0.6) [b]	2.0 [b]
Native Seeding	24.4 (27.1) [a]	0.2 (0.6) [a]	3.4 (4.1) [a]	2.4 (0.6) [a]
Rye Grass	27.3 (16.7) [a]	2.8 (4.0) [a]	9.8 (9.6) [a]	2.6 (0.7) [a]
2009				
Control	9.0 (4.2) [ab]	5.3 (3.8) [a]	3.2 (1.5) [ab]	2.8 (0.6) [ab]
Grazing Exclusion	7.5 (4.2) [b]	1.8 (1.9) [b]	1.4 (1.5) [b]	2.6 (0.9) [ab]
Hand Pulling	4.0 (2.2) [b]	0.8 (1.3) [bc]	0.8 (0.8) [b]	2.4 (0.6) [b]
Herbicide	0.0 [c]	0.0 [c]	0.0 [c]	0.0 [c]
Mixed Approach	0.0 [c]	0.0 [c]	0.0 [c]	0.0 [c]
Native Seeding	20.3 (14.8) [ab]	7.2 (10.4) [a]	3.0 (3.5) [ab]	2.7 (0.7) [ab]
Rye Grass	21.7 (14.5) [a]	11.6 (12.6) [a]	4.3 (3.0) [a]	3.2 (0.7) [a]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B15. Edna's Knoll, August 2008 and 2009 mean percent covers.

Treatment	Russian Thistle	Graminoid	Forb	Total Vegetation	Litter	Exposed Soil
2008						
Control	6.9 (3.8) [a]	18.1 (2.3) [a]	18.4 (9.4) [a]	37.5 (8.5) [a]	9.6 (3.8) [a]	52.3 (6.0) [b]
Grazing Exclusion	2.5 (1.2) [a]	15.4 (6.3) [ab]	10.0 (10.1) [b]	24.6 (8.2) [b]	7.3 (4.2) [a]	67.3 (10.8) [ab]
Hand Pulling	0.2 (0.4) [b]	11.7 (6.1) [b]	8.4 (4.4) [b]	18.8 (5.5) [b]	5.1 (3.6) [a]	74.9 (8.0) [a]
Herbicide	0.0 [b]	13.9 (6.2) [ab]	8.8 (5.1) [b]	21.7 (7.7) [b]	8.2 (4.0) [a]	68.8 (12.2) [ab]
Mixed Approach	0.0 [b]	18.2 (4.1) [a]	8.8 (5.1) [b]	26.9 (7.0) [b]	10.2 (6.0) [a]	61.8 (12.1) [b]
Native Seeding	2.8 (1.9) [a]	14.2 (5.8) [ab]	9.5 (8.9) [b]	23.2 (10.1) [b]	7.4 (3.8) [a]	67.3 (12.7) [ab]
Rye Grass	3.6 (2.8) [a]	14.5 (4.0) [ab]	10.2 (9.6) [b]	26.5 (8.3) [b]	6.8 (4.9) [a]	66.5 (9.6) [ab]
2009						
Control	2.7 (1.3) [a]	8.4 (1.9) [a]	8.3 (5.8) [a]	19.3 (5.6) [ab]	3.8 (0.9) [b]	76.7 (5.5) [b]
Grazing Exclusion	0.9 (1.1) [b]	11.4 (3.8) [a]	16.8 (18.7) [a]	29.1 (16.0) [a]	9.0 (3.1) [a]	62.0 (14.4) [c]
Hand Pulling	0.3 (0.4) [bc]	8.9 (2.4) [a]	4.1 (3.0) [a]	13.2 (4.0) [b]	3.0 (1.0) [b]	83.3 (4.2) [ab]
Herbicide	0.0 [c]	8.0 (3.2) [a]	0.0 [b]	8.1 (3.1) [c]	4.0 (1.1) [b]	87.8 (3.6) [a]
Mixed Approach	0.0 [c]	11.3 (3.2) [a]	0.0 [b]	11.3 (3.2) [bc]	8.6 (3.1) [a]	80.1 (6.1) [b]
Native Seeding	1.6 (1.4) [b]	8.2 (2.4) [a]	6.0 (6.8) [a]	15.7 (6.8) [b]	3.1 (1.0) [b]	81.1 (6.8) [b]
Rye Grass	2.3 (1.2) [b]	9.7 (2.6) [a]	6.4 (3.7) [a]	18.4 (3.8) [ab]	3.5 (1.7) [b]	77.9 (4.2) [b]

Standard deviations of the mean are presented in brackets

[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B16. Edna's Knoll, August 2008 and 2009 mean Russian thistle parameters.

Treatment	Number of Russian Thistle per 0.1m^2	Number of Flowering Russian Thistle per 0.1m^2	Russian Thistle Biovolume (cm^3)	Russian Thistle Height (cm)
2008				
Control	62.3 (36.4) [a]	7.2 (6.4) [a]	37.3 (32.4) [a]	3.6 (0.5) [a]
Grazing Exclusion	44.0 (42.1) [a]	1.3 (2.5) [b]	5.8 (4.4) [b]	2.4 (0.4) [b]
Hand Pulling	4.0 (3.3) [b]	0.4 (1.0) [b]	1.2 (0.6) [c]	1.8 (0.6) [b]
Herbicide	0.0 [b]	0.0 [b]	0.0 [c]	0.0 [c]
Mixed Approach	0.0 [b]	0.0 [b]	0.0 [c]	0.0 [c]
Native Seeding	27.7 (15.3) [a]	1.7 (2.8) [b]	6.7 (4.4) [ab]	2.4 (0.5) [b]
Rye Grass	63.9 (46.4) [a]	4.0 (5.6) [ab]	23.8 (27.8) [ab]	2.9 (0.7) [ab]
2009				
Control	18.5 (7.9) [a]	7.1 (5.8) [a]	4.0 (2.3) [a]	3.8 (0.6) [a]
Grazing Exclusion	9.3 (6.6) [b]	3.3 (3.7) [a]	1.4 (1.3) [ab]	2.9 (0.5) [b]
Hand Pulling	3.2 (3.3) [bc]	0.8 (1.4) [b]	0.3 (0.4) [b]	2.9 (0.5) [b]
Herbicide	0.8 (1.6) [c]	0.0 [b]	0.0 [b]	2.0 [c]
Mixed Approach	0.0 [c]	0.0 [b]	0.0 [b]	0.0 [c]
Native Seeding	10.3 (5.6) [ab]	2.7 (1.6) [a]	2.4 (2.0) [a]	3.3 (0.5) [ab]
Rye Grass	16.7 (6.7) [ab]	6.3 (4.2) [a]	3.4 (1.7) [a]	3.3 (0.5) [ab]

Standard deviations of the mean are presented in brackets

[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B17. Little Windy, August 2008 and 2009 mean percent covers.

Treatment	Russian Thistle	Graminoid	Forb	Total Vegetation	Litter	Exposed Soil
2008						
Control	1.3 (1.6) [ab]	9.4 (3.4) [ab]	8.6 (10.2) [a]	15.0 (10.2) [a]	18.6 (8.7) [ab]	61.8 (13.9) [ab]
Grazing Exclusion	2.4 (1.7) [a]	6.8 (3.7) [b]	3.2 (3.6) [a]	11.2 (7.9) [a]	11.1 (4.8) [b]	75.0 (14.9) [a]
Hand Pulling	0.5 (0.7) [b]	8.5 (5.1) [b]	6.8 (6.6) [a]	15.6 (18.0) [a]	14.4 (5.9) [ab]	70.6 (18.3) [a]
Herbicide	0.0 [c]	14.7 (8.3) [a]	3.9 (3.0) [a]	30.0 (15.1) [a]	17.0 (6.0) [a]	46.4 (15.7) [b]
Mixed Approach	0.5 (0.6) [bc]	14.2 (17.1) [b]	5.2 (5.3) [a]	16.1 (9.9) [a]	19.3 (14.6) [ab]	64.2 (20.0) [ab]
Native Seeding	5.2 (7.1) [a]	7.8 (4.8) [b]	6.0 (6.0) [a]	14.3 (14.3) [a]	18.8 (9.3) [ab]	67.4 (10.0) [a]
Rye Grass	1.4 (1.2) [ab]	11.0 (7.8) [ab]	7.9 (7.4) [a]	18.3 (14.1) [a]	18.2 (7.6) [ab]	61.5 (13.1) [ab]
2009						
Control	2.4 (2.3) [a]	4.2 (3.0) [a]	4.3 (3.0) [a]	15.3 (9.5) [ab]	10.8 (4.1) [a]	73.3 (10.8) [a]
Grazing Exclusion	2.3 (1.7) [a]	4.4 (3.5) [a]	7.0 (10.0) [a]	14.4 (11.9) [b]	13.6 (9.8) [a]	71.7 (14.4) [a]
Hand Pulling	1.4 (0.9) [a]	4.9 (2.3) [a]	5.2 (5.4) [a]	9.5 (6.8) [b]	11.4 (6.2) [b]	78.3 (10.2) [a]
Herbicide	0.0 [b]	7.0 (3.8) [a]	0.0 [b]	19.4 (17.7 [a])	7.0 (3.8) [a]	73.1 (21.5) [a]
Mixed Approach	0.0 [b]	5.5 (4.2) [a]	0.0 [b]	24.7 (19.9) [a]	5.5 (4.2) [a]	69.1 (22.5) [a]
Native Seeding	3.9 (2.9) [a]	3.2 (2.5) [a]	3.2 (3.9) [a]	7.0 (3.8) [b]	10.2 (3.3) [b]	82.7 (4.9) [a]
Rye Grass	2.4 (1.9) [a]	8.0 (5.5) [a]	4.7 (6.5) [a]	21.3 (14.9) [b]	15.3 (8.0) [a]	64.0 (17.7) [a]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B18. Little Windy, August 2008 and 2009 mean Russian thistle parameters.

Treatment	Number of Russian Thistle per 0.1m^2	Number of Flowering Russian Thistle per 0.1m^2	Russian Thistle Biovolume (cm^3)	Russian Thistle Height (cm)
2008				
Control	12.5 (15.0) [a]	1.1 (2.1) [a]	5.9 (8.8) [a]	2.6 (0.8) [a]
Grazing Exclusion	18.8 (15.9) [a]	3.3 (3.7) [a]	17.1 (16.9) [a]	3.3 (0.7) [a]
Hand Pulling	2.0 (2.0) [b]	0.4 (0.8) [b]	1.6 (1.4) [b]	2.8 (1.2) [a]
Herbicide	0.0 [b]	0.0 [b]	0.0 [b]	0.0 [b]
Mixed Approach	0.0 [b]	0.0 [b]	0.0 [b]	0.0 [b]
Native Seeding	32.7 (40.9) [a]	5.6 (7.0) [a]	31.8 (49.7) [a]	3.5 (0.5) [a]
Rye Grass	9.3 (7.8) [a]	2.1 (2.8) [a]	5.8 (6.4) [a]	3.0 (0.9) [a]
2009				
Control	7.9 (4.7) [a]	3.9 (3.8) [a]	5.9 (4.9) [a]	3.6 (0.8) [a]
Grazing Exclusion	6.1 (4.2) [a]	3.1 (3.2) [a]	5.9 (5.1) [a]	4.0 (0.7) [a]
Hand Pulling	3.4 (2.3) [a]	1.3 (1.9) [b]	3.7 (2.6) [a]	3.6 (1.2) [a]
Herbicide	0.0 [b]	0.0 [b]	0.0 [b]	0.0 [b]
Mixed Approach	0.0 [b]	0.0 [b]	0.0 [b]	0.0 [b]
Native Seeding	8.1 (5.4) [a]	4.2 (4.0) [a]	9.5 (6.0) [a]	4.4 (1.7) [a]
Rye Grass	6.7 (4.4) [a]	3.7 (2.8) [a]	7.2 (5.2) [a]	3.5 (0.9) [a]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B19. Talbot Lake, August 2008 and 2009 mean percent covers.

Treatment	Russian Thistle	Graminoid	Forb	Total Vegetation	Litter	Exposed Soil
2008						
Control	4.5 (4.5) ^{a}	17.6 (4.2) ^{b}	11.7 (4.5) ^{a}	9.8 (4.9) ^{a}	29.8 (6.5) ^{a}	15.0 (10.6) ^{a}
Grazing Exclusion	3.0 (1.2) ^{a}	18.8 (7.8) ^{b}	8.0 (6.0) ^{ab}	6.4 (2.0) ^{a}	23.8 (4.6) ^{a}	23.0 (23.0) ^{a}
Hand Pulling	1.5 (0.9) ^{a}	24.2 (8.8) ^{ab}	3.5 (3.3) ^{b}	9.1 (4.2) ^{a}	26.2 (7.0) ^{a}	23.6 (12.2) ^{a}
Herbicide	0.0 ^{b}	19.3 (5.9) ^{b}	12.8 (8.6) ^{a}	9.4 (4.7) ^{a}	29.6 (12.1) ^{a}	28.5 (20.8) ^{a}
Mixed Approach	0.0 ^{b}	19.7 (6.7) ^{b}	5.9 (5.5) ^{b}	7.4 (2.2) ^{a}	25.3 (7.6) ^{a}	14.3 (15.3) ^{a}
Native Seeding	5.2 (5.6) ^{a}	26.2 (6.0) ^{a}	3.8 (3.9) ^{b}	8.8 (4.0) ^{a}	31.3 (7.2) ^{a}	15.7 (15.5) ^{a}
Rye Grass	5.2 (5.6) ^{a}	21.0 (6.4) ^{ab}	7.4 (5.7) ^{ab}	9.0 (5.3) ^{a}	31.8 (5.6) ^{a}	15.5 (10.3) ^{a}
2009						
Control	2.6 (2.5) ^{a}	10.8 (2.7) ^{a}	12.4 (5.2) ^{a}	4.2 (0.7) ^{ab}	25.5 (4.8) ^{b}	21.3 (15.1) ^{b}
Grazing Exclusion	0.7 (1.1) ^{b}	17.8 (8.6) ^{a}	17.7 (14.4) ^{a}	30.6 (5.1) ^{b}	36.3 (13.0) ^{a}	4.8 (4.8) ^{c}
Hand Pulling	0.7 (0.5) ^{ab}	18.3 (8.5) ^{a}	5.6 (7.0) ^{b}	4.1 (1.0) ^{a}	24.8 (7.3) ^{b}	36.0 (12.5) ^{a}
Herbicide	0.0 ^{b}	15.0 (2.4) ^{a}	0.0 ^{c}	4.2 (1.3) ^{c}	15.0 (2.4) ^{b}	35.3 (15.2) ^{ab}
Mixed Approach	0.0 ^{b}	21.7 (10.1) ^{a}	0.0 ^{c}	31.5 (8.8) ^{a}	21.8 (10.4) ^{a}	12.4 (7.7) ^{bc}
Native Seeding	2.3 (1.5) ^{a}	15.8 (4.0) ^{a}	5.1 (5.9) ^{b}	5.1 (1.7) ^{a}	22.5 (4.8) ^{b}	21.8 (15.1) ^{b}
Rye Grass	2.8 (4.4) ^{a}	15.5 (6.3) ^{a}	8.2 (5.7) ^{ab}	3.8 (0.7) ^{ab}	26.3 (4.5) ^{b}	19.1 (12.3) ^{b}

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B20. Talbot Lake, August 2008 and 2009 mean Russian thistle parameters.

Treatment	Number of Russian Thistle per 0.1m^2	Number of Flowering Russian Thistle per 0.1m^2	Russian Thistle Biovolume (cm^3)	Russian Thistle Height (cm)
2008				
Control	39.4 (27.9) [a]	8.2 (7.5) [a]	21.6 (24.2) [a]	2.9 (0.8) [a]
Grazing Exclusion	48.8 (35.0) [a]	7.5 (7.5) [a]	5.8 (3.5) [ab]	2.5 (0.5) [a]
Hand Pulling	15.8 (9.7) [a]	2.8 (2.6) [a]	3.7 (2.1) [b]	2.5 (0.5) [a]
Herbicide	0.0 [b]	0.0 [b]	0.0 [c]	0.0 [b]
Mixed Approach	0.0 [b]	0.0 [b]	0.0 [c]	0.0 [b]
Native Seeding	53.3 (43.1) [a]	3.7 (4.4) [a]	25.3 (25.7) [a]	3.0 (0.4) [a]
Rye Grass	46.8 (45.2) [a]	5.2 (5.6) [a]	68.1 (71.1) [a]	3.1 (1.0) [a]
2009				
Control	16.5 (14.9) [a]	11.7 (12.2) [a]	3.8 (3.2) [a]	2.9 (0.5) [a]
Grazing Exclusion	3.6 (6.5) [b]	2.7 (4.7) [a]	1.3 (2.4) [ab]	3.3 (1.0) [a]
Hand Pulling	3.0 (2.3) [b]	1.9 (1.6) [a]	1.4 (1.1) [a]	3.0 (0.6) [a]
Herbicide	0.2 (0.6) [b]	0.0 [b]	0.0 [b]	2.0 [a]
Mixed Approach	0.1 (0.3) [b]	0.0 [b]	0.0 [b]	1.8 [a]
Native Seeding	12.9 (13.2) [a]	7.8 (5.7) [a]	3.7 (2.6) [a]	3.0 (0.7) [a]
Rye Grass	16.3 (19.2) [a]	12.2 (16.7) [a]	4.0 (4.9) [a]	3.2 (0.8) [a]

Standard deviations of the mean are presented in brackets
[a] Means within columns not followed by the same letter are significantly different ($P < 0.05$)

Table B21. Devona Hill, August 2008 P-values for multiple treatment comparisons of number of Russian thistle parameters and mean percent cover.

Treatment	Number of R. Thistle	Number of Flowering R. Thistle	R. Thistle Biovolume	R. Thistle Height	R.Thistle Cover	Graminoid Cover*	Forb Cover	Total Vegetation Cover	Litter Cover*	Exposed Soil
Cont vs. Grz Ex	0.205	0.716	0.937	0.536	0.897	0.171	0.616	0.997	0.070	0.017
Cont vs. Herb	0.001	0.083	< 0.001	< 0.001	< 0.001	0.171	0.063	0.977	0.070	0.368
Cont vs. Mixed	0.003	0.083	< 0.001	< 0.001	< 0.001	0.171	0.003	0.298	0.070	0.645
Cont vs. Native	0.264	0.154	0.360	0.953	0.933	0.171	0.519	0.998	0.070	0.208
Cont vs. Pulling	0.034	0.083	0.004	0.181	0.034	0.171	0.825	0.962	0.070	0.033
Cont vs. Rye	0.052	0.913	0.685	0.854	0.236	0.171	0.522	1.000	0.070	0.844
Grz Ex vs. Herb	< 0.001	0.036	< 0.001	< 0.001	< 0.001	0.171	0.175	0.771	0.070	0.136
Grz Ex vs. Mixed	< 0.001	0.036	< 0.001	< 0.001	< 0.001	0.171	0.015	0.087	0.070	0.004
Grz Ex vs. Native	0.880	0.073	0.319	0.498	0.963	0.171	0.887	1.000	0.070	0.259
Grz Ex vs. Pulling	0.001	0.036	0.003	0.050	0.024	0.171	0.469	1.000	0.070	0.795
Grz Ex vs. Rye	0.498	0.799	0.744	0.663	0.292	0.171	0.890	0.986	0.070	0.028
Herb vs. Mixed	0.864	1.000	0.750	0.808	0.706	0.171	0.282	0.822	0.070	0.174
Herb vs. Native	< 0.001	0.760	< 0.001	< 0.001	< 0.001	0.171	0.225	0.792	0.070	0.719
Herb vs. Pulling	0.292	1.000	0.066	0.004	0.036	0.171	0.038	0.542	0.070	0.219
Herb vs. Rye	< 0.001	0.066	< 0.001	< 0.001	< 0.001	0.171	0.223	0.994	0.070	0.482
Mixed vs. Native	< 0.001	0.760	< 0.001	< 0.001	< 0.001	0.171	0.022	0.095	0.070	0.085
Mixed vs. Pulling	0.377	1.000	0.129	0.008	0.086	0.171	0.002	0.034	0.070	0.010
Mixed vs. Rye	< 0.001	0.066	< 0.001	< 0.001	< 0.001	0.171	0.022	0.407	0.070	0.511
Native vs. Pulling	0.001	0.760	0.046	0.200	0.027	0.171	0.386	1.000	0.070	0.384
Native vs. Rye	0.407	0.125	0.186	0.808	0.271	0.171	0.997	0.989	0.070	0.288
Pulling vs. Rye	< 0.001	0.066	0.001	0.128	0.001	0.171	0.389	0.911	0.070	0.053

Cont = Control; Grz Ex = Grazing Exclusion; Herb = Herbicide; Native = Native Seeding; Pulling = Hand Pulling; Rye = Rye Grass

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B22. Devona Hill, August 2009 P-values for multiple treatment comparisons of number of Russian thistle parameters and mean percent cover.

Treatment	Number of Russian Thistle	Number of Flowering Russian Thistle	Russian Thistle Biovolume	Russian Thistle Height	Russian Thistle Cover	Graminoid Cover	Forb Cover	Total Vegetation Cover	Litter Cover	Exposed Soil
Cont vs. Grz Ex	0.592	0.030	0.071	0.722	0.173	0.472	0.598	0.027	0.006	0.002
Cont vs. Herb	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.027	< 0.001	0.001	0.054	0.744
Cont vs. Mixed	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.003	< 0.001	0.010	< 0.001	0.009
Cont vs. Native	0.368	0.454	0.424	0.670	0.920	0.670	0.539	0.584	0.410	0.893
Cont vs. Pulling	0.074	0.002	0.022	0.199	0.035	0.847	0.360	0.262	0.020	0.019
Cont vs. Rye	0.141	0.760	0.779	0.474	0.584	0.828	0.750	0.396	0.296	0.264
Grz Ex vs. Herb	< 0.001	0.040	0.001	< 0.001	0.001	0.135	< 0.001	< 0.001	0.419	0.001
Grz Ex vs. Mixed	< 0.001	0.040	0.001	< 0.001	0.001	0.025	< 0.001	< 0.001	0.088	0.627
Grz Ex vs. Native	0.151	0.156	0.315	0.943	0.206	0.770	0.253	0.006	0.056	0.003
Grz Ex vs. Pulling	0.211	0.386	0.624	0.353	0.456	0.598	0.697	0.273	0.688	0.454
Grz Ex vs. Rye	0.045	0.013	0.037	0.284	0.056	0.616	0.834	0.171	0.092	0.047
Herb vs. Mixed	1.000	1.000	1.000	1.000	1.000	0.451	1.000	0.477	0.012	0.003
Herb vs. Native	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.074	0.002	0.006	0.271	0.645
Herb vs. Pulling	0.023	0.235	0.007	0.002	0.010	0.043	< 0.001	< 0.001	0.685	0.007
Herb vs. Rye	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.046	< 0.001	< 0.001	0.380	0.149
Mixed vs. Native	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.011	0.002	0.042	< 0.001	0.013
Mixed vs. Pulling	0.023	0.235	0.007	0.002	0.010	0.006	< 0.001	< 0.001	0.035	0.792
Mixed vs. Rye	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.006	< 0.001	0.001	0.001	0.134
Native vs. Pulling	0.007	0.022	0.135	0.391	0.045	0.815	0.126	0.095	0.132	0.027
Native vs. Rye	0.566	0.292	0.280	0.253	0.517	0.834	0.351	0.162	0.825	0.325
Pulling vs. Rye	0.001	0.001	0.010	0.046	0.008	0.980	0.550	0.786	0.199	0.217

Cont = Control; Grz Ex = Grazing Exclusion; Herb = Herbicide; Native = Native Seeding; Pulling = Hand Pulling; Rye = Rye Grass

Table B23. Edna's Knoll, August 2008 P-values for multiple treatment comparisons of number of Russian thistle parameters and mean percent cover.

Treatment	Number of Russian Thistle	Number of Flowering Russian Thistle	Russian Thistle Biovolume	Russian Thistle Height	Russian Thistle Cover	Graminoid Cover	Forb Cover	Total Vegetation Cover	Litter Cover*	Exposed Soil
Cont vs. Grz Ex	0.362	0.007	0.046	0.016	0.104	0.851	0.010	0.003	0.061	0.013
Cont vs. Herb	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.410	0.024	0.000	0.061	0.004
Cont vs. Mixed	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	1.000	0.030	0.028	0.061	0.293
Cont vs. Native	0.196	0.017	0.116	0.009	0.113	0.528	0.010	0.001	0.061	0.013
Cont vs. Pulling	< 0.001	0.001	< 0.001	< 0.001	< 0.001	0.048	0.025	<.0001	0.061	<.0001
Cont vs. Rye	0.700	0.188	0.319	0.162	0.193	0.614	0.018	0.020	0.061	0.022
Grz Ex vs. Herb	< 0.001	0.299	< 0.001	< 0.001	< 0.001	0.991	0.766	0.973	0.061	1.000
Grz Ex vs. Mixed	< 0.001	0.299	< 0.001	< 0.001	< 0.001	0.842	0.700	0.991	0.061	0.863
Grz Ex vs. Native	0.703	0.750	0.670	0.847	0.970	0.998	0.977	1.000	0.061	1.000
Grz Ex vs. Pulling	0.007	0.630	0.030	0.141	0.017	0.585	0.750	0.579	0.061	0.554
Grz Ex vs. Rye	0.598	0.162	0.315	0.315	0.747	1.000	0.851	0.997	0.061	1.000
Herb vs. Mixed	1.000	1.000	1.000	1.000	1.000	0.398	0.930	0.679	0.061	0.656
Herb vs. Native	< 0.001	0.175	< 0.001	< 0.001	< 0.001	1.000	0.744	0.999	0.061	1.000
Herb vs. Pulling	0.077	0.578	0.085	0.020	0.067	0.947	0.983	0.976	0.061	0.786
Herb vs. Rye	< 0.001	0.015	< 0.001	< 0.001	< 0.001	1.000	0.913	0.757	0.061	0.998
Mixed vs. Native	< 0.001	0.175	< 0.001	< 0.001	< 0.001	0.515	0.679	0.911	0.061	0.855
Mixed vs. Pulling	0.077	0.578	0.085	0.020	0.067	0.045	0.947	0.184	0.061	0.045
Mixed vs. Rye	< 0.001	0.015	< 0.001	< 0.001	< 0.001	0.601	0.844	1.000	0.061	0.928
Native vs. Pulling	0.020	0.424	0.009	0.200	0.015	0.888	0.728	0.838	0.061	0.567
Native vs. Rye	0.364	0.280	0.564	0.231	0.776	1.000	0.828	0.948	0.061	1.000
Pulling vs. Rye	0.001	0.060	0.001	0.013	0.007	0.831	0.897	0.237	0.061	0.440

Cont = Control; Grz Ex = Grazing Exclusion; Herb = Herbicide; Native = Native Seeding; Pulling = Hand Pulling; Rye = Rye Grass

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B24. Edna's Knoll, August 2009 P-values for multiple treatment comparisons of number of Russian thistle parameters and mean percent cover.

Treatment	Number of Russian Thistle	Number of Flowering Russian Thistle	Russian Thistle Biovolume	Russian Thistle Height	Russian Thistle Cover	Graminoid Cover*	Forb Cover	Total Vegetation Cover	Litter Cover	Exposed Soil
Cont vs. Grz Ex	0.043	0.064	0.055	0.040	0.023	0.053	0.474	0.157	< 0.001	0.016
Cont vs. Herb	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.053	< 0.001	< 0.001	0.766	< 0.001
Cont vs. Mixed	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.053	< 0.001	0.001	0.001	0.222
Cont vs. Native	0.097	0.088	0.282	0.284	0.219	0.053	0.400	0.152	0.245	0.097
Cont vs. Pulling	< 0.001	< 0.001	< 0.001	0.010	0.001	0.053	0.228	0.022	0.186	0.019
Cont vs. Rye	0.802	0.773	0.870	0.315	0.697	0.053	0.799	0.997	0.432	0.818
Grz Ex vs. Herb	0.001	0.003	0.001	0.002	0.003	0.053	< 0.001	< 0.001	0.001	< 0.001
Grz Ex vs. Mixed	< 0.001	0.003	< 0.001	< 0.001	0.001	0.053	< 0.001	< 0.001	0.847	< 0.001
Grz Ex vs. Native	0.719	0.884	0.400	0.323	0.294	0.053	0.120	0.004	< 0.001	< 0.001
Grz Ex vs. Pulling	0.057	0.047	0.095	0.598	0.264	0.053	0.055	< 0.001	< 0.001	< 0.001
Grz Ex vs. Rye	0.077	0.118	0.080	0.292	0.059	0.053	0.332	0.159	< 0.001	0.008
Herb vs. Mixed	0.598	1.000	0.750	0.706	0.725	0.053	1.000	0.253	0.003	0.008
Herb vs. Native	< 0.001	0.002	< 0.001	< 0.001	< 0.001	0.053	< 0.001	0.004	0.144	0.027
Herb vs. Pulling	0.192	0.315	0.110	0.009	0.063	0.053	0.001	0.043	0.105	0.126
Herb vs. Rye	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.053	< 0.001	< 0.001	0.279	< 0.001
Mixed vs. Native	< 0.001	0.002	< 0.001	< 0.001	< 0.001	0.053	< 0.001	0.080	< 0.001	0.660
Mixed vs. Pulling	0.067	0.315	0.055	0.003	0.027	0.053	0.001	0.377	< 0.001	0.264
Mixed vs. Rye	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.053	< 0.001	0.001	< 0.001	0.321
Native vs. Pulling	0.024	0.033	0.012	0.130	0.030	0.053	0.716	0.386	0.874	0.498
Native vs. Rye	0.159	0.156	0.362	0.947	0.400	0.053	0.558	0.151	0.706	0.152
Pulling vs. Rye	< 0.001	< 0.001	0.001	0.114	0.003	0.053	0.342	0.021	0.592	0.035

Cont = Control; Grz Ex = Grazing Exclusion; Herb = Herbicide; Native = Native Seeding; Pulling = Hand Pulling; Rye = Rye Grass

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B25. Little Windy, August 2008 P-values for multiple treatment comparisons of number of Russian thistle parameters and mean percent cover.

Treatment	Number of Russian Thistle	Number of Flowering Russian Thistle	Russian Thistle Biovolume	Russian Thistle Height	Russian Thistle Cover	Graminoid Cover	Forb Cover*	Total Vegetation Cover*	Litter Cover	Exposed Soil
Cont vs. Grz Ex	0.388	0.164	0.124	0.094	0.145	0.112	0.574	0.192	0.988	0.371
Cont vs. Herb	< 0.001	0.156	0.001	< 0.001	< 0.001	0.098	0.574	0.192	0.096	0.278
Cont vs. Mixed	< 0.001	0.126	< 0.001	< 0.001	0.128	0.333	0.574	0.192	1.000	1.000
Cont vs. Native	0.367	0.101	0.101	0.054	0.302	0.282	0.574	0.192	1.000	0.974
Cont vs. Pulling	0.035	0.512	0.471	0.408	0.267	0.521	0.574	0.192	1.000	0.807
Cont vs. Rye	0.997	0.390	0.742	0.313	0.735	0.879	0.574	0.192	0.994	1.000
Grz Ex vs. Herb	< 0.001	0.007	< 0.001	0.003	< 0.001	0.002	0.574	0.192	0.014	0.001
Grz Ex vs. Mixed	< 0.001	0.003	< 0.001	0.021	0.003	0.535	0.574	0.192	0.957	0.607
Grz Ex vs. Native	0.969	0.805	0.921	0.774	0.671	0.609	0.574	0.192	0.996	0.891
Grz Ex vs. Pulling	0.003	0.041	0.024	0.419	0.010	0.344	0.574	0.192	0.975	0.992
Grz Ex vs. Rye	0.390	0.594	0.226	0.531	0.263	0.082	0.574	0.192	0.785	0.340
Herb vs. Mixed	1.000	1.000	1.000	0.504	0.028	0.011	0.574	0.192	0.151	0.140
Herb vs. Native	< 0.001	0.003	< 0.001	0.008	< 0.001	0.008	0.574	0.192	0.069	0.044
Herb vs. Pulling	0.080	0.417	0.010	< 0.001	0.010	0.025	0.574	0.192	0.123	0.012
Herb vs. Rye	< 0.001	0.027	< 0.001	0.001	< 0.001	0.130	0.574	0.192	0.334	0.303
Mixed vs. Native	< 0.001	0.002	< 0.001	0.041	0.011	0.914	0.574	0.192	1.000	0.999
Mixed vs. Pulling	0.059	0.381	0.005	0.003	0.680	0.745	0.574	0.192	1.000	0.948
Mixed vs. Rye	< 0.001	0.017	0.000	0.005	0.063	0.263	0.574	0.192	0.999	1.000
Native vs. Pulling	0.003	0.022	0.018	0.283	0.032	0.664	0.574	0.192	1.000	0.999
Native vs. Rye	0.369	0.435	0.190	0.371	0.488	0.220	0.574	0.192	0.983	0.965
Pulling vs. Rye	0.034	0.130	0.294	0.859	0.147	0.427	0.574	0.192	0.998	0.778

Cont = Control; Grz Ex = Grazing Exclusion; Herb = Herbicide; Native = Native Seeding; Pulling = Hand Pulling; Rye = Rye Grass

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B26. Little Windy, August 2009 P-values for multiple treatment comparisons of number of Russian thistle parameters and mean percent cover.

Treatment	Number of Russian Thistle	Number of Flowering Russian Thistle	Russian Thistle Biovolume	Russian Thistle Height	Russian Thistle Cover	Graminoid Cover*	Forb Cover	Total Vegetation Cover	Litter Cover	Exposed Soil*
Cont vs. Grz Ex	0.593	0.583	0.870	0.668	0.837	0.085	0.305	0.387	0.842	0.136
Cont vs. Herb	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.085	< 0.001	0.083	0.953	0.136
Cont vs. Mixed	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.085	< 0.001	0.011	0.365	0.136
Cont vs. Native	0.906	0.953	0.262	0.443	0.284	0.085	0.194	0.822	0.025	0.136
Cont vs. Pulling	0.054	0.020	0.487	0.997	0.456	0.085	0.620	0.946	0.093	0.136
Cont vs. Rye	0.582	0.796	0.688	0.620	0.912	0.085	0.248	0.269	0.472	0.136
Grz Ex vs. Herb	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.085	0.006	0.011	0.797	0.136
Grz Ex vs. Mixed	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.085	0.009	0.001	0.278	0.136
Grz Ex vs. Native	0.675	0.624	0.350	0.748	0.400	0.085	0.807	0.278	0.046	0.136
Grz Ex vs. Pulling	0.177	0.084	0.399	0.665	0.350	0.085	0.588	0.352	0.148	0.136
Grz Ex vs. Rye	0.997	0.767	0.818	0.361	0.921	0.085	0.917	0.829	0.366	0.136
Herb vs. Mixed	1.000	1.000	1.000	1.000	1.000	0.085	0.866	0.426	0.397	0.136
Herb vs. Native	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.085	0.010	0.132	0.021	0.136
Herb vs. Pulling	0.005	0.069	0.001	0.000	0.001	0.085	0.001	0.096	0.082	0.136
Herb vs. Rye	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.085	0.006	0.005	0.509	0.136
Mixed vs. Native	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.085	0.016	0.021	0.002	0.136
Mixed vs. Pulling	0.005	0.069	0.001	< 0.001	0.001	0.085	0.001	0.014	0.010	0.136
Mixed vs. Rye	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.085	0.011	< 0.001	0.852	0.136
Native vs. Pulling	0.071	0.023	0.069	0.441	0.069	0.085	0.421	0.876	0.570	0.136
Native vs. Rye	0.666	0.842	0.472	0.207	0.336	0.085	0.886	0.184	0.003	0.136
Pulling vs. Rye	0.169	0.038	0.273	0.623	0.392	0.085	0.509	0.241	0.016	0.136

Cont = Control; Grz Ex = Grazing Exclusion; Herb = Herbicide; Native = Native Seeding; Pulling = Hand Pulling; Rye = Rye Grass

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B27. Talbot Lake, August 2008 P-values for multiple treatment comparisons of number of Russian thistle parameters and mean percent cover.

Treatment	Number of Russian Thistle	Number of Flowering Russian Thistle	Russian Thistle Biovolume	Russian Thistle Height	Russian Thistle Cover	Graminoid Cover	Forb Cover	Total Vegetation Cover	Litter Cover	Exposed Soil*
Cont vs. Grz Ex	0.747	0.703	0.206	0.273	0.940	0.864	0.100	0.459	0.420	0.166
Cont vs. Herb	< 0.001	< 0.001	< 0.001	0.001	< 0.001	0.663	0.710	1.000	1.000	0.166
Cont vs. Mixed	< 0.001	< 0.001	< 0.001	0.001	< 0.001	0.670	0.011	0.784	0.798	0.166
Cont vs. Native	0.610	0.238	0.506	0.427	0.930	0.004	< 0.001	0.999	0.997	0.166
Cont vs. Pulling	0.156	0.193	0.039	0.306	0.110	0.073	< 0.001	0.906	1.000	0.166
Cont vs. Rye	0.786	0.459	0.654	0.671	0.642	0.303	0.075	0.994	0.999	0.166
Grz Ex vs. Herb	< 0.001	0.001	0.001	< 0.001	< 0.001	0.792	0.203	0.493	0.549	0.166
Grz Ex vs. Mixed	< 0.001	0.001	0.001	< 0.001	< 0.001	0.799	0.375	0.999	0.997	0.166
Grz Ex vs. Native	0.851	0.424	0.054	0.058	0.870	0.007	0.064	0.190	0.798	0.166
Grz Ex vs. Pulling	0.082	0.357	0.422	0.942	0.128	0.105	0.055	0.986	0.680	0.166
Grz Ex vs. Rye	0.552	0.719	0.087	0.128	0.697	0.391	0.893	0.135	0.711	0.166
Herb vs. Mixed	1.000	1.000	1.000	0.923	1.000	0.993	0.031	0.812	0.891	0.166
Herb vs. Native	< 0.001	0.015	< 0.001	0.010	< 0.001	0.014	0.002	0.998	1.000	0.166
Herb vs. Pulling	0.003	0.021	0.009	< 0.001	0.002	0.175	0.001	0.924	1.000	0.166
Herb vs. Rye	< 0.001	0.004	< 0.001	0.004	< 0.001	0.552	0.160	0.990	1.000	0.166
Mixed vs. Native	< 0.001	0.015	< 0.001	0.007	< 0.001	0.014	0.334	0.459	0.984	0.166
Mixed vs. Pulling	0.003	0.021	0.009	< 0.001	0.002	0.173	0.303	1.000	0.952	0.166
Mixed vs. Rye	< 0.001	0.004	< 0.001	0.003	< 0.001	0.547	0.451	0.360	0.962	0.166
Native vs. Pulling	0.054	0.903	0.006	0.069	0.092	0.275	0.950	0.635	1.000	0.166
Native vs. Rye	0.434	0.660	0.828	0.711	0.581	0.064	0.085	1.000	1.000	0.166
Pulling vs. Rye	0.252	0.575	0.012	0.148	0.257	0.446	0.075	0.529	1.000	0.166

Cont = Control; Grz Ex = Grazing Exclusion; Herb = Herbicide; Native = Native Seeding; Pulling = Hand Pulling; Rye = Rye Grass

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B28. Talbot Lake, August 2009 P-values for multiple treatment comparisons of number of Russian thistle parameters and mean percent cover.

Treatment	Number of Russian Thistle	Number of Flowering Russian Thistle	Russian Thistle Biovolume	Russian Thistle Height*	RussianThistle Cover	Graminoid Cover*	Forb Cover	Total Vegetation Cover	Litter Cover	Exposed Soil
Cont vs. Grz Ex	0.001	0.004	0.007	0.258	0.005	0.085	0.923	0.075	< 0.001	0.002
Cont vs. Herb	< 0.001	< 0.001	< 0.001	0.258	< 0.001	0.085	< 0.001	< 0.001	0.808	0.047
Cont vs. Mixed	< 0.001	< 0.001	< 0.001	0.258	< 0.001	0.085	< 0.001	0.174	< 0.001	0.202
Cont vs. Native	0.747	0.983	0.907	0.258	0.874	0.085	0.034	0.262	0.439	0.947
Cont vs. Pulling	0.013	0.020	0.110	0.258	0.066	0.085	0.024	0.957	0.799	0.031
Cont vs. Rye	0.294	0.259	0.589	0.258	0.407	0.085	0.266	0.776	0.514	0.825
Grz Ex vs. Herb	0.126	0.093	0.104	0.258	0.102	0.085	< 0.001	< 0.001	0.000	< 0.001
Grz Ex vs. Mixed	0.118	0.093	0.104	0.258	0.102	0.085	< 0.001	0.002	0.953	0.074
Grz Ex vs. Native	0.003	0.004	0.005	0.258	0.003	0.085	0.027	0.004	0.001	0.002
Grz Ex vs. Pulling	0.410	0.569	0.264	0.258	0.321	0.085	0.019	0.067	< 0.001	< 0.001
Grz Ex vs. Rye	0.024	0.076	0.030	0.258	0.046	0.085	0.227	0.135	< 0.001	0.005
Herb vs. Mixed	0.973	1.000	1.000	0.258	1.000	0.085	1.000	0.025	< 0.001	0.001
Herb vs. Native	< 0.001	< 0.001	< 0.001	0.258	< 0.001	0.085	0.002	0.013	0.309	0.055
Herb vs. Pulling	0.018	0.025	0.006	0.258	0.009	0.085	0.004	< 0.001	0.990	0.861
Herb vs. Rye	< 0.001	0.001	< 0.001	0.258	< 0.001	0.085	< 0.001	< 0.001	0.682	0.027
Mixed vs. Native	< 0.001	< 0.001	< 0.001	0.258	< 0.001	0.085	0.002	0.812	0.001	0.179
Mixed vs. Pulling	0.017	0.025	0.006	0.258	0.009	0.085	0.004	0.192	< 0.001	0.001
Mixed vs. Rye	< 0.001	0.001	< 0.001	0.258	< 0.001	0.085	< 0.001	0.100	< 0.001	0.292
Native vs. Pulling	0.030	0.021	0.086	0.258	0.046	0.085	0.897	0.286	0.303	0.036
Native vs. Rye	0.467	0.268	0.511	0.258	0.323	0.085	0.313	0.160	0.154	0.773
Pulling vs. Rye	0.150	0.228	0.290	0.258	0.313	0.085	0.255	0.735	0.691	0.017

Cont = Control; Grz Ex = Grazing Exclusion; Herb = Herbicide; Native = Native Seeding; Pulling = Hand Pulling; Rye = Rye Grass

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B29. August 2008 P-values for multiple treatment comparisons of number of Russian thistle parameters and mean percent cover (data combined for all sites).

Treatment	Number of Russian Thistle	Number of Flowering Russian Thistle	Russian Thistle Biovolume	Russian Thistle Height	Russian Thistle Cover	Graminoid Cover*	Forb Cover	Total Vegetation Cover	Litter Cover*	Exposed Soil*
Cont vs. Grz Ex	0.475	0.422	0.652	0.469	0.956	0.739	0.005	0.008	0.467	0.896
Cont vs. Herb	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.739	0.028	0.020	0.467	0.896
Cont vs. Mixed	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.739	< 0.001	0.008	0.467	0.896
Cont vs. Native	0.486	0.101	0.976	0.723	0.955	0.739	0.001	0.254	0.467	0.896
Cont vs. Pulling	< 0.001	0.001	< 0.001	0.002	< 0.001	0.739	0.008	0.006	0.467	0.896
Cont vs. Rye	0.702	0.577	0.778	0.702	0.735	0.739	0.044	0.267	0.467	0.896
Grz Ex vs. Herb	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.739	0.588	0.787	0.467	0.896
Grz Ex vs. Mixed	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.739	0.218	0.976	0.467	0.896
Grz Ex vs. Native	0.986	0.401	0.631	0.712	0.912	0.739	0.596	0.133	0.467	0.896
Grz Ex vs. Pulling	< 0.001	0.012	< 0.001	0.016	< 0.001	0.739	0.904	0.907	0.467	0.896
Grz Ex vs. Rye	0.740	0.806	0.464	0.733	0.694	0.739	0.438	0.126	0.467	0.896
Herb vs. Mixed	0.940	1.000	0.907	0.921	0.251	0.739	0.079	0.765	0.467	0.896
Herb vs. Native	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.739	0.287	0.227	0.467	0.896
Herb vs. Pulling	< 0.001	0.048	< 0.001	< 0.001	< 0.001	0.739	0.672	0.701	0.467	0.896
Herb vs. Rye	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.739	0.826	0.216	0.467	0.896
Mixed vs. Native	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.739	0.482	0.126	0.467	0.896
Mixed vs. Pulling	< 0.001	0.045	< 0.001	< 0.001	< 0.001	0.739	0.176	0.931	0.467	0.896
Mixed vs. Rye	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.739	0.045	0.118	0.467	0.896
Native vs. Pulling	< 0.001	0.094	< 0.001	0.006	< 0.001	0.739	0.515	0.106	0.467	0.896
Native vs. Rye	0.753	0.278	0.801	0.978	0.778	0.739	0.192	0.976	0.467	0.896
Pulling vs. Rye	< 0.001	0.006	< 0.001	0.006	< 0.001	0.739	0.513	0.099	0.467	0.896

Cont = Control; Grz Ex = Grazing Exclusion; Herb = Herbicide; Native = Native Seeding; Pulling = Hand Pulling; Rye = Rye Grass

* Kruskal-Wallis chi square value for percent cover parameters. The absence of significant differences between the seven study treatments for a given parameter are indicated by chi square values greater than 0.05.

Table B30. August 2009 P-values for multiple treatment comparisons of number of Russian thistle parameters and mean percent cover (data combined for all sites).

Treatment	Number of Russian Thistle	Number of Flowering Russian Thistle	Russian Thistle Biovolume	Russian Thistle Height	Russian Thistle Cover	Graminoid Cover	Forb Cover	Total Vegetation Cover	Litter Cover	Exposed Soil
Cont vs. Grz Ex	0.002	< 0.001	0.002	0.072	0.002	0.023	0.964	0.011	< 0.001	0.014
Cont vs. Herb	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.015	< 0.001	< 0.001	0.321	0.075
Cont vs. Mixed	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.390
Cont vs. Native	0.645	0.249	0.724	0.705	0.927	0.374	0.028	0.205	0.634	0.268
Cont vs. Pulling	< 0.001	< 0.001	< 0.001	0.046	< 0.001	0.228	0.178	0.610	0.744	0.541
Cont vs. Rye	0.885	0.491	0.789	0.785	0.749	0.038	0.419	0.296	0.702	0.434
Grz Ex vs. Herb	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.872	< 0.001	< 0.001	< 0.001	< 0.001
Grz Ex vs. Mixed	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.216	< 0.001	< 0.001	0.168	0.112
Grz Ex vs. Native	0.007	0.005	0.005	0.156	0.002	0.167	0.025	< 0.001	< 0.001	< 0.001
Grz Ex vs. Pulling	0.069	0.078	0.624	0.841	0.482	0.288	0.163	0.002	< 0.001	0.002
Grz Ex vs. Rye	0.003	0.001	0.004	0.128	0.005	0.849	0.394	0.137	< 0.001	0.096
Herb vs. Mixed	0.744	1.000	0.871	0.803	0.867	0.282	0.947	0.164	< 0.001	0.008
Herb vs. Native	< 0.001	0.000	< 0.001	< 0.001	< 0.001	0.123	< 0.001	< 0.001	0.142	0.499
Herb vs. Pulling	< 0.001	0.001	< 0.001	< 0.001	< 0.001	0.221	< 0.001	< 0.001	0.187	0.241
Herb vs. Rye	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.725	< 0.001	< 0.001	0.542	0.010
Mixed vs. Native	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.009	< 0.001	0.008	< 0.001	0.049
Mixed vs. Pulling	< 0.001	0.001	< 0.001	< 0.001	< 0.001	0.021	< 0.001	0.001	< 0.001	0.141
Mixed vs. Rye	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.153	< 0.001	< 0.001	< 0.001	0.938
Native vs. Pulling	< 0.001	< 0.001	0.001	0.106	0.000	0.751	0.393	0.450	0.881	0.620
Native vs. Rye	0.753	0.643	0.932	0.916	0.819	0.234	0.163	0.021	0.391	0.059
Pulling vs. Rye	< 0.001	< 0.001	0.001	0.085	0.000	0.383	0.589	0.120	0.478	0.164

Cont = Control; Grz Ex = Grazing Exclusion; Herb = Herbicide; Native = Native Seeding; Pulling = Hand Pulling; Rye = Rye Grass

Table B31. Devona Hill mean biomass for each of the study treatments.

Treatment	Grass Biomass (kg/ha)	Forb Biomass (kg/ha)	Russian Thistle Biomass (kg/ha)	Litter Biomass (kg/ha)	Shrub Biomass (kg/ha)	Total Biomass (kg/ha)
Control	173.6 (57.4)	400.8 (161.5)	24.7 (12.6)	252.7 (182.2)	0.0	851.8 (368.9)
Grazing Exclusion	221.0 (128.7)	536.9 (302.9)	19.2 (14.8)	546.6 (269.2)	0.0	1323.7 (469.0)
Hand Pulling	236.1 (85.7)	463.8 (156.5)	16.6 (6.2)	585.5 (374.4)	0.0	1302.0 (472.5)
Herbicide	408.4 (95.5)	0.0	0.0	449.7 (165.2)	0.0	858.2 (206.1)
Mixed Approach	502.5 (383.3)	0.0	0.0	847.5 (606.8)	0.0	1350.0 (981.9)
Native Seeding	276.4 (54.8)	297.5 (191.7)	44.6 (46.1)	268.0 (123.3)	0.0	886.5 (274.8)
Rye Grass	235.9 (85.8)	347.6 (69.7)	58.1 (36.3)	292.3 (87.8)	0.0	933.9 (74.8)

Standard deviations of the mean are presented in brackets

Table B32. Edna's Knoll mean biomass for each of the study treatments.

Treatment	Grass Biomass (kg/ha)	Forb Biomass (kg/ha)	Russian Thistle Biomass (kg/ha)	Litter Biomass (kg/ha)	Shrub Biomass (kg/ha)	Total Biomass (kg/ha)
Control	339.6 (40.6)	165.9 (45.6)	68.0 (45.9)	57.0 (16.4)	0.0	630.4 (99.0)
Grazing Exclusion	511.7 (132.8)	370.4 (225.2)	16.9 (17.8)	290.3 (62.6)	0.0	1189.2 (63.7)
Hand Pulling	414.1 (32.4)	72.2 (45.2)	22.3 (32.5)	56.3 (24.1)	0.0	565.0 (62.4)
Herbicide	410.3 (200.4)	0.0	0.0	58.7 (20.2)	0.0	469.0 (186.8)
Mixed Approach	593.9 (174.3)	0.0	0.0	252.1 (173.0)	0.0	846.0 (102.6)
Native Seeding	322.9 (72.0)	112.5 (81.3)	38.1 (28.5)	59.5 (17.8)	0.0	533.0 (141.8)
Rye Grass	367.1 (108.8)	189.4 (68.1)	72.1 (42.3)	59.6 (20.1)	0.0	688.3 (122.4)

Standard deviations of the mean are presented in brackets

Table B33. Little Windy mean biomass for each of the study treatments.

Treatment	Grass Biomass (kg/ha)	Forb Biomass (kg/ha)	Russian Thistle Biomass (kg/ha)	Litter Biomass (kg/ha)	Shrub Biomass (kg/ha)	Total Biomass (kg/ha)
Control	150.0 (102.2)	146.6 (135.9)	52.5 (86.2)	271.4 (95.2)	126.6 (253.1)	747.1 (317.2)
Grazing Exclusion	200.6 (105.8)	78.0 (93.2)	53.8 (64.6)	303.6 (120.5)	0.0	636.0 (210.0)
Hand Pulling	144.2 (60.6)	291.6 (265.1)	18.2 (13.6)	258.8 (118.0)	0.0	712.9 (160.7)
Herbicide	282.5 (207.9)	0.0	0.0	313.1 (204.7)	0.0	595.7 (406.9)
Mixed Approach	375.8 (435.8)	0.0	0.0	597.7 (284.2)	46.6 (93.2)	1020.1 (663.1)
Native Seeding	50.8 (27.0)	119.7 (80.5)	100.7 (73.2)	212.2 (88.2)	10.6 (21.3)	493.9 (237.8)
Rye Grass	173.8 (119.3)	53.0 (65.0)	43.5 (50.4)	435.4 (393.3)	0.0	705.6 (426.6)

Standard deviations of the mean are presented in brackets

Table B34. Talbot Lake mean biomass for each of the study treatments.

Treatment	Grass Biomass (kg/ha)	Forb Biomass (kg/ha)	Russian Thistle Biomass (kg/ha)	Litter Biomass (kg/ha)	Shrub Biomass (kg/ha)	Total Biomass (kg/ha)
Control	389.9 (52.8)	154.1 (64.8)	76.7 (70.0)	32.1 (15.1)	0.0	652.7 (53.2)
Grazing Exclusion	715.0 (253.7)	394.4 (223.3)	4.9 (7.9)	518.9 (175.8)	0.0	1633.2 (459.6)
Hand Pulling	494.5 (89.6)	151.8 (163.8)	49.5 (49.8)	15.1 (6.0)	0.0	710.8 (233.9)
Herbicide	522.4 (18.9)	1.4 (2.8)	0.0	21.2 (8.2)	0.0	545.0 (26.8)
Mixed Approach	933.9 (406.4)	0.0	0.0	427.6 (152.0)	0.0	1361.4 (552.9)
Native Seeding	472.2 (25.9)	56.0 (32.4)	42.9 (26.1)	17.4 (4.9)	0.0	588.4 (60.5)
Rye Grass	556.5 (133.7)	97.1 (84.9)	47.1 (70.5)	22.8 (3.4)	0.0	723.5 (64.6)

Standard deviations of the mean are presented in brackets

Table B35. Direct pairwise comparisons of biomass categories between treatments and the control (data combined from all sites).

Treatment	Grass Biomass	Forb Biomass	Russian Thistle Biomass	Litter Biomass	Total Biomass
Grazing Exclusion vs. Control	0.094	0.102	0.030	<0.001	0.003
Hand Pulling vs. Control	0.246	0.836	0.137	0.985	0.692
Herbicide vs. Control	0.009	<0.001	<0.001	0.777	0.194
Mixed Approach vs. Control	0.018	<0.001	<0.001	<0.001	0.040
Native Seeding vs. Control	0.736	0.086	0.749	0.836	0.283
Rye Grass vs. Control	0.213	0.418	0.865	0.895	0.356

Table B36. P-values for the direct pairwise comparisons of treatment biomass categories with control biomass categories for each site.

Site	Treatment	Grass	Forb	Russian Thistle	Litter	Total
Devona Hill						
	Grazing Exclusion	0.046	0.327	0.057	0.029	0.029
	Hand Pulling	0.091	0.029	0.550	0.081	0.645
	Herbicide	0.003	0.979	0.029	0.254	0.011
	Mixed Approach	0.114	0.035	0.029	0.029	0.057
	Native Seeding	0.031	0.029	0.401	0.113	0.161
	Rye Grass	0.114	0.084	0.573	0.277	0.142
Edna's Knoll						
	Grazing Exclusion	0.048	0.125	0.083	<0.001	<0.001
	Hand Pulling	0.028	0.027	0.156	0.964	0.306
	Herbicide	0.515	0.029	0.029	0.898	0.178
	Mixed Approach	0.029	0.029	0.029	0.066	0.023
	Native Seeding	0.701	0.296	0.311	0.844	0.303
	Rye Grass	1.000	0.587	0.898	0.848	0.491
Little Windy						
	Grazing Exclusion	0.517	0.457	0.686	0.690	0.956
	Hand Pulling	0.926	0.368	0.686	0.874	0.854
	Herbicide	0.296	0.029	0.029	0.886	0.579
	Mixed Approach	0.486	0.029	0.029	0.114	0.486
	Native Seeding	0.200	0.745	0.427	0.396	0.200
	Rye Grass	0.772	0.260	0.886	0.449	0.343
Talbot Lake						
	Grazing Exclusion	0.526	0.458	0.343	0.121	0.165
	Hand Pulling	0.272	0.595	0.292	0.161	0.184
	Herbicide	0.006	0.029	0.029	0.160	0.977
	Mixed Approach	0.343	0.029	0.029	0.110	0.379
	Native Seeding	0.041	0.486	0.436	0.894	0.885
	Rye Grass	0.273	0.686	0.133	0.709	0.678

Table B37. P-values for multiple treatment comparisons for different biomass categories (across sites).

Treatment	Grass	Forb	Russian Thistle	Litter	Total
Control vs. Grazing Exclusion	0.085	0.557	0.092	0.001	0.004
Control vs. Herbicide	0.020	<0.001	<0.001	0.586	0.330
Control vs. Mixed	0.003	<0.001	<0.001	0.000	0.045
Control vs. Native Seeding	0.719	0.322	0.773	0.765	0.341
Control vs. Hand Pulling	0.335	0.892	0.269	0.785	0.590
Control vs. Rye Grass	0.358	0.477	0.896	0.811	0.542
Grazing Exclusion vs. Herbicide	0.538	<0.001	<0.001	0.008	<0.001
Grazing Exclusion vs. Mixed	0.229	<0.001	<0.001	0.752	0.402
Grazing Exclusion vs. Native Seeding	0.174	0.114	0.048	0.001	0.000
Grazing Exclusion vs. Hand Pulling	0.449	0.469	0.560	0.004	0.021
Grazing Exclusion vs. Rye Grass	0.424	0.194	0.069	0.003	0.025
Herbicide vs. Mixed	0.557	0.924	1.000	0.003	0.003
Herbicide vs. Native seeding	0.048	<0.001	<0.001	0.399	0.983
Herbicide vs. Hand Pulling	0.170	<0.001	<0.001	0.785	0.130
Herbicide vs. Rye Grass	0.157	<0.001	<0.001	0.761	0.113
Mixed vs. Native Seeding	0.010	<0.001	<0.001	<0.001	0.003
Mixed vs. Hand Pulling	0.050	<0.001	<0.001	0.001	0.142
Mixed vs. Rye Grass	0.045	<0.001	<0.001	0.001	0.162
Native Seeding vs. Hand Pulling	0.546	0.393	0.163	0.568	0.136
Native Seeding vs. Rye Grass	0.575	0.779	0.875	0.590	0.118
Hand Pulling vs. Rye Grass	0.965	0.566	0.217	0.974	0.944

Table B38. P-values for comparisons of Russian thistle parameters between the August 2008 and August 2009 vegetation assessments by treatment using Mann-Whitney Rank Sum Tests.

Treatment	Russian Thistle Percent Cover	Number of Russian Thistle	Number of Flowering Russian Thistle	Russian Thistle Biovolume	Average Russian Thistle Height
Control	0.649	0.07	0.003	0.034	0.022
Grazing Exclusion	<0.001	<0.001	0.997	<0.001	0.304
Hand Pulling	0.430	0.765	0.071	0.085	0.010
Native Seeding	0.429	<0.001	<0.001	0.003	0.027
Rye Grass	0.737	0.063	0.002	0.017	0.025