SUPPRESSING CANADA THISTLE ESTABLISHMENT WITH NATIVE SEED MIXES AND RESULTING COST ANALYSIS

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Suppressing Canada Thistle Establishment With Native Seed Mixes And Resulting Cost Analysis

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MASTER OF SCIENCE

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ABSTRACT

Canada thistle *(Cirsium arvense*) on conservation lands is costly and diminishes conservation objectives. This project was designed to control Canada thistle by spiking native seed mixtures. Spiking is where a native seed mixture had 3-5 native forbs that are functionally similar to Canada thistle at 3-10 times the recommended seeding density added to it. The project consisted of small-scale experiments on lands in eastern North Dakota and large-scale experiments on U.S. Fish and Wildlife land in eastern North and South Dakota. The results show that the spiked method reduced the establishment of Canada thistle immediately after seeding. The cost analysis showed the spike method was equal or lower in cost compared to herbicide control if herbicide control is: 1) 25% or less effective, 2) logistically problematic, 3) operationally more costly, 4) needed on two-thirds of the area, and 5) producing a high risk of affecting non-target species.

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INTRODUCTION

The degradation of biological communities by the invasion of non-native plant species impedes the survival of many species native to North America. Non-native plants can alter communities and ecosystems they infiltrate by using resources that would be utilized by native species, extirpating local species, changing soil properties, causing species extinctions, and even altering the patterns of resource availability in an ecosystem (Sax et al. 2007). Non-native species can reduce or even eliminate native species or communities within ecosystems, even in areas that are protected from human disturbances like national parks and nature preserves (Randall 1996).

Canada thistle (*Cirsium arvense* (L) Scop) is a perennial weed that is aggressive and is spread throughout the North American continent (Figure 1). It is established in many ecosystems where it replaces many native species and competes for space with neighboring species. Areas affected include wetlands, prairies, forests, crop fields, rangelands, pastures, road ditches, river banks, and lawns and gardens.

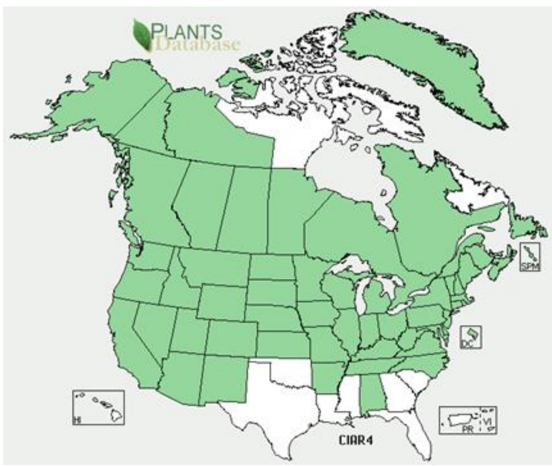

Figure 1. Map of the Canada thistle distribution on North American continent (USDA 2012).

Canada thistle is native to Europe, Western Asia, and Northern Africa and has multiple other common names (Hodgson 1968). It was introduced to North America from Europe in the beginning of the 18th century and in 1900 there were numerous reports stating Canada thistle to be in all states north of or bordering the 37th parallel (Hodgson 1968, Becker et al. 2008). Thirty-one of the states that reported incursions of Canada thistle declared it to be a noxious weed in 1901 and in 1957 it was listed in the seed laws of all the states except Alaska, Arkansas, Hawaii, and New Mexico as a noxious weed (Hodgson 1968). Today, Canada thistle is a noxious weed in forty-one states of the United States and is the most frequently listed noxious weed in the United States and provinces of Canada (Bodo Slotta et al. 2006, Becker 2008). Infestations of Canada thistle cause greater crop loss than most other perennial broadleaf weed species throughout the northern half of United States and North American continent (Wilson and Kachman 1999).

The prolific ability of Canada thistle to spread has led to research projects that dealt with controlling this noxious weed with chemical/mechanical and biological control agents including different perennial grasses, cover crops, and use of the exotic weevil (*Larinus planus*) (Wilson and Kachman 1999, Louda and O'Brien 2002, Ferrero-Serrano et al. 2008, Perry et al. 2009). Controlling Canada thistle by using native species has not been tried but other researchers have spent efforts exploring control methods for other noxious weed species using native plant species that share the same characteristics, such as annuals or perennial life history, as the target weed species (Larson and McInnis 1989, Ferrell et al. 1998, Crawley et al. 1999, Symstad 2000).

This research focuses on using traits that are shared by both the target invasive species and the native species. These traits, such as root biomass and structure, plant height, growth rate, and nutrient use efficiency and uptake, are the focal point of this research. These functional traits can in theory increase the resistance to invasion of invasive species while promoting the stability of the native plant community (Biondini 2007). Biondini's (2007) research led to the conclusion that using higher numbers of native species in restorations/reconstructions with the full suite of functional traits will increase productivity and resistance to invasion. This study proposes to use those native species that are functionally similar to Canada thistle (see Table 1) to reduce establishment of thistle in the first several years after a reconstruction. By using native species the goals of reconstruction can be met while still controlling an invasive species without the introduction of a non-native species or the use of other methods of control such as herbicide control which are not always favored by managers of conservation lands.

Table 1. List of the functional trait groups of species (Levang-Brilz and Biondini 2002). (Functional Trait Group contains species similar to Canada thistle.)

Functional Trait Group 1	Functional Trait Group 2	Functional Trait Group 3
Achillea millefolium	*Allium stellatum*	*Symphyotrichum ericoides*
Anaphalis margaritacea	*Chenopodium album*	*Astragalus canadensis*
Artemisia dracunculus	*Galium boreale*	*Conyza canadensis*
Artemisia tridentata	*Liatris punctata*	*Dalea purpurea*
Asclepias verticillata	*Oxytropis lambertii*	*Grindelia squarrosa*
Chrysopsis villosa	*Psoralea esculenta*	*Hedeoma hispida*
Cirsium arvense		*Helianthus maximiliani*
Coreopsis lanceolata		*Linum perenne*
Gaillardia aristata		*Oenothera biennis*
Geum triflorum		*Rosa arkansana*
Lupinus perennis		*Sphaeralcea coccinea*
Melilotus officinalis		
Potentilla arguta		
Ratibida columnifera		
Rudbeckia hirta		
Solidago missouriensis		
Solidago rigida		
Taraxacum officinale		
Tragopogon dubius		
Verbena stricta		
Vicia americana		

The first objective of this study was to determine the effects on Canada thistle establishment by planting a native seed mixture with an increased forb species seeding rate that shares functional trait groups with Canada thistle, the spike method. The second objective of this study was to use the information from objective one and create a cost comparison to aid managers in deciding which type of native seed mix to use and how that compares to other methods of controlling Canada thistle.

LITERATURE REVIEW

Natural disturbance and succession define the present prairie ecosystem (Sampson et al. 2004, Hobbs et al. 2007, Axelord 1985). Historic human manipulation of landscapes has promoted the spread of introduced species and many prairies have been invaded to varying degrees by non-indigenous species (Dale et al. 2000, Grant et al. 2009). Consequently, invasive species pose a threat to many native species in grassland ecosystems (Dukes 2002). This degradation of prairie ecosystems by invasive and introduced species has led to the need for prairie restorations. A restoration is a method of hastening natural succession and can take one of two alternative forms (Luken 1990). One type is functional restoration which increases productivity, habitat for wildlife, ecosystem services, erosion control, lands used for grazing, and other economic resources (Prach et al. 2007). Another type of restoration is an ecological restoration which is the restoration of any natural system that has been degraded in some way, whether the system has been damaged or destroyed (SER 2004). Functional restoration and ecological restoration differ considerably in species diversity, composition, form, and the goals they meet (Wilson 2002).

Over time, restored prairies are also challenged with a steady trend of declining species richness and species composition (Sluis 2002). The characteristics of an establishment (patchiness, evenness, and diversity) are often highly unpredictable (Wilson et al. 2004, Martin et al. 2005, Polley et al. 2005). This high unpredictability could lead to an increased chance of introduced and invasive species establishing during and after the restoration (Stachowicz and Tilman 2005). Species composition and richness influence the establishment of incidental species with decreasing incidental species relative to increasing species richness and functional form richness (Hooper et al. 2005, Biondini 2007). Species composition and species richness have been the target of many recent studies (Tilman 1997, Sluis 2002, Hooper et al. 2005, Guo et al. 2006, Biondini 2007, Brudvig et al. 2007, Grygiel et al. 2009).

Forbs and grasses, both native and introduced, fall into three different functional trait groups (three for forbs and three for grasses), which also include perennial weeds like Canada thistle (*Cirsium arvense* [L.] Scop.). Functional traits are related to structure and physiology. These consist of quantitative trait clusters which include resource uptake, growth rates, root development, and productivity (Levang-Brilz and Biondini 2002, Biondini 2007). Different characters between plants allow multiple species to coexist and compete for limited resources (Hooper 1998). Forb and grass species that share the same functional traits as a perennial weed species would likely hinder that weed species the most (Zimdahl 2004, Zimdahl 2007). Some studies have revealed that certain species and functional traits were more effective than others at suppressing a given invading species (Larson and McInnis 1989, Ferrell et al. 1998, Crawley et al. 1999, Symstad 2000). In a recent study, Biondini (2007) found that when native species were increased in a seeding mixture there was an increased stability of production and resistance to invasion by other species. This stability and resistance to weed invasion could be accounted for by the seed mixture having a certain number of species, different functional traits, and seeding at a higher proportion due to less space and resources available for weed formation (Zimdahl 2004, Biondini 2007, Zimdahl 2007). Diversity and heterogeneity increase with the increase in number of species and functional form traits that are in the seeding mixture (Wilson 2000, Del Moral et al. 2007). High diversity may also compensate for loss of species structure and function by easily replacing species structure and function from the high diversity species pool (Biondini 2007). Increased pressure from invasive species propagation highlights the importance of replacement from the diverse species pool. The possibility that dominant species could out-compete less dominant species is increased by a more diverse seed mixture (Piper and Pimm 2002). Diverse systems use more resources overall and are more likely to have a competitor that impedes the invading species success, making that system difficult to invade (Tilman et al. 1996, Dukes 2002). A minimum of nine species that cover three functional traits are needed to attain aboveground biomass variability (Biondini 2007). One study suggested sixteen species were needed in the seeding mixture to attain maximum productivity within the mixed grass prairie region (Guo et al. 2006). Low biodiversity can reduce a community's resistance to invasion and the ability to persist (Dukes 2002).

High density seed blends results in higher coverage and possibly higher production while compensating for poor seed quality, low seedling formation, low survival, and producing enough seedlings to compete against weeds (Kindscher and Tieszen 1998, Wilson et al. 2004, Guo et al. 2006, Zimdahl 2004). Effectiveness of high seed density is limited because of competition among species and interspecies competition for available resources (Piper and Pimm 2002). The exclusion of other desirable species by certain higher seeded species dominating the available resources is an argument that counters the high density seed mixtures. This competition is seen with the individuals and species which can uptake the most nutrients the fastest. This uptake of nutrients is related to the growth rates of the species. The species that grows the fastest will use the most nutrients and out-compete slower growing species. This leads to asymmetric competition between species due to size advantage and rate of nutrient uptake. Asymmetric competition is the proportionally greater use of resources by the individual or by the species (Schwinning and Weiner 1998, Freckleton and Watkinson 2001, Dybzinski and Tilman 2009). Freckleton and Watkinson (2001) found that individuals and species formed a competitive hierarchy where the species that are at the top use the most resources versus the species at the bottom. They found that yield-density was on an exponential decline for both the species and individual levels.

The use of annual cover crops has been applied to controlling invasive species in conservation lands and agriculture settings (Hoffman and Regnier 2006, Sheley et al. 2006, Perry et al 2009). Cover crops that can control the invasive species usually limit the desired species success while the opposite is true when cover crops that do not suppress the invasive species do not limit the desired species success (Perry et al 2009). Perry et al (2009) used annual and perennial native cover crops, in a greenhouse setting, to control four exotic invasive species: cheatgrass (*Bromus tectorum*), Japanese brome (*Bromus japonicus*), Canada thistle, and whitetop (*Cardaria draba*). They found that annual ragweed (*Ambrosia artemisiifolia*) and common annual sunflower (*Helianthus annuus*) controlled the invasive species and reduced the desired species. The perennial species Canada goldenrod (*Solidago canadensis*) and littleleaf pussytoes (*Antennaria microphylla*) rarely control the four invasive species but did increase the desired species (Perry et al 2009). They suggested the use of annual species may be effective in controlling invasive species and larger field experiments are needed to test the use of cover crops under pertinent conditions.

Other methods for control of invasive species include:

- The use of cover crops to effectively combat invading weeds is explained with the same reasoning as previously stated, less resources available for weed formation (Hoffman and Regnier 2006, Sheley et al. 2006).
- Reducing the competitive ability of a target invading species could be done with the use of a biological control by killing individual plants and reducing fecundity. Biological control and competitive plants often have an independent or cumulative

effect on invasive species (Ferrero-Serrano et al. 2008). Ferreo-Serrano (2008) found that needle and thread grass (*Hesperostipa comata* [Trin. & Rupr.] Barkworth) and weevil attack had independent cumulative effects on Canada thistle's root biomass and led to greater reduction when used together versus by themselves.

- One study found when you combine mowing, spraying chemicals, and rototilling before applying a seed mixture, it will help establish a mix of perennial grasses. This combination of pre-seeding treatment also increased the ability of perennial grasses to compete against Canada thistle (Wilson and Kachman 1999).
- Wilson and Kachman (1999) found perennial grasses that were competitive can be as effective as a control for Canada thistle as spraying clopyralid; when used together, they delivered better control of Canada thistle, and furthermore mowing twice a year added to this control. The study also stated that rototilling would be impractical since the coverage of the rototill equipment was small. However, a disk tiller could be a possible substitute.

Over time, restorations generally gain species because of low diversity in the plant community. This low diversity leaves space for opportunistic non-seeded species to utilize unused resources. High diversity seed mixtures may contain species similarly found in the surrounding environment and the seed banks from the surrounding area could influence the establishment of additional species (Platt 1975, Kalamas and Zobel 2002, Hooper et al. 2005, Biondini 2007). Native predators and pathogens tend to focus on just a few species and this focus allows reduction of the dominant species over time while allowing other desirable species to grow (Sax et al. 2007). Predators and pathogens of the dominant species can be a destructive force by causing plant mortality, reducing its overall health, and shifting the structure and composition of the plant community. This interaction between plant species and predator/pathogen can maintain species diversity and expedite succession (Gilbert 2002). Interactions of competition and host-pathogen dynamics can be interdependent and competition for limited resources can increase susceptibility to disease so much so that competition from the bottom-up can create an increased top-down pathogen effect (Gilbert 2002).

Canada thistle, when present, reduces the value of grassland plantings that are used for forage, conservation, hay, and recreation. Canada thistle reduces the overall value in grassland plantings by negatively affecting forage production and quality (Lym and Duncan 2005). Canada thistle can cause severe loss in yield and crop more than any other broadleaf weed species and displaces natives in ecosystems that are protected from human disturbances as in national parks and preserves (Randall 1996, Wilson and Kachman 1999). Land reduced in value by noxious weeds due to cost of control and lost in forage value can range in the millions of dollars.

Current research on control methods of leafy spurge (*Euphorbia esula* L) has shown that control of this noxious weed species can range in tens of thousands of dollars and because of these high control costs, the value of land in need of active control of leafy spurge is reduced (Bangsund et al. 1999, Leistritz et al. 2004, Lym 2005).

The lands set aside for conservation like the Conservation Reserve Program (CRP) plots usually require some form of renewal to the land because there is a lack of nutrient cycling and a build-up of litter (North Dakota State University Extension Service 2009). Renovating CRP lands with the use of a high diversity native species/spiked forbs would help to re-establish a healthy cycling of nutrients, increase tiller development, increase soil health, and help control soil erosion while at the same time reducing Canada thistle establishment. While CRP is known to benefit wildlife by providing cover and substance, the high diversity/spike mixture would provide the same benefit to wildlife with a more natural native cover and a wider variety of plants to provide food sources with different nutrient loads (Johnson and Schwartz 1993). Heterogeneity of plant species can be used as an indicator for overall system health (wildlife diversity conservation, ecosystem services, and soil conservation) while renovating CRP plantings with a high diversity/spike mixture would increase the total system health by providing benefits to the diversity of wildlife, birds and mammals, increasing native plant diversity, and increasing natural processes like carbon sequestration and erosion control (Woodward et al.1999, Fuhlendorf and Engle 2001, Fuhlendorf et al. 2006).

Decision analysis, also known as decision theory, is the process or a set of quantitative methods for coming to the ideal decision for a problem or set of problems. The optimal decision is one that follows the logic of maximum gain. The main goal of decision theory is to create a routine for making rational choices (Hansson 1994). The decreasing desirability under which decisions are made in certain environments include: certainty, risk, uncertainty, conflict, and ignorance. The most common decision environments are risk, where alternative actions are known and outcomes can be predicted, and uncertainty, where alternative actions are known but the outcome has no information available (Duft 1972, Hansson 1994).

Decision theory is most appropriate to decision making in an environment of risk or uncertainty which complements experience and knowledge of practices, but does not replace the basic manager decision making (Duft 1972). Using decision theory or decision analysis to help make a management decision could be associated with adaptive management. Learning from management decisions' outcomes can create a systematic approach for improving resource management; this systematic approach is call adaptive management (Williams et al. 2007).

Adaptive management is an active management tool to promote control of invasive species, replication of native prairies, obtaining positive results, and restoration execution.

METHODS

Study Sites

The study sites for this research project were located in mixed grass and tallgrass communities within the prairie pothole region of eastern North and South Dakota (NPWRC 2006). The study area has a continental climate with cold winters and hot summers. Annual temperatures and precipitation varied geographically because the study was spread over a large area. South central North Dakota has a ten year average of 4.8°C annual mean temperature and annual mean rainfall of 282.26 mm. East central North Dakota has a ten year average of 5.8°C annual mean temperature and annual mean rainfall of 629.07 mm. Southeast North Dakota has a ten year average of 6.4°C annual mean temperature and annual mean rainfall of 595.54 mm. Southeast South Dakota has a ten year average of 7.2°C annual mean temperature and annual mean rainfall of 624.36 mm (NOAA 2012).

The sites were located on land owned by the State of North Dakota and United States Fish and Wildlife Service (USFWS). The USFWS land consisted of Waterfowl Production Areas (WPA) and National Wildlife Refuges. The State of North Dakota study area included the Albert Ekre Grassland Preserve (Ekre, privately owned by non-profit group) (Latitude 46.553073˚ Longitude -97.133525˚) in Richland County and Central Grassland Research Extension Center (CGREC) (Latitude 46.717228˚ Longitude -99.463829˚) in Stutsman County; both are operated by North Dakota State University. The USFWS study areas included: Tewaukon National Wildlife Refuge (NWR), Sargent County, North Dakota (Latitude 46.007759˚ Longitude -97.353295˚); Fuller Lake WPA in the Valley City Wetland Management District, Steele County, North Dakota (Latitude 47.301479˚ Longitude -97.578778˚); Clear Lake WPA in the Madison Wetland Management District, Minnehaha County, South Dakota (Latitude

43.762905˚ Longitude -97.001009˚); and Halverson WPA in the Madison Wetland Management District, Kingsbury County, South Dakota (Latitude 44.401935˚ Longitude -97.524902˚).

The soils at each site were unique and their textures ranged from sandy to clayey. The following soil descriptions are from the Natural Resources Conservation Service (NRCS) web soil survey (WSS 2012). Soils found at Ekre Preserve consisted of the Mantador-Delamere-Wyndmere soil series and are classified as coarse-loamy, mixed, superactive, frigid Typic Endoaquolls. Soils at the CGREC site included the Hecla and west-Ulen series which are classified as sandy, mixed, frigid Oxyaquic Haplustolls along with the Kreme-Flaxton complex series which are classified as Fine-loamy, mixed, superactive, frigid Typic Paleustolls. The soils at Fuller Lake WPA site were of the Heimdal-Emrick soil series complex and classified as coarse-loamy, mixed, superactive, frigid Pachic Hapludolls and coarse-loamy, mixed, superactive, frigid Calcic Hapludolls. The soils at the Tewaukon National Wildlife Refuge were of the Forman-Aastad-Parnell complex soil series classified as fine-loamy, mixed, superactive, frigid Calcic Argiudolls (WSS 2012). Seven soil series were present at Clear Lake WPA and six of the seven soil series made up four soil series complexes. The one soil series and the four complexes included: Baltic, Egan-Wentworth-Trent soil series complex, Ethan-Egan soil series complex, Wakonda-Chancellor soil series complex, and Wentworth-Chancellor-Wakonda soil series complex. The Baltic soil series is classified as fine, smectitic, calcareous, mesic Cumulic Vertic Endoaquolls. The Egan-Wentworth-Trent soil series complex is classified as fine-silty, mixed, superactive, mesic Udic Haplustolls. The Ethan-Egan soil series complex is classifies as fine-loamy, mixed, superactive, mesic Typic Calciustolls. The Wakonda-Chancellor soil series complex is classified as fine-silty, mixed, superactive, mesic Aeric Calciaquolls. The Wentworth-Chancellor-Wakonda soil series complex is classified as fine-silty, mixed, superactive, mesic Udic Haplustolls (WSS 2012). Seven soil series were present at Halverson WPA and five of the seven make up two soil series complexes. The two soil series and the two complexes included: Lowe soil series, Marysland soil series, La Prairie-Holmquist soil series complex, and Poinsett-Rusklyn-Waubay soil series complex. The Lowe soil series is classified as fine-loamy, frigid Typic Calciaquolls. The Marysland soil series is classified as fine-loamy over sandy or sandy-skeletal, frigid Typic Calciaquolls. The La Prairie-Holmquist soil series complex is classified as fine-loamy, mixed, frigid Cumulic Udic Haploborolls. Poinsett-Rusklyn-Waubay soil series complex is classified as fine-silty, mixed, frigid Udic Haploborolls (WSS 2012).

Experiment Design

A total of twenty-four small scale plots were located on the State of North Dakota study sites, twelve on the Ekre site, and twelve on the CGREC site. Four large scale plots were located on the USFWS property. Each site displayed multiple distinctive soil characteristics and topography typical of tallgrass and mixed grass prairies in the prairie pothole region. The large scale sites were composed of a mosaic of upland and wetland community. The sampling plots within each large scale site were located in the upland portion. The small scale plots were located on what available land was open for research due to their size. Portions of the plots located on the CGREC site were in the wet meadow community.

Data collected for the study were obtained by visiting sites that were planted with a native mixture for restoring conservation lands. Data were collected during the summer of 2011 and 2012 during the months of July and August. Data collection entailed plant community data, invasive/undesirable weed information, and the physical location of Canada thistle.

The small plot experiment was a randomized block design with two treatment levels and six replications for a total of twelve plots at each small scale site. Each plot was 4 x 4 m with a two meter buffer between each plot. Treatment one consisted of a native plant seed mixture typically used for forage production and conservation and was seeded at 300 seeds/m^2 (Table 2).

Table 2. Species seeded at each of the small scale sites.

Species	Ekre	CGREC
Big bluestem (*Andropogon gerardii*)	x	
Little bluestem (*Schizachyrium scoparium*)	x	x
Side oats grama (*Bouteloua curtipendula*)	x	x
Indiangrass (*Sorghastrum nutans*)	x	
Green needlegrass (*Nassella viridula*)		x
Slender wheatgrass (*Elymus trachycaulus*)		x
Western wheatgrass (*Pascopyrum smithii*)		x
Purple prairie clover (*Dalea purpurea*)	x	x
White prairie clover (*Dalea candida*)	x	x
Stiff sunflower (*Helianthus pauciflorus*)	x	x

To counteract the dependence of the naturally occurring weed seed bank found on each site, which is often highly variable, we added Canada thistle seed to each plot. Canada thistle seed was collected and checked for germination the growing season preceding the seeding. Canada thistle seed was added to this mixture at a rate of 100 seeds/m^2. Treatment two used the same mixture of seed that was used in treatment one, but four forbs were added to the mixture to increase the seeding rate to 3000 seed/m^2. Treatment two also had Canada thistle seed added at a rate of 100 seeds/m^2. The four forbs had similar functional group traits as Canada thistle and consisted of common yarrow (*Achillea millefolium*), black-eyed Susan (*Rudbeckia hirta*), prairie coneflower (*Ratibida columnifera*), and Lewis flax (*Linum lewisii*).

The large scale experiment was done under different pretreatment management practices and changing environmental conditions. The majority of pretreatment management practices consisted of killing the sod with glyphosate and till/cropping the site. This pretreatment practice was done with the hope of creating seedbed free of existing plants and to reduce the seed bank. Plots greater than 400 m^2 across the eastern half of North Dakota and eastern South Dakota have high variability within and among sites due to different soil types, existing weeds, previous land practice, plant dispersal, and soil health (biotic and abiotic). The large plot experiments were designed to test the effectiveness of forb addition at a higher seeding rate in similar conditions as used by practitioners of this management method. The treatments for the large scale experiment were the typical restoration seed mix planted at the normal seed rates used by each of the practioners and then a spike seed mix planted at a 3 to 10 times higher seed rate. None of the treatments had any addition of Canada thistle. The practitioner was in control of the seed mixture used, addition of the higher rate of forbs, and time of year for seeding. The species list for each of the large scale sites can be found in Appendix A. The species used in the spike for the USFWS sites are as follows. Clear Lake WPA and Halverson WPA: Hoary Vervain (*Verbena hastata*), common yarrow (*Achillea millefolium*), and purple prairie clover (*Dalea purpurea*). Fuller Lake WPA: Maximilian sunflower (*Helianthus maximiliani*), purple prairie clover (*Dalea purpurea*), and black-eyed Susan (*Rudbeckia hirta*). Tewaukon NWR: black-eyed Susan (*Rudbeckia hirta*), purple prairie clover (*Dalea purpureum*), prairie coreopsis (*Coropsis palmata*), and prairie coneflower (*Ratibida columnifera*). Each of the large scale sites consisted of a native-only plot and spike plot which were randomly assigned.

Seeding

The small scale plots were seeded in the fall of 2010 and were broadcasted by hand after the ground was tilled. The seed was raked into the top inch of the soil after broadcasting. No pre-treatment was applied to the small scale sites. The large scale sites had different site histories and pretreatment applications. Clear Lake WPA and Halverson WPA sites were farmed for two years with genetically engineered crops resistant to glyphosate and seeded by broadcasting into soybean stubble. Both sites were planted to genetically engineered soybeans for both years and had multiple applications of glyphosate each year. The process would begin with a fall graze or hay, followed by fall tillage and spring planting of the first year. Clear Lake WPA was seeded in the spring of 2010 and Halverson WPA was seeded in the spring of 2011. Tewaukon National Wildlife Refuge site had been farmed since 1952 (Askerooth 2012). The crop rotation for the last five years before seeding was soybeans in 2009, corn in 2008, soybeans in 2007, spring wheat in 2006, soybeans in 2005. The site was treated with two glyphosate applications (mid-June and early-July) by the cooperator on genetically engineered soybeans resistant to glyphosate in the year before seeding. The USFWS did not apply any herbicide to the site and no pre-emergence was used or seed treatment before broadcasting the seed mixture. Fuller Lake WPA was conventionally farmed (herbicides, tillage, etc.) for 5 years and the crops were soybeans and corn. The crop in 2010 was Roundup-Ready soybeans. The native grass and native grass with forb seed mix was broadcast on to the snow-covered field in March 2011.

Sampling

Small plot experiment sampling consisted of estimating the plant canopy coverage of all species and Canada thistle density within two-1 m^2 quadrats per plot via ocular estimation. Sampling occurred the first and second growing season after the seed mixture was planted. The large scale experiment sampling consisted of dividing the plots into five equal portions and then randomly locating a sampling point into each portion resulting in a restricted randomization sampling scheme. The random sampling point within each portion was found by walking to the center of the portions and then walking south (randomly chosen) eighteen paces (randomly chosen) to the location of the sampling point. All sample points were located in upland areas with wet meadows and wetlands being avoided. Wet meadows and wetlands were avoided because the majority of the seed mix and the spiked species were best adapted to upland sites. Sampling wet meadow and wetlands sites would be unrepresentative of the ability of the seeded to species to reduce Canada thistle establishment. At each sampling point a 1 m^2 quadrat was placed to estimated plant composition and Canada thistle density via ocular estimation. Also at this sampling point, five 20 by 50 cm (1/10 m^2) quadrats were laid out with one quadrat in the middle and two to each side 0.25 m from the middle and 0.5 m apart as seen in Figure 2. The two different sampling methods conform to the methods used in the small plot experiment and to methods used by the USFWS.

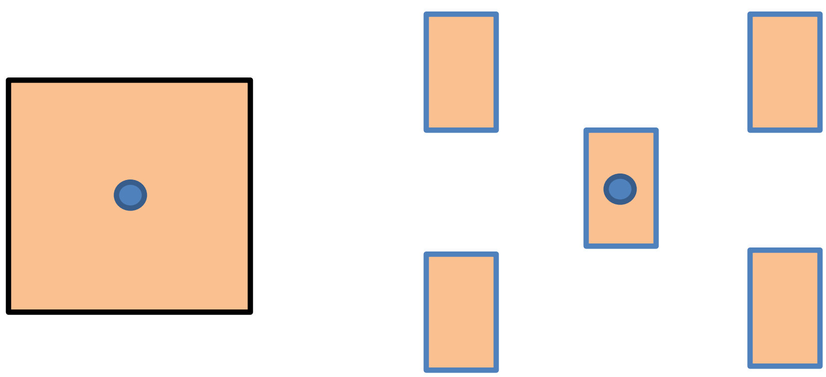

Figure 2. Design of the method used to sample plant composition of the large scale sites. The 1 m^2 quadrat outlined in black with the sampling point in the middle and1/10 m^2 quadrat outlined in blue with the sampling point in the middle quadrat. The 1/10 m^2 quadrats were arranged with one quadrat in the middle at the sampling point and two to each side 0.25 m from the middle and 0.5 m apart.

Canada thistle patches were mapped in the large scale experiment plots with use of GPS units utilizing Esri® Arcpad software (version 7). The patches were mapped to determine if the plot fell into the USFWS action stage of >10% coverage of Canada thistle to trigger the active control of invasive species (personal communication with Cami Dixon 2012). Canada thistle patch mapping consisted of walking in a back-and-forth motion across each plot in both the spike plot and the paired control plot. Patches that were found in each plot were mapped by standing on one edge and using the Arcpad tool editor to draw a polygon of the estimated size of the patch being mapped by ocular estimation. Individual Canada thistle plants were not counted unless it was obvious it was part of a larger less-dense patch.

Statistical Analysis

Data collected were analyzed using the paired t-test method. The paired t-test method tests the equality of means from more than two paired plots that are independent. Because the comparison is only interested in one-way tests such as is the spike lower in cover, density of Canada thistle, or higher in native cover; the one-tailed p values will be reported. The paired t-test method was run using Microsoft Excel (version 2010) data Analysis Toolpak. The small plot data were averaged for each plot before analysis. The USFWS large scale plots were combined to compare between spike and native-only over a very large area that differed in site characteristics. The paired t-test was also used on the comparison of weedy species for each of the small scale sites and the combined USFWS sites. Using the data collected each species was categorized as planted grass, planted forb, non-planted grass, non-planted forb, weedy grass, or weedy forb. The species that were categorized as weedy species were further broken down into annual, biennial, and perennial weed species. Each species was categorized using the United States Department of Agriculture (USDA) plant database; if a species was listed as a weedy species in any state, it was considered as a weedy species (Table 3). Trees were considered a weedy species within the planting.

Areas covered by > 10% of Canada thistle canopy for the large scale plots were compared within each site by measuring the area covered and then finding percent area covered for the whole site for only the upland area. Measurement was done using Esri® Arcmap software tools (Version 10). The analysis of the area covered by the 10% Canada thistle cover for the four sites used an arcsine square-root transformation with a paired T-test and only considered a one-tailed test that the spike was lower in area than the native-only.

Table 3. The species listed categorized as weedy species and the duration of each species: annual, biennial, and perennial.

Species	Duration	Species	Duration
Acer negundo	Perennial	*Galium spp.*	Annual
Amaranthus albus	Annual	*Hordeum jubatum*	Perennial
Ambrosia artemisiifolia	Annual	*Ipomoea calantha*	Perennial
Ambrosia trifida	Annual	*Iva annua*	Annual
Artemisia biennis	Biennial	*Medicago lupulina*	Perennial
Asclepias syriaca	Perennial	*Mentha arvensis*	Perennial
Brassica cretica	Biennial	*Panicum capillare*	Annual
Brassica rapa	Biennial	*Phragmites australis*	Annual
Bromus inermis	Perennial	*Plantago major*	Perennial
Bromus japonicus	Annual	*Poa pratensis*	Perennial
Chamaesyce maculata	Annual	*Polygonum amphibium*	Perennial
Chamerion angustifolium	Perennial	*Populus spp.*	Perennial
Chenopodium album	Annual	*Potentilla spp.*	Perennial
Cirsium vulgare	Biennial	*Rumex acetosella*	Perennial
Convolvulus Spp.	Perennial	*Rumex crispus*	Perennial
Conyza canadensis	Biennial	*Setaria italica*	Annual
Descurainia sophia	Biennial	*Solanum demissum*	Perennial
Digitaria Haller	Annual	*Sonchus arvensis*	Perennial
Echinochloa crus-galli	Annual	*Taraxacum officinale*	Perennial
Elymus repens	Perennial	*Thlaspi arvense*	Annual
Equisetum arvense	Perennial	*Typha spp.*	Perennial
Eragrostis cilianensis	Annual	*Ulmus pumila*	Perennial
Eriogonum Michx	Annual		

RESULTS

Vegetation Analysis

When comparing spiked and native-only for the first year of this study, the Ekre small plot spiked treatment had significantly lower ($p=0.0014$) percent Canada thistle cover (spiked 3.5, native-only 17.75) and density ($p=0.0009$) (spiked 4.3, native-only 11.0 plants/m^2). Native plant cover was significantly higher ($p=0.0003$) for the spiked seeding (spiked 37.1, native-only 5.2). The second year, Ekre small plot spiked treatment had significantly lower ($p=0.0317$) percent Canada thistle cover (spiked 1.08, native-only 7.25) and density ($p=0.0246$) (spiked 0.42, native-only 4.0 plants/m^2). Native plant cover was significantly higher ($p=0.0052$) for the spiked seeding (spiked 49.9, native-only 10.25) (Figure 3).

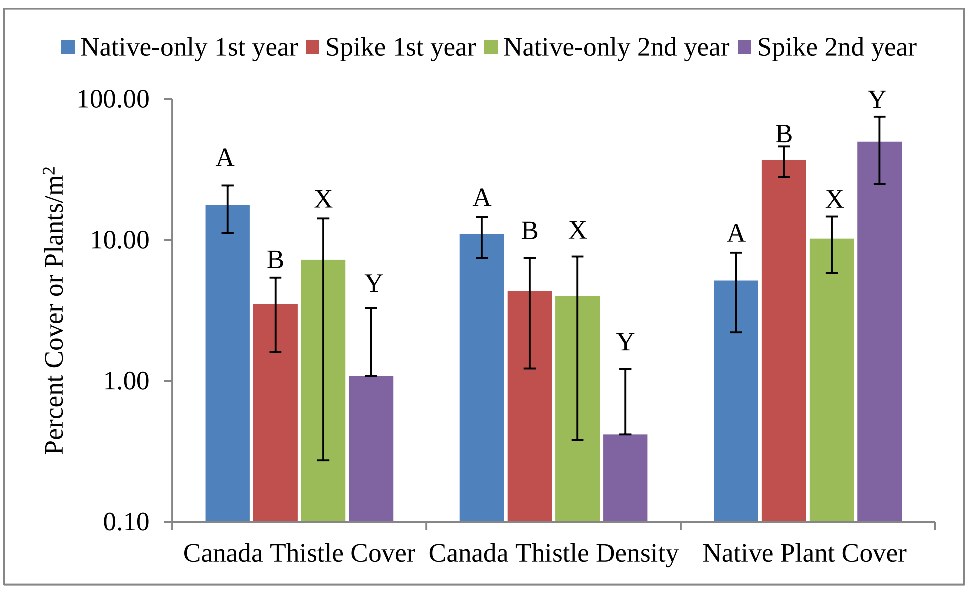

Figure 3. Canada thistle density (density/m^2) and percent cover along with native plant percent cover for the small scale plots at the Ekre site (n=6). Treatment levels followed by different letter-pairs were significantly different ($p<0.05$) within years, 1st year (A, B) and 2nd year (X,Y). The log scale is used so all categories could be displayed on one graph.

The first year comparison for the CGREC small plot spiked treatment had a significantly lower (*p*=0.05) Canada thistle cover (spiked 5.75, native-only 12.25) and no significant difference in density (p=0.06) (spiked 5.58, native-only 12.25 plants/m^2). Native plant cover was significantly higher (p=.0001) for the spiked seeding (spiked 38.8, native-only 1.08). During the second year, CGREC small plot spiked treatment had significantly lower (p=0.031) percent Canada thistle cover (spiked 7.5, native-only 17.25) and a density that showed no significant difference (p=0.053) (spiked 3.83, native-only 9.42 plants/m^2). Native plant cover was significantly higher (p=0.0017) for the spiked seeding (spiked 41.3, native-only .42) (Figure 4).

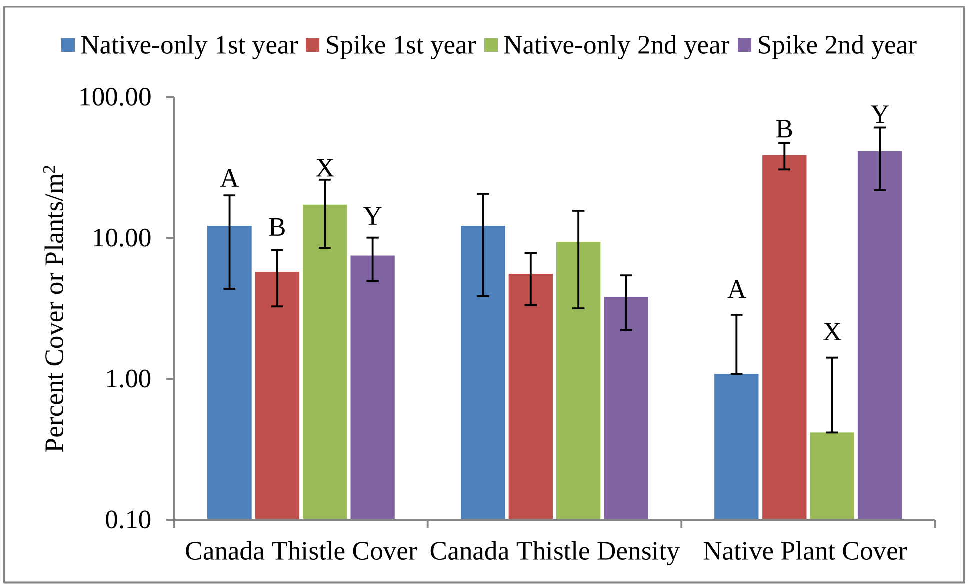

Figure 4. Canada thistle density (density/m^2) and percent cover along with native plant percent cover for the small scale plots at the CGREC site (n=6). Treatment levels followed by different letter-pairs were significantly different (p<0.05) within years, 1st year (A, B) and 2nd year (X,Y). The log scale is used so all categories could be displayed on one graph.

The USFWS large plots 1 m^2 frame data had the spiked having significantly lower (p=0.014) percent cover of Canada thistle (spiked 4.7, native-only 11.95) and density (p=0.035) (spiked 1.3, native-only 3.6 plants/m^2). Native plant cover was significantly higher (p=.0143) for the spiked seeding (spiked 49.2, native-only 7.7) (Figure 5). The large plot 1/10 m^2 frame data for the first year had the spike with no significant difference (p=0.064) in percent Canada thistle cover (spiked 2.82, native-only 6.32) but a significantly lower (p=0.029) density (spiked 0.53, native-only 1.3). Native plant cover was significantly higher (p=0.002) for the spiked seeding (spiked 31.96, native-only 4.38) (Figure 6).

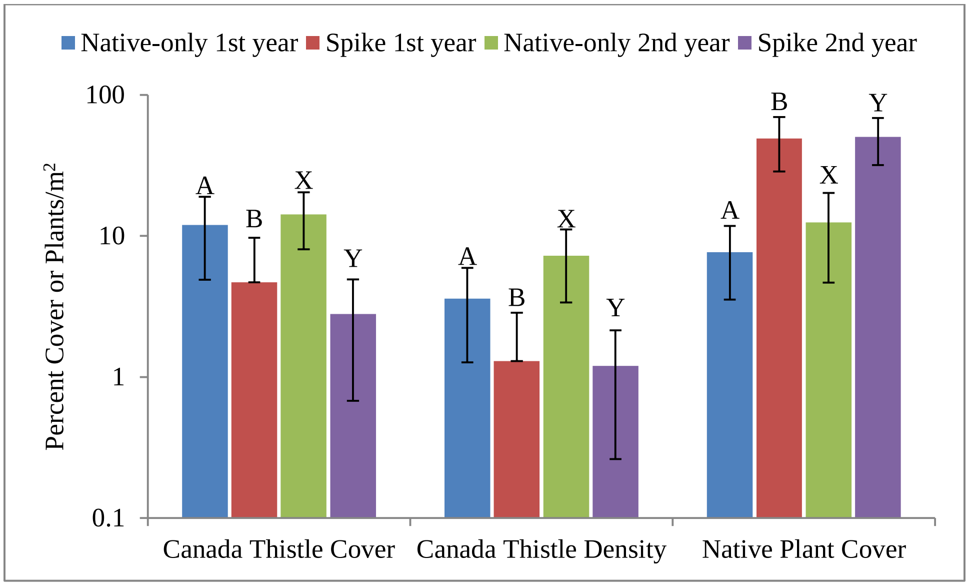

Figure 5. Canada thistle density (density/m^2) and percent cover along with native plant percent cover for the large 1 m^2 frame data from the large scale USFWS sites (n=4). Treatment levels followed by different letter-pairs were significantly different ($p<0.05$) within years, 1st year (A, B) and 2nd year (X,Y). The log scale is used so all categories could be displayed on one graph.

The USFWS large plots 1 m^2 frame data for the second year had the same response as the first year data with the spiked having significantly lower (p=0.007) percent cover of Canada thistle (spiked 2.8, native-only 14.2) and density (p=0.014) (spiked 1.2, native-only 7.25 plants/m^2). Native plant cover was significantly higher (p=0.003) for the spiked seeding (spiked 50.3, native-only 12.45) (Figure 5). The large plots 1/10 m^2 frame data for the second year had the spike with a significantly lower (p=0.005) percent Canada thistle cover (spiked 0.79, native-only 8.12) and density (p=0.002) (spiked 0.23, native-only 1.53). Native plant cover was significantly higher (p=0.006) for the spiked seeding (spiked 31.15, native-only 4.62) over the four sites (Figure 6).

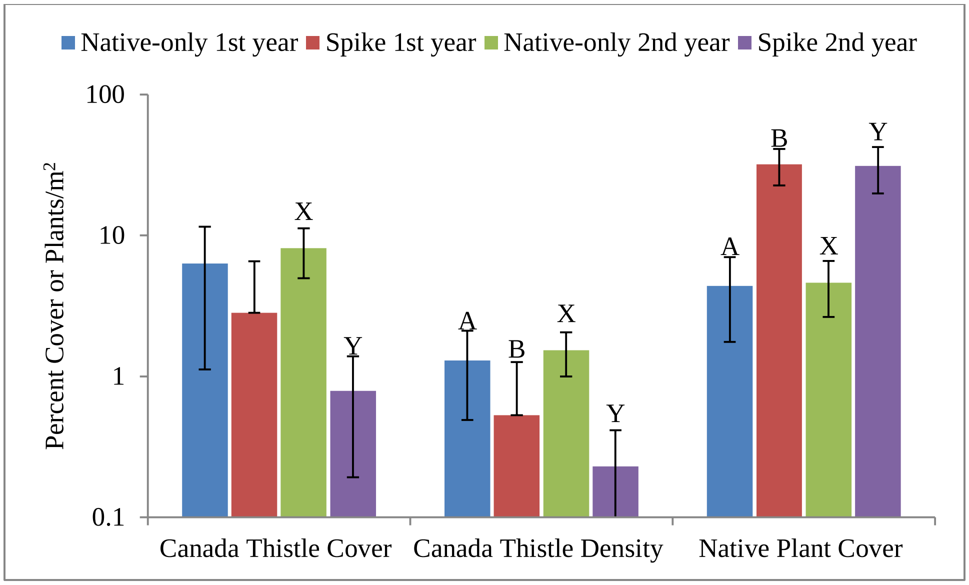

Figure 6. Canada thistle density (density/m^2) and percent cover along with native plant percent cover for the 1/10 m^2 frame data from the large scale USFWS sites (n=4). Treatment levels followed by different letter-pairs were significantly different ($p<0.05$) within years, 1st year (A, B) and 2nd year (X,Y). The log scale is used so all categories could be displayed on one graph.

The first year, Ekre small plot annual weed cover was not significant (p=0.397) between the spiked and native-only plots (spiked 47.85, native-only 50.92). Biennial weed cover was significantly lower (p=0.0285) in the spike treatment than the native-only (spiked 8.58, native-only 12.75). Perennial weed cover showed no significant difference (p=0.0903) in the spiked versus the native-only (spiked 10.44, native-only 19.58). The second year, Ekre small plot annual weed cover showed no significant difference (p=0.0739) between the spiked and native-only plots (spiked 0.25, native-only 3.83). Biennial weed cover was significantly lower (p=0.0285) in the spike treatment than the native-only (spiked 0.0, native-only 2.42). Perennial weed cover was not significantly different (p=0.136) in the spiked versus the native-only (spiked 34.17, native-only 46.92) (Figure 7).

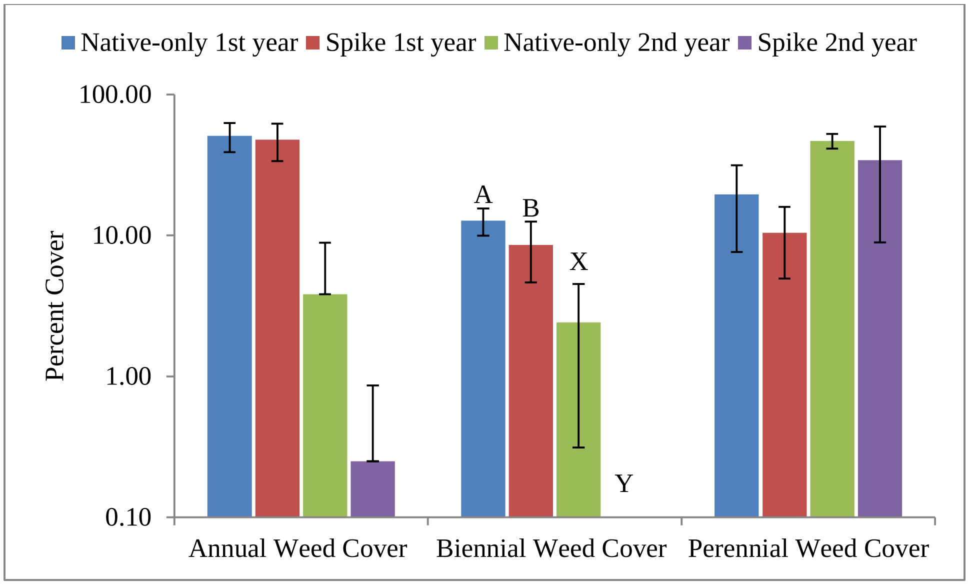

Figure 7. Annual weed, biennial weed, and perennial weed percent cover for the small scale plots at the Ekre site (n=6). Treatment levels followed by different letter-pairs were significantly different ($p<0.05$) within years, 1st year (A, B) and 2nd year (X,Y). The log scale is used so all categories could be displayed on one graph.

The first year CGREC small plot annual weed cover was not significantly different ($p=0.051$) between the spiked and native-only plots (spiked 59.33, native-only 69.17). Biennial weed cover was not significantly different ($p=0.228$) between the spike treatment and the native-only (spiked 0.667, native-only 0.417). Perennial weed cover was not significantly different ($p=0.337$) in the spiked versus the native-only (spiked 11.08, native-only 9.51). The second year, CGREC small plot annual weed cover was significantly lower ($p=0.050$) between the spiked and native-only plots (spiked 5.42, native-only 17.25). Biennial weed cover was not significantly different ($p=0.132$) in the spiked treatment versus the native-only (spiked 1.08, native-only 2.42). Perennial weed cover was significantly lower ($p=0.0018$) in the spiked versus the native-only (spiked 18.67, native-only 27.58) (Figure 8).

The USFWS large plots 1 m^2 frame data first year annual weed cover was not significantly different ($p=0.486$) between the spiked and native-only plots (spiked 4.41, native-only 4.45). Biennial weed cover was significantly lower ($p=0.028$) between the spiked treatment

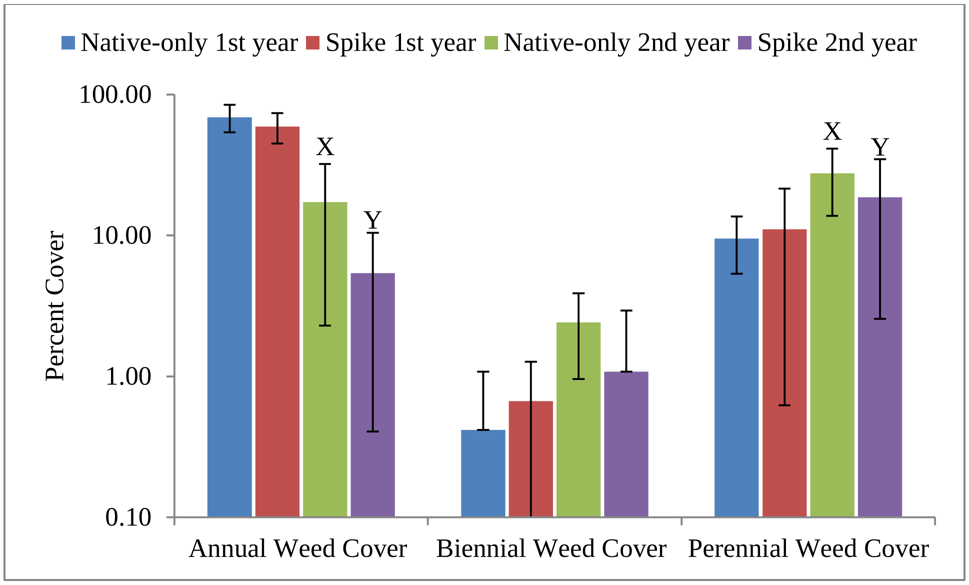

Figure 8. Annual weed, biennial weed, and perennial weed percent cover for the small scale plots at the CGREC site (n=6). Treatment levels followed by different letter-pairs were significantly different ($p<0.05$) within years, 1st year (A, B) and 2nd year (X,Y). The log scale is used so all categories could be displayed on one graph.

and the native-only (spiked 4.95, native-only 22.0). Perennial weed cover was not significantly different ($p=0.247$) in the spiked versus the native-only (spiked 9.1, native-only 8.1) (Figure 9). The large plots 1/10 m^2 frame data first year annual weed cover was not significantly different ($p=0.203$) between the spiked and native-only plots (spiked 1.231, native-only 2.396). Biennial weed cover was significantly lower ($p=0.032$) between the spiked treatment and the native-only (spiked 1.12, native-only 13.04). Perennial weed cover was not significantly different ($p=0.392$) in the spiked versus the native-only (spiked 4.40, native-only 3.66) (Figure 10).

The USFWS large plots 1 m^2 frame data second year data had the same response as the first year data with the annual weed cover not being significantly different ($p=0.248$) between the spiked and native-only plots (spiked 0.40, native-only 1.20). Biennial weed cover was not significant ($p=0.088$) for the spiked treatment compared to the native-only (spiked 1.50, native-only 4.35). Perennial weed cover was not significant ($p=0.074$) in the spiked versus the native-only (spiked 3.75, native-only 13.0) (Figure 9). The large plots 1/10 m^2 frame data second year annual weed cover was not significantly different (p=0.123) between the spiked and native-only plots (spiked 0.05, native-only 1.22). Biennial weed cover was significantly lower (p=0.050) between the spiked treatment and the native-only (spiked 0.26, native-only 4.95). Perennial weed cover was not significantly different (p=0.392) in the spiked versus the native-only (spiked 2.31, native-only 10.5) over the four sites (Figure 10).

Area covered by > 10 cover of Canada thistle, the action level for USFWS, in the Clear lake WPA was 24.8% for native-only plot and 8.96% for the spiked plot. For the Halverson WPA area covered by > 10% Canada thistle cover was 32.8% for the native-only plot and 8.52% for the spiked plot. For the Fuller Lake WPA area covered by > 10% Canada thistle cover was 6.82% for native-only plot and 0.06% for the spiked plot. For the Tewaukon National Wildlife Refuge area covered by > 10% Canada thistle cover was 66.3% for native-only plot and 4.48% for the spiked plot. The average area covered by >10% cover of Canada thistle for the combined USFWS sites was 32.7% for the native-only plot and 5.50% for the spike plots which was significantly different (p<0.026) resulting in an overall 27.2% increase in >10% Canada thistle cover for the large plots when not using the spike method.

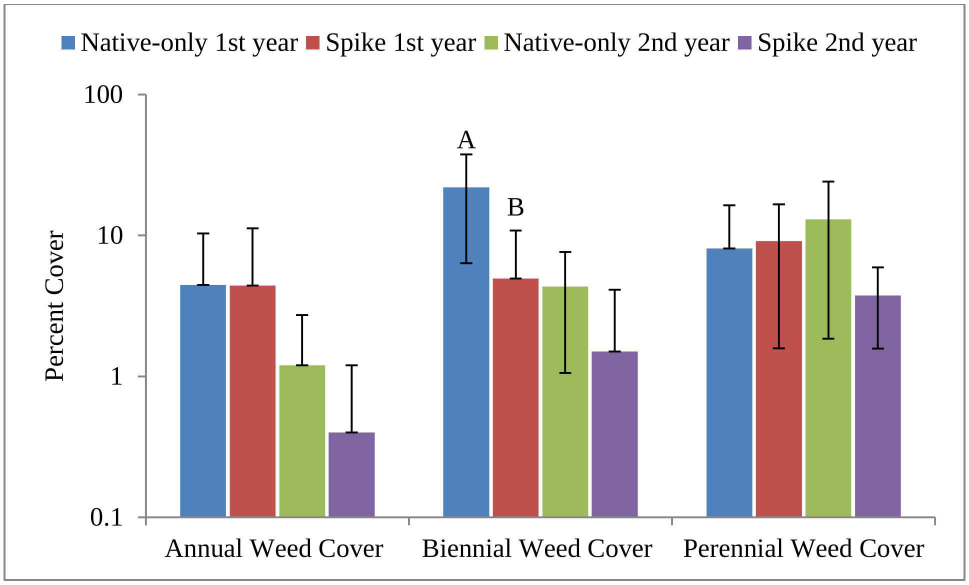

Figure 9. Annual weed, biennial weed, and perennial weed percent cover for the large 1 m^2 frame data from the large scale USFWS sites (n=4). Treatment levels followed by different letter-pairs were significantly different ($p<0.05$) within years, 1st year (A, B) and 2nd year (X,Y). The log scale is used so all categories could be displayed on one graph.

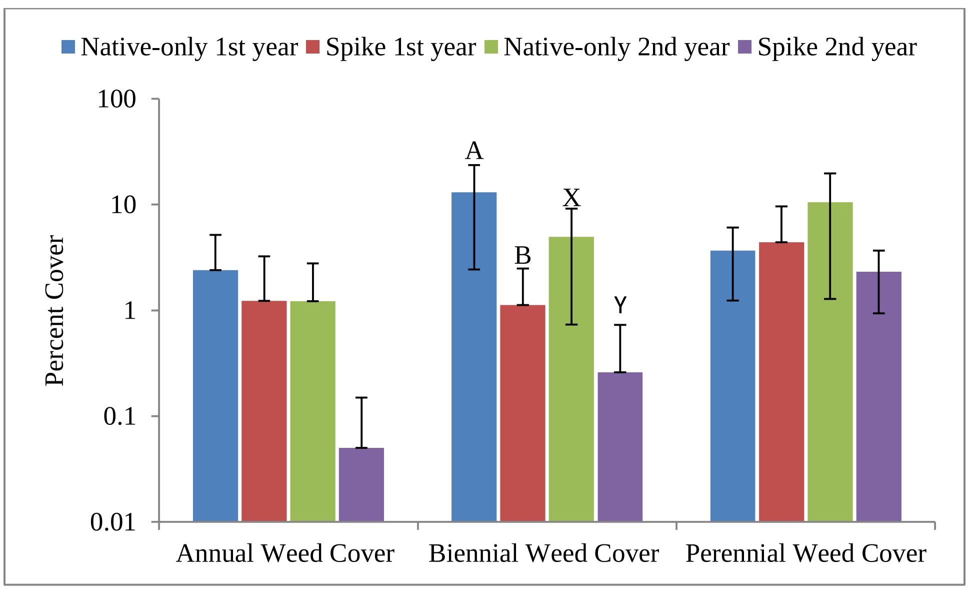

Figure 10. Annual weed, biennial weed, and perennial weed percent cover for the 1/10 m^2 frame data from the large scale USFWS sites (n=4). Treatment levels followed by different letter-pairs were significantly different ($p<0.05$) within years, 1st year (A, B) and 2nd year (X,Y). The log scale is used so all categories could be displayed on one graph.

DISCUSSION

Vegetation Analysis

Canada thistle cover and density were affected by the increase in forbs in the spiked native seed mixture at both the small and large scale sites after the first and second year of growth. There was also a higher cover of native species in the spiked plantings compared to the native-only. This result was consistent across all sites that were spread out over a large area with many different site characteristics. The consistency across sites that were far apart strengthens the argument that the results were not a result of specific site condition favoring the spiked seed mixture or a random event but rather a generalizable result that can be applied to eastern North and South Dakota and other regions similar to these regions.

A possible explanation for action of the spiked seed mix on Canada thistle can be attributed to the competition between the species used in the spike mixture and Canada thistle. The hypothesis is that the species in the spiked mixture limited the available resources for Canada thistle establishment (Taylor and Aarssen 1990, Bengtsson et al. 1994). This competitive exclusion is enhanced by using a mix of forbs at a higher seeding rate which share functional traits such as growth rates, root development, and productivity with Canada thistle (Levang-Brilz and Biondini 2002) resulting in competition for resources at several different levels with Canada thistle.

One possible mechanism for the competition is that there is a high probability for individuals of the spiked species establishing before Canada thistle due to the high density of the spiked seeds. With such a high density there is increased probability that certain individuals would find sites that are conducive to fast establishment compared to the existing seed bank of Canada thistle. Factors such as chance and other natural factors have been found to result in the favoring of a few individuals over others (Schwinning and Weiner 1998, Freckleton and Watkinson 2001, Dybzinski and Tilman 2009). The competition with Canada thistle due to differences in early establishment resulting in differential growth rate and subsequent plant size is asymmetrical competition. There is an unequal division of resources between the spiked species individuals and Canada thistle individuals (Dybzinski and Tilman 2009). This competition creates a hierarchy from top - down individual and species competition where performance of resource acquiring is decreased for species not dominating the upper levels of the hierarchy (Schwinning and Weiner 1998, Freckleton and Watkinson 2001, Dybzinski and Tilman 2009). The other possible competition mechanisms are related to the symmetric competition that occurs for the most part below ground and is related to some of the functional characteristics that the spiked species have in common with Canada thistle. These competition mechanisms are the same proposed for how cover crops reduce weeds. Cover crops mainly use annual species in the seed mixture while the spike method uses biennial or perennial species (Perry at al 2009).

Another possible mechanism for the interference of the spiked species on Canada thistle is that there are some allelopathic properties of the spiked species. After a thorough search of literature, it was found that the species used in the spike mixture had no allelopathic or parasitic properties. A study by Perry et al. (2009) found that allelopathy had only limited effect when native species were used as cover crops reducing weeds and the circumstances for when allelopathy is effective are restricted to a certain set of conditions. Therefore the inference of the spiked species on Canada thistle was attributable to competition.

There is an assumption in the study that the plantings had no adult Canada thistle present and all thistle establishments were from seeds and the seed bank. If there were adults surviving then the spike method may not be as effective since the adults will have a size advantage over the newly sprouting spike species. In addition, thistle can vegetatively reproduce through rhizomes, quickly increasing the amount of resources that it can use thus making it competitive against other species and individuals. It is unknown if the spike method will be effective in preventing or reducing Canada thistle establishment when adult plants are present. This will require further research. The situation where adults are present in most native plantings is currently low since often the pre-planting process is designed to kill adult weeds such as Canada thistle through herbicide or tillage, therefore, the risk of being present at plantings is low.

Most native plantings take at least five years to move from the initial establishment phase onto the phase where most of the planted native species have had time to establish and contribute to the plant community. The experiments reported here have only existed for two years. Two years is not long enough to predict how the other native species and Canada thistle will react in another three years. It will be necessary to follow the experiment over time to see if the desired plant community results.

It is hypothesized that at the end of the five years this induced competition between the spiked forbs and Canada thistle will not result in the exclusion of the other planted species. This is because many of the other species planted are functionally different based on the niche differentiation principle. All the native grass species planted are functionally different along with some of the forbs. Other factors that make native species tolerant to the competition provided by spiked species are slow growth with accompanying reduced need for certain resources, shade tolerant, and ability to survive on reduced resources such as nutrient and water stress (Perry et al. 2009). The findings of Perry et al. (2009) support the notion that native perennials planted as a cover crop did not affect the other planted desired species and in some cases promoted their growth.

Most plantings are characterized by a phase where annuals dominate, but as time passes the composition shifts from weedy annuals to the planted native species (Larson 2011). The native seeded species will establish initially, but because of their slow growth these species take time to appear in the restoration's life span. It is anticipated that the same trend will occur in these plantings with the eventual plant community made up of the planted native species.

Over time, natural processes, predators, and pathogens of the spiked species will reduce the canopy coverage and dominance of those species (Klironomos 2002). This reduction due to natural processes has been seen in other studies on diversity where monocultures of these spiked species were planted (Mario Biondini, personal communication). This reduction would allow native species that have established but are not contributing to the plant community to replace the spike species individuals, thereby increasing the evenness and diversity of the plant community over time. Additionally individuals that were seeded but are still in the seed bank can then establish, replacing the pathogen affected spiked species, contributing to the plant community.

The increased opportunity for native species to replace the affected spike species will result in the increase of native species and functional trait groups in a planting contributing to the resistance to the invasion of weed species (Biondini 2007). High diversity seed mixtures with different functional groups represented increased the overall stability of production and resistance to invasion while under both high and low nutrient regimes. Increasing the resistance of a planting would allow the site to meet the goals of the reconstruction while reducing the probability of species like Canada thistle to dominate or be at a level where some action to control Canada thistle is needed. Often the control is left to herbicide control or mowing, which both have a risk of reducing non-target desired species. Avoidance of such control actions makes the use of spiked seed mixes desirable to managers who wish to reduce management actions after planting.

The decision to use perennial and biennial species functionally similar to Canada thistle rather than native annuals is borne out of Perry et al's. (2009) work which found that annual native cover crops were less effective when reducing perennial weeds such as Canada thistle. The annuals sometimes did allow the desired species to grow and be part of the plant community. The fact that the spike species are already desired species means their continued contribution to the resulting plant community is not a problem but desired. The uses of native annuals are normally not thought to be part of a successful native planting and would take away from the objectives of a reconstruction.   Support for the decision to use functionally similar natives to Canada thistle is further reinforced by Knudson et al. (2012) who found that native grasses planted to reduce Canada thistle had little effect. Most native grasses are not functionally similar to Canada thistle and therefore would be poor competitors compared to the species chosen for the spike which are functionally close to Canada thistle.

The increase in native species (with decreased Canada thistle) will increase the overall value of the forage and forage availability for domestic animals and wildlife that utilize conservation lands (Johnson and Schwartz 1993, Lupis et al. 2006). This rise in forage value would increase the value of the land rented since it would have higher production and forage quality. Reduction in cover/density of Canada thistle would also be beneficial to agroecosystem services of conservation lands which would further increase the value of the land (Lym and

Duncan 2005). The agroecosystem services that would benefit from the Canada thistle reduction are wildlife conservation, recreation, soil conservation, and species richness.

Weed Analysis Excluding Canada Thistle

The results from the spiked forb mixture on other weed species (annual weed, biennial weed, and perennial weed) indicated overall that the increased forbs did not have an effect on other weed establishment. There were three significant exceptions. At the Ekre site there was a significant decrease in biennial weedy species for both the first and second years, At the CGREC there was a significant decrease in perennial weed species only for the second year, and the first year for the USFW sites had a significant reduction in biennial weed species.

The reduction in the biennial species for the first year USFWS sites can be attributed to one site, the Halverson WPA. This WPA had an extensive infestation of wormwood (*Artemisia biennis* Willd) the first year of sampling in the native-only plot of Halverson. The first year spike plot had little wormwood and this was the same result for the second year spike. In the second year, the native-only plot still had wormwood present but not to the extent of the previous year. This reduction in wormwood from first year to second year in the native-only plot could be accounted by the plant's natural life cycle being a biennial. Since this site had abundant biennial species (high percent cover of wormwood) that were naturally established, it provided a glimpse of how wormwood reacts to a high diversity spiked mixture. The other USFWS sites had little or no biennial weed species recorded in the quadrat frames and this lack of biennial species in the study sites could lead to research that targets invasive biennial species that are costly and difficult to manage.

Ekre sites showed significant reduction of biennial weedy species for both years. The first year, both the native-only and spike plots had recorded biennial species with less recorded in the spike plots. The second year there was a reduction in cover of biennial weedy species for the native-only plots and zero recorded cover in the spike plots. I can only speculate that either the biennial species' natural life cycle reduced the cover or the spiked mixture provided enough competition to reduce the establishment of biennial species to the point where they became subdominant in the plantings. The first year results showing significance leads me to believe the spike mixture did have an effect on biennial weedy species and this should be further researched in the future. The biennial life cycle could be making the interpretation of the results for both the Ekre sites and USFW sites difficult and skewed.

Comparison of the Large to Small Plots

The small plots were a controlled situation because the amount of Canada thistle seeds planted in them was controlled. In comparison the large plots were less controlled because the amount of Canada thistle depended on the seed bank which was not controlled and subject to past conditions. The results from the small plots reveled there was a significant difference between the densities and the coverage of Canada thistle with lower levels for the spike method. This would lead one to believe that the spiking of forbs would probably be successful to reduce Canada thistle establishment, but when the small plots are scaled up to larger plots, we not only see the differences between the spike and the native-only but the difference between the methods is larger than what was seen at the small plot level. The 28% increase on average in area covered in the 10% Canada thistle canopy coverage over the spike method is not predictable from the small plot results and yet the effect is probably more important on how land manager will view decisions on whether to use the spike method and will be utilized in the cost analysis. Managers have an implicit coverage percent of about 10% cover for Canada thistle to reach before active control is applied to infestations; the action stage that most USFWS managers deem is the trade off point where the cost of applying control is justified (personal communication with Cami Dixon 2012). One site, Fullers Lake WPA, had less than 6.8% in area, in the 10% Canada thistle coverage than the other sites. This low area in actionable Canada thistle coverage could be attributed to the site's history of being farmed with the use of herbicide for 5 years. The other sites were farmed with use of herbicide for only 2 years and had thistle infestations for a long period so there was a large buildup of Canada thistle seeds in the seed bank.

Cost Comparison Between the Spiked and Native-only Plantings

Managing conservation lands can cost an organization a substantial amount of money. Costs can take many different forms, such as labor, field preparation, burning, planting, seed, and herbicide and/or mechanical control of weeds. Deciding what seeding method to implement for conservation lands can be aided by comparing the costs associated with each method over a 10-year period. Such a cost comparison can be used as a decision tool by managers in meeting their management goals under limited funds.

Scaling for Inflation

Projecting prices five, ten, and fifteen years in the future or even continuously from current value is done by a simple economic equation. The equation is $FV = PV \times (1+R\%)^{T}$ where PV is the present value, FV is the future value, R% is the rate (discount rate or interest rate), and T is years in the future (Black 2002). Calculating FV gives us the future value of the costs associated with this study where an R% value of .05 or 5% was used.

Component Values

Controlling invasive species can significantly increase the cost of managing conservations lands. Multiple management costs taken into account include labor, field preparation, burning the field, herbicide control, cost of chemical, mechanical control, and seeding. Over time these costs change as inflation affects the current price and is reflected in Table 4.

Table 4. The average current cost, five year future cost, ten year future cost, and fifteen year future cost per hectare for restoration management efforts in the Northern Great Plains. The costs calculated are from Natural Resources Conservation Service (2009), North Dakota custom rate (2010), South Dakota State University custom rate (2004). The burning cost was from a US Fish and Wildlife fire report from Sand Lake NWR (unpublished data 2011).

Management	Current Cost per ha	5 Year Future Cost per ha	10 Year Future Cost per ha	15 Year Future Cost per ha
Labor	$46.04	$58.76	$75.00	$95.72
Field Preparation	$22.38	$28.56	$36.45	$46.52
Burning	$49.40	$63.05	$80.47	$102.70
Chemical Control with Cost of Labor	$86.45	$110.33	$140.82	$179.72
Cost of Chemical	$13.41	$17.12	$21.85	$27.88
Mechanical Control	$16.72	$21.34	$27.24	$34.76
Seeding (Drill/Broadcast)	$28.33	$36.16	$46.15	$58.90

The cost of seed is a major factor in the overall price to manage conservation lands. The cost for seeding by drilling and broadcast seeding is estimated to be roughly the same price and so will not be factored into the price of seeding. The cost of seed is mainly determined by the type of seed management used on the selected conservation land. The types of seed management include low diversity seeding and high diversity seeding. Low diversity seeding is a mixture of grasses, both cool-season and warm-season, and forbs with a species richness of ten or less. High diversity seeding is a mixtures of grasses, both cool-season and warm-season, and forbs with a species richness of fifteen or more. Low diversity is usually cheaper than high diversity to plant because the difference in number of species used in the mix, so the lower the number of species, the cheaper the cost. High diversity cost is higher than the low diversity cost because of the amount of the species present in the mix. The spike is the highest because of the amount of seed that is used with this option of management.

The cost of the seed depends on what seed is used and the current price of seed. Because the price of seed can change, a cost range was used to indicate a high and low value. The prices for low diversity and high diversity are an estimated price from the USFWS commonly used in plantings for North and South Dakota (unpublished data). The spiked treatment cost was calculated from using 2010 prices from two seed vendors, Mustang and Milborn (http://www.mustangseeds.com/, http://millbornseeds.com/), and averaging the cost of the spiked treatment from Fuller Lake WPA in the Valley City Wetland Management District and Clear Lake WPA in the Madison Wetland Management District. These costs and cost ranges are shown in Table 5, and Table 6 shows the future inflated cost.

Table 5. The estimated average cost for low diversity, high diversity, and spike seeding restoration management methods.

	Estimated Cost	Cost Range
Low Diversity	$247.00/ha	$185.25 - $370.50 /ha
High Diversity	$494.00/ha	$432.25 - $555.75/ha
Spike	$684.29/ha	$617.50 - $864.50/ha

Table 6. Future inflation cost for five years, ten years, and fifteen years for low diversity, high diversity, and spike seeding restoration management methods.

Future cost for 5 years	Estimated Cost	Cost Range
Low Diversity	$315.25/ha	$236.43 - $472.86/ha
High Diversity	$630.49/ha	$576.37 - $709.29/ha
Spike	$873.34/ha	$788.10 - $1103.35/ha
Future cost for 10 years		
Low Diversity	$402.34/ha	$301.76 - $603.50/ha
High Diversity	$804.68/ha	$704.10 - $905.26/ha
Spike	$1114.64/ha	$1005.83 - $1408.17/ha
Future cost for 15 years		
Low Diversity	$513.49/ha	$385.12 - $770.25/ha
High Diversity	$1027.00/ha	$898.61 - $1155.37/ha
Spike	$1422.60/ha	$1283.73 - $1797.22/ha

Analysis of Cost and Sensitivity Analysis

Low diversity plantings makes for an initial low cost management method but have multiple recurring costs which can increase the overall cost over time. In addition, low diversity plantings can allow undesired species to take root and flourish and provide a low resistance to invasion (Larson 2010). High diversity seedings have a resistance to invasion by undesired species (Tilman 1997, Dukes 2002, Biondini 2007). Therefore the costs for managing a high diversity management plan are mainly higher upfront (amount of seed needed) but have lower recurring costs over the lifespan of the seeding. High diversity seedings tend to have lower undesired species as the seeding ages while retaining a moderate to high species diversity (Dukes 2002, Larson 2011). This trend results in fewer costs in the future to manage undesired species and in some instances completely eliminating the costs of spraying and reseeding.

The cost of the spike is really determined by what species are selected for the spike application and the availability of commercial seed. The addition of spiked species to a native-only mix will increase the upfront cost of this management plan. As seen in this study, the addition of a spike treatment increases resource competition between desirable and undesirable species and will decrease the need of active control of the undesirable species over time. The cost to control invasive weeds does contribute to the overall cost of management.

Sites that require Canada thistle control have a recommended schedule of spraying the site eight out of ten years (personal communication with Kyle Kelsey 2012). If spraying herbicide to control thistle is done as recommended by the manufacturer, managers can anticipate a reduction of 60% to 70% in Canada thistle cover for the first and subsequent years (Figure 11). This amount of reduction is possible when the herbicide is applied as recommended with a knowledgeable crew, however if the personnel or the herbicide application is not as reliable, the overall reduction rate is reduced to less than 60% (personal communication with Kyle Kelsey 2012). With a well applied chemical, each of the first three years a manager could probably switch to spot spraying after the third or fourth year of continuous spraying. The manager would still be expected to spray eight out of ten years to get a Canada thistle infestation under control (personal communication with Kyle Kelsey 2012).

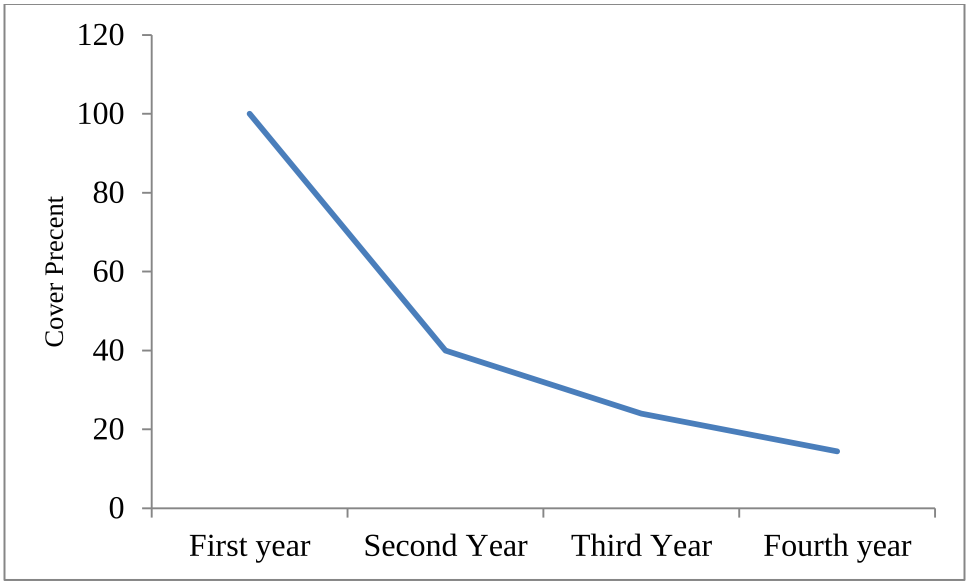

Figure 11. Reduction in field acreage of a 100 hectare field over four years with an estimated reduction rate of 60% while using herbicide application.

The USFWS native-only plots as mapped had on average 32.7 percentage of the area that fell above the 10% threshold for Canada thistle coverage that would require active control. Control is normally in the form of herbicide application to the affected portion of the field. The spike plots had on average a 5.5% of the area above 10% coverage requiring only spot spraying of the patches of Canada thistle that do get established.

Comparison of Canada thistle control with herbicide on the native-only, high diversity seed mix and spike seed mix at the 60% to 70% success rate over a four year control cycle within a ten year period on a 100 ha field basis finds that herbicide control for the Canada thistle costs roughly $10,480 for the native-only planting and $1,580 for the spike plantings using the coverage of 10% or greater Canada thistle found in the large plots (Table 7). This results in an $8,900/100 ha savings of herbicide spraying when using the spike method planting over the native-only planting.

Table 7. Cost comparison of Canada thistle herbicide control, herbicide spraying, between the native-only mixture and spike mixture at the 60% reduction in area (success rate) that needs control for the first two years in the four year cycle and 70% reduction in area in the last two years. [a]

Native-only Mixture	Hectares That Need Spraying	Cost of Spraying per Hectares	Hectares X Cost
Year 1	33.00	85.00	2805.00
Year 2	13.20	93.71	1237.01
Year 3	5.28	98.40	519.54
Year 4	2.11	103.32	218.21
Year 5			
Year 6			
Year 7	33.00	119.60	3946.92
Year 8	9.90	125.58	1243.28
Year 9	2.97	131.86	391.63
Year 10	0.89	138.46	123.36
Cost of Native-only Mix.		Total Cost of Spraying.	10484.95
49400.00	Total Cost of Restoration. (Seed mix cost + ten year spraying cost)		59884.95
Spike Mixture	Hectares That Need Spraying	Cost of Spraying per Hectare	Hectares X Cost
Year 1	5.00	85.00	425.00
Year 2	2.00	93.71	187.43
Year 3	0.80	98.40	78.72
Year 4	0.32	103.32	33.06
Year 5			
Year 6			
Year 7	5.00	119.60	598.02
Year 8	1.50	125.58	188.38
Year 9	0.45	131.86	59.34
Year 10	0.14	138.46	18.69
Cost of Spike Mix.		Total Cost of Spraying.	1588.63
68400.00	Total Cost of Restoration. (Seed mix cost + ten year spraying cost)		69988.63

[a] The comparison uses a 100 ha field with an initial average area coverage of 33% for the native-only and 5% for the spike of the 10% or greater Canada thistle canopy coverage as found in the large plot surveys. Over a ten year period two spray cycles of four consecutive years are used for the comparison. The second cycle starts at the same initial percent of coverage of Canada thistle above 10% canopy coverage. The costs of spraying per hectare are adjusted for inflation at a 5% inflation rate. The costs of spraying per hectare are a combination on the hectares cost of spraying $75 and average cost of herbicide $10. The cost of the two seed mixes are adjusted to the 100 ha level.

The comparison of the cost of the spike method including the herbicide application is $10,104/100 ha more than the native-only mix ($69,988-$59,884). Even though the herbicide cost is higher for the native-only the cost of the native-only seed mix is $19,000 less so the total cost, seed mix + herbicide control, is higher for spike method due to the high seed mix cost. Therefore a manager who is cost conscious and confident in the ability to control Canada thistle with herbicide over the ten year period would choose to plant the native-only mix and not the spike, thus saving $10,104/100 ha.

A sensitivity analysis was performed on the level of herbicide application success where the cost of herbicide application over 10 years rises to the point where the total cost for the two methods are equal. This point of equal costs is at 24% herbicide success (Table 8). The 24% success rate is 36% lower than the 60% initially used and reported by the USFWS. In this case, this would be judged to be a poor success rate and only under certain conditions would a manger expect such low success. If on the other hand a manager would expect such low herbicide success due to certain conditions then the spike method would become equal in cost and an acceptable alternative.

Another assumption of the 60% to 70% cost analysis is that the area of Canada thistle with less than 10% canopy coverage is reduced from roughly 33 hectares down to 2 hectares (Table 7). It is conceivable that under varying conditions the probability that managers are likely to achieve this level of reduction may be low. A sensitivity analysis was conducted assuming an initial area covered by the 10% Canada thistle coverage to be the average found on the four surveyed sites to see what level of reduction in thistle area is needed so that the total costs of both methods are equal. Assumptions for the sensitivity analysis were that even though herbicide spraying will reduce the density of Canada thistle, the area needed to be controlled will be the same for the first two years out of the four year control cycle. Then the area for the last two years in the control cycle will be reduced to some level so the total costs are equal. The results of the sensitivity analysis found that a reduction in the third and fourth year of 55% will produce a total cost for the native-only method that is a couple hundred dollars more than the spike method (Table 9). So conditions where the spike method would be chosen because of cost would be where managers feel that even though herbicide control reduces density of Canada thistle, the area controlled would be the same for the first two years of a four year control cycle and then is limited to 55% or less reduction in area for the last two years.

Table 8. The total cost and cost of herbicide control over the course of a ten year control plan with a 24% success rate for the native-only seed mix. See Table 7 for details.

Native-only Mixture	Hectares That Need Spraying	Cost of Spraying per Hectare	Hectares X Cost
Year 1	33.00	85.00	2805.00
Year 2	25.08	93.71	2365.77
Year 3	19.06	98.40	1900.31
Year 4	14.49	103.32	1526.42
Year 5			
Year 6			
Year 7	33.00	119.60	3946.92
Year 8	25.08	125.58	3170.36
Year 9	19.06	131.86	2546.59
Year 10	14.49	138.46	2045.55
Cost of Native-only Mix.		Total Cost of Spraying.	20306.92
49400.00	Total Cost of Restoration. (Seed cost + ten year spraying cost)		69706.92
Total Cost of The Spike.	69988.63		

A sensitivity analysis was conducted to see what the initial amount of area covered by the 10%Canada thistle coverage that would have the total costs for both methods be equal under the 60% to 70% herbicide success rate. The amount of initial area cover by 10% thistle coverage that produces equal costs for the two methods would be 66% of the total field (Table 10). This level of area with 10% thistle coverage was found in one of the native-only planting sites used in the study. If a manager feels that there is a possibility for Canada thistle to infest close to 66% of the area then the spike method would be a lower cost method to reduce Canada thistle establishment.

Table 9. Total cost and cost of herbicide control where the area controlled is the same for the first two years in the control cycle with a 55% reduction in area for the third and fourth year of the cycle in a ten year control plan.

Native-only Mixture	Hectares That Need Spraying	Cost of Spraying per Hectare	Hectares X Cost
Year 1	33.00	85.00	2805.00
Year 2	33.00	93.71	3092.51
Year 3	15.00	98.40	1475.97
Year 4	15.00	103.32	1549.77
Year 5			
Year 6			
Year 7	33.00	119.60	3946.92
Year 8	33.00	125.58	4144.26
Year 9	15.00	131.86	1977.94
Year 10	15.00	138.46	2076.84
Cost of Native-only Mix.		Total Cost of Spraying.	21069.22
49400.00		Total Cost of Restoration. (Seed mix cost + ten year spraying cost)	70469.22
Total Cost of The Spike.	69988.63		

The cost comparison and sensitivity analyses show that under the following conditions choosing the spike will result in more costs than using a native-only seed mix when:

1. Herbicide success on Canada thistle over a ten year period is better than 24% assuming an average initial coverage of Canada thistle of 33%.
2. The area that needs herbicide control is reduced after the second year more than 55% assuming an average initial coverage of Canada thistle of 33%.
3. The area covered by Canada thistle is less than 66% assuming herbicide control is 60% to 70%.

If these conditions are not thought to be met then the spike method would be lower cost. There are other considerations that can be used to when deciding whether to use the spike over the native-only method. The spike consistently had a low amount of area, 8.9% or less in all four sites, with 10% Canada thistle canopy coverage. This relegates any herbicide control to only spot spraying. This reduces the risk of a significant loss of desirable non-target species to herbicide control. In contrast native-only sites with an average of 33% coverage of 10% Canada thistle coverage there is a large risk to non-target species from herbicide control. The risk to non-target species is not very well known but if there is a loss of non-target species then this is a lost benefit and would be an additional cost associated with the herbicide control. There is no direct way to value this loss but if the loss of the non-target species was one present in the seed mix then then the cost of the seed could be used as a way to value the loss. This loss in non-target species can be weighed against the $10,104/100 ha cost advantage of the native-only planting and whether the tradeoff between spike method and low amount of herbicide use is worth the cost savings of not using the spike mix.

Another consideration that may make the spike method more desirable to use is the prospect of not having to use herbicide control on large areas after restoration. The need to have a large standing operation to treat many hectares can be a logistic and financial hardship for managers with reduced funding and resources. The ability to do a one-time operation to significantly reduce Canada thistle establishment so that only a minimal amount of maintenance is needed may in the end be more effective for certain operations. There is also the prospect that conservation practitioners would rather use native species to reduce Canada thistle establishment than herbicides. This is justified in that the native species are something that the conservation practitioners want to promote and conserve and the use of herbicides does not meet a conservation goal. The spike method fits better into their goals and mission and substituting the spike method for herbicide use is a win-win for conservation.

Table 10. The total cost and cost of herbicide control over the course of a ten year control plan with 66% of the area with 10% Canada thistle coverage with a 60% to 70% herbicide success rate.

Native-only Mixture	Hectares That Need Spraying	Cost of Spraying per Hectare	Hectares X Cost
Year 1	66.00	85.00	5610.00
Year 2	26.40	93.71	2474.01
Year 3	10.56	98.40	1039.08
Year 4	4.22	103.32	436.42
Year 5			
Year 6			
Year 7	66.00	119.60	7893.83
Year 8	19.80	125.58	2486.56
Year 9	5.94	131.86	783.27
Year 10	1.78	138.46	246.73
Cost of Native-only Mix.		Total Cost of Spraying.	20969.89
49400.00		Total Cost of Restoration. (Seed mix cost + ten year spraying cost)	70369.89
Total Cost of The Spike.	69988.63		

Further Research

This study represents the effects of using an increased seeding rate of a forb mixture on one invasive species (Canada thistle) in the tallgrass and mixed grass prairie ecosystems. Locations in the prairie ecosystem (short grass prairies and the wet meadow zone of wetlands) where Canada thistle poses a threat should be researched. This additional research would add to the results of this study and establish a more complete understanding of how functional traits of species can be used to control undesirable species. Further research needs to be done on the use of spike forbs as a control method of other noxious and invasive forb weed species like wormwood and leafy spurge. More research should be conducted on additional species and what functional traits each species display as outlined by the research conducted Levang-Brilz and Biondini (2002). This would allow for more testing of species as a suitable spike species for a targetable weed species. As more and more species get categorized in to functional trait groups, this would allow the practitioners of this control method more of a choice of which species they could use and also possibly reducing costs while being effective by selecting the more available species. This study's research focuses on the forb community and could be applied to invasive grass species in future research.

The multiplication factor that was used for the spike seeding rate was a random arbitrary number that was large enough to provide adequate seed to produce an effect. Since ten times the seeding rate was used, there is a possibility that some of the spike seed is wasted, meaning that the seed does not get a chance to germinate before the seed is lost to environmental factors like decay or predators that use the seeds as forage. The margin of safety was set high to account for these losses but future research needs to be conducted as to ascertain the minimal amount of spike seed needed to produce the same effect but still account for issues that arise with the seed itself or seed establishment.

Additional work should be conducted on the growth rates of Canada thistle, the growth rates of the species used in the native seed mixture, and the species used in the spiked forbs. Conducting this additional research would allow a practitioner to select species that share functional traits as outlined by Levang-Brilz and Biondini (2002), which display a faster growth rate than Canada thistle. By selecting native species that have faster growth rates, the asymmetrical competition will be increased between the high diversity spike seed mixture and Canada thistle.

Further research into the possible allelopathic characteristics of the species used in the native and spike mix should be conducted since there is a lack of information available. If any properties were found, possible ramifications of using species that have allelopathic properties in the species mixture should be investigated.

MANAGEMENT IMPLICATIONS

High diversity native seed mixtures (minimum of 9 grass species and a minimum of 10 forb species) that are broadcast seeded have an 80% chance being a successful reconstruction. A successful reconstruction has characteristics that include moderate to high species diversity retention, low invasive/undesirable species, low litter amount, and high invasion resistance (Larson 2011). Using a high diversity seed mix with spike forbs of varying functional traits as outlined by Biondini (2007) would further ensure that the restoration would have a high resistance to invasion from noxious weeds like Canada thistle.

To achieve a reduction in Canada thistle establishment in a planting, a manager using the spiked forbs method should plant a high diversity native seed mixture with an added native forb mixture (spike) of at least four species that share functional traits with Canada thistle. The forb mixture should be seeded at a rate 3 to 10 times the high diversity seeding rate. A list of species that share functional traits with Canada thistle can be found in the research conducted by Levang-Brilz and Biondini (2002) (Table 1). Adding other forb species from other functional trait groups to the spike would increase the resistance from other possible invasive species invasions.

The reduction of Canada thistle in conservation lands with a spiked seed mix would result in a reduced need to actively control Canada thistle. The presence Canada thistle leads to more user input (user being the manager) and their need to apply control measures to the conservation lands they manage. The reduced need to control Canada thistle could, over time and under certain conditions, save the manager the monetary value that is associated with Canada thistle control.

CONCLUSION

This study found that seeding a high density of native perennial forbs species that share functional traits with Canada thistle reduced the establishment and caused a 3-6 fold reduction in cover of this noxious invasive species in the first years of a planting. The spike method produces a competitive environment where Canada thistle is less able to establish from the seed bank and so there is only a small area of the planting, on average 5%, where Canada thistle requires herbicide control. The plantings without the spiked seeds had 6 times more area covered by Canada thistle that required herbicide control. A cost comparison between the spike method of reducing Canada thistle and herbicide control in a native species planting without the spike found that if a moderate to high successful reduction rate with herbicide control over a ten year period is achievable then the cost of the spike method was higher due to the high seed cost compared to the cost of herbicide control. The spike method costs are equal or lower compared to herbicide control if herbicide control is: 1) 25% or less effective, 2) logistically problematic, 3) operationally more costly, 4) needed on two-thirds of the area, and 5) producing a high risk of affecting desired non-target species. The spike method also reduces the need for herbicide control to spot spraying which can be a goal for conservation land managers who want to reduce their overall reliance on chemical uses for management.

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APPENDIX. LISTS OF PLANTED SPECIES AT LARGE SCALE SITES

Table A1. Species planted at Clear Lake WPA.

Common Name	Scientific Name	Common Name	Scientific Name
Common Yarrow	*Achillea millefolium*	Maximillian Sunflower	*Helianthus maximilliani*
Leadplant	*Amorpha canescens*	Smooth Oxeye	*Heliopsis helianthoides*
Big Bluestem	*Andropogon gerardii*	Tall Blazing Star	*Liatris aspera*
White Sage	*Artemisia Iudoviciana*	Wild Bergamot	*Monarda fistulosa*
Butterfly Milkweed	*Asclepias tuberosa*	Switchgrass	*Panicum virgatum*
White Heath Aster	*Symphyotrichum ericoides*	Western Wheatgrass	*Pascopyrum smithii*
Smooth Blue Aster	*Symphyotrichum leave*	Large Beardtongue	*Penstemon grandiflorus*
New England Aster	*Symphyotrichum novae-angliae*	Prairie Coneflower	*Ratibida columnifera*
Canada Milkvetch	*Astragalus canadensis*	Pinnate Prairie Coneflower	*Ratibida pinnata*
White Wild Indigo	*Baptisia alba*	Prairie Rose	*Rosa arkansana*
Sideoats Grama	*Bouteloua curtipendula*	Blackeyed Susan	*Rudbeckia hirta*
Partridge Pea	*Chamaecrista fasciculata*	Little Bluestem	*Schizachyrium scoparium*
Prairie Coreopsis	*Corepsis palmata*	Stiff Goldenrod	*Solidago rigida*
Purple Prairie Clover	*Dalea purpurea*	Indiangrass	*Sorghastrum nutans*
Illinois Bundleflower	*Desmanthus illinoensis*	Rough Dropseed	*Sporobolus clandestinus*
Showy Ticktrefoil	*Desmodium canadense*	Green Needlegrass	*Nassella viridula*
Pale Purple Coneflower	*Echinacea pallida*	Hoary Verbena	*Verbena stricta*
Canada Wildrye	*Elymus canadensis*	Golden Alexanders	*Zizia aurea*
Slender Wheatgrass	*Elymus trachycaulus*		

Table A2. Species planted at Halverson WPA.

Common Name	Scientific Name	Common Name	Scientific Name
Common Yarrow	*Achillea millefolium*	Maximillian Sunflower	*Helianthus maximilliani*
Leadplant	*Amorpha canescens*	Smooth Oxeye	*Heliopsis helianthoides*
Big Bluestem	*Andropogon gerardii*	Tall Blazing Star	*Liatris aspera*
White Sage	*Artemesia Iudoviciana*	Wild Bergamot	*Monarda fistulosa*
Butterfly Milkweed	*Asclepias tuberosa*	Switchgrass	*Panicum virgatum*
White Heath Aster	*Symphyotrichum ericoides*	Western Wheatgrass	*Pascopyrum smithii*
New England Aster	*Symphyotrichum novae-angliae*	Large Beardtongue	*Penstemon grandiflorus*
Canada Milkvetch	*Astragalus canadensis*	Prairie Coneflower	*Ratibida columnifera*
White Wild Indigo	*Baptisia alba*	Prairie Rose	*Rosa arkansana*
Sideoats Grama	*Bouteloua curtipendula*	Blackeyed Susan	*Rudbeckia hirta*
Partridge Pea	*Chamaecrista fasciculata*	Little Bluestem	*Schizachyrium scoparium*
Prairie Coreopsis	*Coropsis palmata*	Stiff Goldenrod	*Solidago rigida*
White Prairie Clover	*Dalea candida*	Indiangrass	*Sorghastrum nutans*
Illinois Bundleflower	*Desmanthus illinoensis*	Green Needlegrass	*Stipa viridula*
Showy Ticktrefoil	*Desmodium canadense*	Purple Meadow-rue	*Thalictrum dasycarpum*
Slender Wheatgrass	*Elymus trachycaulus*	Hoary Verbena	*Verbena stricta*
Bearded slender wheat	*E. trachycaulus* ssp. *subsecundus*	Golden Alexanders	*Zizia aurea*
Blanketflower	*Gaillardia aristata*		

Table A3. Species planted at Tewaukon.

Common Name	Scientific Name	Common Name	Scientific Name
Big Bluestem	*Andropogon gerardii*	Pale Purple Coneflower	*Echinacea pallida*
Little Bluestem	*Schizachyrium scoparium*	Blanketflower	*Gaillardia aristata*
Indiangrass	*Sorghastrum nutans*	Wild Bergamot	*Monarda fistulosa*
Switchgrass	*Panicum virgatum*	New England Aster	*Symphyotrichum novae-angliae*
Green Needlegrass	*Nassella viridula*	Prairie Onion	*Allium stellatum*
Sideoats Grama	*Bouteloua curtipendula*	Golden Alexanders	*Zizia aurea*
Prairie Junegrass	*Koeleria macrantha*	Stiff Goldenrod	*Solidago rigida*
Canada Wildrye	*Elymus canadensis*	Prairie Coreopsis	*Coropsis palmata*
Prairie Dropseed	*Sporobolus heterolepis*	Purple Prairie Clover	*Dalea purpureum*
Canada Milkvetch	*Astragalus canadensis*	Prairie Coneflower	*Ratibida columnifera*
Leadplant	*Amorpha canescens*	Black-Eyed Susan	*Rudbeckia hirta*
Maximillian Sunflower	*Helianthus maximilliani*		

Table A4. Species planted at Fuller Lake WPA.

Common Name	Scientific Name	Common Name	Scientific Name
Slender Wheatgrass	*Elymus trachycaulum*	Prairie Coneflower	*Ratibida columnifera*
Western Wheatgrass	*Pascopyrum smithii*	Common Yarrow	*Achillea millefolium*
Canada Wildrye	*Elymus canadensis*	Golden Alexanders	*Zizia aurea*
Green Needlegrass	*Nassella viridula*	Stiff Goldenrod	*Solidago rigida*
Little Bluestem	*Schizachyrium scoparium*	Blanketflower	*Gaillardia aristata*
Sideoats Grama	*Bouteloua curtipendula*	Canada Milkvetch	*Astragalus canadensis*
Prairie Dropseed	*Sporobolus heterolepis*	White Prairie Clover	*Dalea candida*
Northern Reedgrass	*Calamagrostis stricta*	Sliverleaf Indian Breadroot	*Pediomelum argophyllum*
Big Bluestem	*Andropogon gerardii*	Leadplant	*Amorpha canescens*
Indiangrass	*Sorghastrum nutans*	Prairie Coreopsis	*Corepsis palmata*
Switchgrass	*Panicum virgatum*	Hoary Verbena	*Verbena stricta*
Maximillian Sunflower	*Helianthus maximilliani*	Giant Hyssop	*Agastache Clayton*
Lewis Flax	*Linum lewisii*	New England Aster	*Symphyotrichum novae-angliae*
Pale Purple Coneflower	*Echinacea pallida*	Stiff Sunflower	*Helianthus pauciflorus*
Wild Bergamot	*Monarda fistulosa*	Black-Eyed Susan	*Rudbeckia hirta*
Purple Prairie Clover	*Dalea purpurea*		