

Presence and abundance of non-native plant species associated with recent energy development in the Williston Basin

Todd M. Preston

Received: 29 September 2014 / Accepted: 4 March 2015 / Published online: 24 March 2015
© Springer International Publishing Switzerland (outside the USA) 2015

Abstract The Williston Basin, located in the Northern Great Plains, is experiencing rapid energy development with North Dakota and Montana being the epicenter of current and projected development in the USA. The average single-bore well pad is 5 acres with an estimated 58,485 wells in North Dakota alone. This landscape-level disturbance may provide a pathway for the establishment of non-native plants. To evaluate potential influences of energy development on the presence and abundance of non-native species, vegetation surveys were conducted at 30 oil well sites (14 ten-year-old and 16 five-year-old wells) and 14 control sites in native prairie environments across the Williston Basin. Non-native species richness and cover were recorded in four quadrats, located at equal distances, along four transects for a total of 16 quadrats per site. Non-natives were recorded at all 44 sites and ranged from 5 to 13 species, 7 to 15 species, and 2 to 8 species at the 10-year, 5-year, and control sites, respectively. Respective non-native cover ranged from 1 to 69, 16 to 76, and 2 to 82 %. Total, forb, and graminoid non-native species richness and non-native forb cover were significantly greater at oil well sites compared to control sites. At oil well sites, non-native species richness and forb cover were significantly greater adjacent to the well pads and decreased with distance to values similar to control sites. Finally, non-native species whose presence and/or abundance

were significantly greater at oil well sites relative to control sites were identified to aid management efforts.

Keywords Bakken Formation · Energy development · Native prairie · Non-native species · Williston Basin

Introduction

The Williston Basin, which spans portions of Montana, North Dakota, and South Dakota in the USA as well as parts of Manitoba and Saskatchewan in Canada, has been a leading domestic source of oil and gas production for over a half century (Fig. 1). New advances in horizontal drilling and hydraulic fracturing technologies have resulted in a dramatic increase in drilling and oil production from the Bakken Total Petroleum System (TPS). The Bakken TPS includes strata from the Devonian Three Forks Formation, the Devonian and Mississippian Bakken Formation, and the lower portion of the Mississippian Lodgepole Formation (Gaswirth et al. 2013). While the presence of oil in the Bakken TPS had been known since the early 1950s, it was not until the first successful horizontal test well targeting the middle Bakken was drilled in 2000 in the Elm Coulee field of Montana that the full potential of this resource was understood (Sonnenberg and Pramudito 2010). The U.S. Geological Survey (USGS) estimates that the Bakken TPS contains 7.38 billion barrels of recoverable oil and 6.7 trillion cubic feet of natural gas (Gaswirth et al. 2013). The majority of current oil development within the US portion of the Williston Basin is occurring

T. M. Preston (✉)
Parallel Inc., USGS Northern Rocky Mountain Science
Center, 2327 University Way, suite 2, Bozeman, MT 59718,
USA
e-mail: tmpreston@usgs.gov

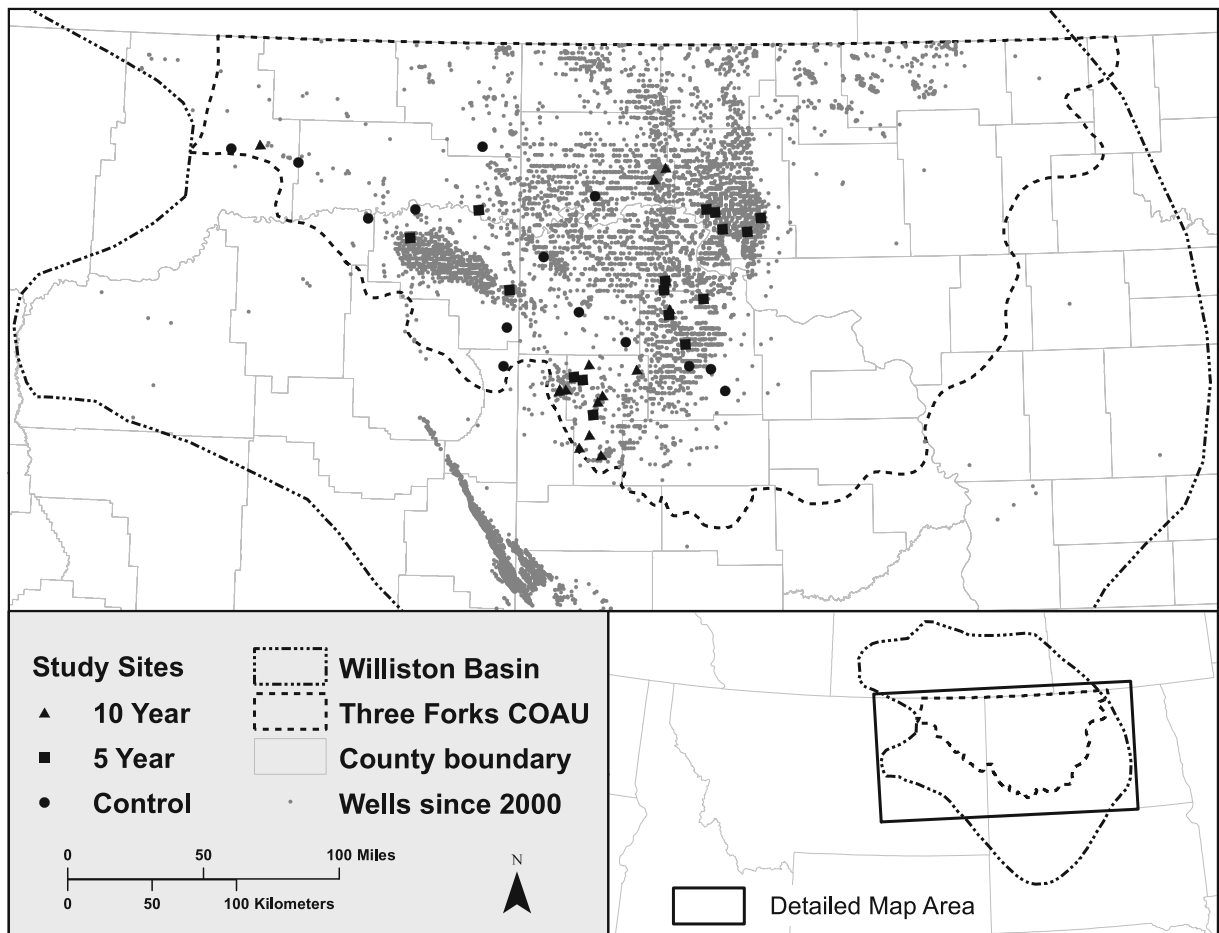


Fig. 1 Map showing the Williston Basin, Three Forks Continuous Oil Assessment Unit (COAU), study sites, and petroleum-related wells drilled since 2000 in the Williston Basin

within the lateral extent of the Three Forks Continuous Oil Assessment Unit (COAU) defined by Gaswirth et al. (2013).

Previous studies have documented increased presence and abundance of non-native plant species in lands disturbed by energy development (Bergquist et al. 2007; Manier et al. 2011; Nasen et al. 2011; Nielsen et al. 2011; Manier et al. 2014). Increased presence and abundance of non-natives is associated with road and well pad construction as well as increased vehicular traffic which can provide a vector for the transport and dispersal of these species. For example, significantly greater non-native species richness and greater proportions of non-native species were documented in Wyoming's Powder River Basin at sites disturbed from energy development relative to undisturbed control sites (Bergquist et al. 2007). Additionally, the large amount of vehicle traffic to the well pad sites, estimated at up to

1000 truck trips during installation of the typical hydraulically fractured well (Gibson 2013), likely provides a transport mechanism for non-native species as vehicles can transport seeds and plant parts on tires/mud and air turbulence generated by passing vehicles can induce seed dispersal (Lonsdale and Lane 1994; Gelbard and Belnap 2003; Davies and Sheley 2007; von der Lippe and Kowarik 2007). Therefore, the construction of oil well pads and the vehicle traffic required to develop the Bakken TPS will likely provide landscape-level disturbances and transport mechanisms conducive to the introduction and establishment of non-native plant species.

The presence of noxious weeds and non-native plant species has significant biological implications. Non-native species compete with native species for limited resources (Ringwall et al. 2000), can reduce native species richness and abundance (Wilcove et al. 1998),

degrade native habitat (Ellstrand and Schierenbeck 2000), affect native wildlife through trophic (i.e., food) and non-trophic (i.e., habitat) pathways (Litt and Pearson 2013), and reduce forage potential and agricultural yields (Pimentel et al. 2005). For example, in the Northern Great Plains, the presence of *Euphorbia esula* (leafy spurge) has been shown to reduce habitat use by bison, deer, and elk in North Dakota (Trammel and Butler 1995), and *Centaurea maculosa* (spotted knapweed) was reported to influence elk and deer population distribution in Montana (Thompson 1996).

The Montana and North Dakota Departments of Agriculture list 32 and 11 species on their respective state noxious weed lists, with another 18 listed on North Dakota county noxious weed lists. According to the latest reports, it is estimated that noxious weeds covered roughly 7.6 million acres in Montana in 2008 (Duncan 2008) and 2.05 million acres in North Dakota in 2013 (North Dakota Department of Agriculture 2014). The Montana and North Dakota state and county noxious weed lists are dominated by highly aggressive forbs; however, other non-native plant species pose similar and unique threats to vegetation and animal communities in the Northern Great Plains (Larson et al. 2001; Sinkins and Oftinowski 2012). For example, non-native grass species are often omitted from state noxious weed lists as they provide forage for livestock (Rice 2012); however, non-native grasses, which account for the majority of non-native cover in the Great Plains (Cully et al. 2003), can spread into native grasslands and adversely affect the diversity of native plant communities (D'Antonio and Vitousek 1992), invertebrates (Litt and Pearson 2013), small mammals (Kurz et al. 1995), and ecosystem properties such as fire regimes and nutrient cycling (D'Antonio and Vitousek 1992).

Given the rapid pace of energy development and the numerous potential ecological threats posed by non-native species in Montana and North Dakota, this project explored the relationship between energy development and non-native forb and graminoid species presence and abundance in the Williston Basin. Specifically, this work focused on oil wells drilled within native prairie (i.e., non-tilled) environments within the geographic extent of the Three Forks COAU of the Bakken TPS (Gaswirth et al. 2013). Field surveys documented the presence and abundance of non-native species adjacent to well pads constructed 10 and 5 years ago

(referred to as 10-year and 5-year sites hereafter). Control sites, located in similar, undeveloped native prairie environments, were also sampled.

Methods

Site selection

Much of the site selection process was done within a geographic information systems (GIS) framework, and unless otherwise noted, all spatial analyses were performed with ArcGIS10. Shapefiles identifying the locations of all oil and gas wells in Montana and North Dakota were obtained on 11 April 2013 from the Montana Board of Oil and Gas and the North Dakota Industrial Commission, Division of Oil and Gas, respectively. To identify well pads constructed 10 and 5 years ago, only wells with spud dates (defined as the date at which drilling first began) of 2003 or 2008 and classified as oil or oil and gas were retained. Next, the remaining oil wells were clipped to the geographic extent of the Three Forks COAU (Gaswirth et al. 2013) and a 150-m buffer was created around each well. Land cover classifications in the 150-m buffer were determined from the 30-m resolution National Land Cover Dataset (NLCD) (Fry et al. 2011) using the “isectpolyrst” tool, which calculates the percentage of all raster pixel values within a set of polygons, in the Geospatial Modeling Environment from SpatialEcology.com. To ensure well pads were in prairie environments, a minimum of 70 % of the pixels within the 150-m buffer had to be classified as either grassland/herbaceous or shrub/scrub from the NLCD and have no pixels classified as cultivated crops or pasture/hay. A total of 191 wells, 27 ten-year-old and 164 five-year-old wells, met the study criteria. Potential well sites were randomly ordered within each age category, and landowner permissions were obtained for 22 of the 10-year-old wells and 28 of the 5-year-old wells.

Potential control sites were identified by creating a 32.2-km (20-mile) buffer around the 191 possible oil wells and generating 500 random points using a random point generator in a GIS. As with oil well sites, land cover classifications were determined within 150-m buffers created around the random points. In order for the control sites to be as similar as possible to the oil well sites, the land cover classification requirements for control sites were the same as for oil well sites; however, control sites had to be at least 1.6 km from the nearest oil

well, regardless of the spud date. Additionally, control sites had to be located within 0.8 km of a road visible on aerial imagery to facilitate access by foot. A total of 38 potential control sites meet all the study requirements. Landowner permissions were obtained for 31 control sites.

Vegetation surveys

Field surveys of non-native plant species were conducted by a two-person field crew from the Montana Natural Heritage Program during three separate field trips in summer 2013 (25 July–30 July, 8 August–14 August, and 22 August–26 August). To ensure maximum spatial coverage across the Williston Basin, oil well and control sites were grouped into three broad geographic strata (southern North Dakota, northern North Dakota, and Montana). The three strata contained a similar number of sites (approximately 25 to 30), and sites within each stratum were randomly selected for field surveys. Each of the three field trips focused on one geographic stratum. Although it was expected that less than 20 sites could be surveyed in the allotted time during each field trip, extra sites were included in each stratum in case sites had been overly grazed or hayed. Field trips were timed to minimize differences in plant phenology; therefore, it is assumed that detection of non-native species was not confounded by survey date or geographic stratum.

A total of 51 sites were sampled (17 ten-year, 18 five-year, and 16 control sites); however, the site selection process was insufficient to ensure that all study sites were in previously unbroken prairie environments. Follow-up interviews with landowners and historical aerial photo interpretation revealed that 44 of the 51 study sites were located in native prairie (prior to well construction) and seven sites were located in areas that had been broken (tilled) in the past and reseeded either as part of the Conservation Reserve Program or by the landowner. The primary goal of this study was to evaluate the presence and abundance of non-native species associated with energy development in native prairie environments; therefore, the seven previously tilled sites were removed, leaving a total of 44 sites (14 ten-year sites, 16 five-year sites, and 14 control sites).

Non-native species were recorded within four quadrats (5 by 10 m) located along four transects at each study site for a total of 16 quadrats per site. At the oil well sites, transects were located along the cardinal

directions and began at the edge of the well pad. At the control sites, transects were also orientated along the cardinal directions and began 15 m from the random point identified during the site selection process to simulate a well pad. A quadrat was placed at 0–10, 40–50, 80–90, and 120–130 m along each transect. Only three of the four transects were surveyed at one of the 5-year sites due to pipeline construction.

All non-native vascular plant species in each quadrat were determined from visual field identification and recorded using nomenclature from the USDA PLAN TS database (U.S. Department of Agriculture 2014). The abundance, determined by the percent of canopy cover within the quadrat, was also recorded for each non-native species. Visually estimated cover was recorded as an integer value corresponding to a cover class (Table 1). Due to time and financial constraints, no data were collected on the presence and abundance of native plant species.

Statistical analysis

Total, forb, and graminoid non-native species richness (number of non-native species) and cover (percent) were determined for each study site. For this and all other abundance analyses, cover was assigned as the midpoint of the recorded cover class similar to Daubenmire (1959), with cover class values of 1 (<1 %) assigned a value of 0.5 %. One-way analysis of variance (ANOVA) tests were used to evaluate differences in total, forb, and graminoid non-native species richness and cover between the different site classes (10-year, 5-year, and control sites).

To assess whether there was a preferential direction of invasion and the distance of invasion, total non-native species richness and non-native forb and graminoid cover were determined for each transect (combined across the four quadrats) and each distance (combined

Table 1 Cover classification system used for visually estimated non-native vegetation cover

Cover class	Cover (%)	Cover class	Cover (%)
0	Unobserved	5	10–<25
1	<1	6	25–<50
2	1–<2	7	50–<75
3	2–<5	8	75–<95
4	5–<10	9	>95

across each set of concentric quadrats), respectively. ANOVAs with transect direction and distance that included site as a fixed effect were used to assess differences in total non-native species richness and forb and graminoid cover for each site class. The response variables were total non-native species richness and forb and graminoid cover in each transect and set of concentric quadrats. These fixed effects models account for the fact that all cardinal directions or sets of concentric quadrats were assessed within each site. Additionally, ANOVA was used to evaluate whether non-native species richness and forb and graminoid cover varied by distance between the different site classes.

Additionally, non-native species richness and non-native forb and graminoid cover were evaluated between quadrats disturbed from energy development and those without disturbance at the oil well sites. Oil well pads in the Williston Basin often have a “halo” of reclaimed land around the well pad that represents the original pad dimensions and/or areas where material was either taken from or deposited during the construction of the well pad. After drilling is completed, the area of the pad is reduced to the minimal size required for production and previously disturbed areas around the pad are revegetated; however, the reclaimed area is often visible in aerial photos. Quadrat locations were recorded with a handheld GPS in the field, and quadrats within the reclaimed area, determined from orthoimagery interpretation, were classified as disturbed, as were the first quadrat in each transect. Disturbance of the first quadrat in each transect were clearly visible in aerial photos at 27 of 30 well pad sites and deemed likely in the remaining three. This resulted in a total of 169 quadrats out of the 476 quadrats examined at the oil well sites being classified as disturbed: 79 of the 224 quadrats (35.3 %) at the 10-year sites and 90 out of 252 quadrats (35.7 %) at the 10-year sites. Paired *t* tests were used to determine differences in the average non-native species richness and forb and graminoid cover per area surveyed (total number of non-native species and non-native forb and graminoid cover divided by the number of quadrats sampled) for disturbed and undisturbed quadrats at the 10-year and 5-year sites. This approach was used to remove the influence of differences in the amount of

surveyed area between the disturbed and undisturbed quadrats at each oil well site.

Finally, a pair of analyses was performed to determine which non-native species were more common and more abundant at the oil well sites compared to control sites. To determine if certain non-native species occurred at a greater proportion of oil well sites relative to control sites, proportion tests comparing both the 10-year and 5-year sites to control sites were conducted for each species identified from the vegetation surveys. A proportion test examines the number of success (the number of sites in each site class with a given species present in at least one quadrat) versus the number of trials (the total number of sites in each class) to determine if the proportions of the two classes are statistically different. To determine if certain non-native species were more abundant between site classes, ANOVA analyses were performed on the cover data, combined for the first quadrat in each transect, of each species observed in the vegetation surveys. For this and all previously described ANOVA analyses, a Tukey multiple comparison test was used to determine significant differences in pairwise comparisons.

Species accumulation curves are a common technique to determine species richness between sites at the landscape level (Thompson et al. 2003) and to evaluate if the sampling effort was sufficient to provide reliable estimates of species richness (Ugland et al. 2003). Therefore, species accumulation curves were generated to evaluate the observed non-native species richness at the landscape level and sampling effort of this study. Data from the oil well sites was separated into quadrats disturbed from energy development and those without disturbance, producing species accumulation curves for the 10-year disturbed, 10-year undisturbed, 5-year disturbed, 5-year undisturbed, and control quadrats.

All statistical analyses were performed in R: A Language and Environment for Statistical Computing version 2.14.0 from the R Foundation for Statistical Computing, as was the generation of the species accumulation curves. Statistical analyses used a significance level of 0.05 for statistically significant results and 0.1 for suggestive results. Mean and standard errors were calculated for each spatial scale of analysis described above. Normality of all variables was checked prior to analysis, and skewed data was $\log(x+1)$ transformed due to the presence of zeros in the dataset.

Results

Vegetation surveys

A total of 25 non-native plant species were identified during the vegetation surveys and included a mixture of forbs and graminoids. The list of non-native plant species identified and the number of sites in each site class in which they occurred are listed in Table 2. Although

the species from the *Brassica* genus was unknown, USDA PLANTS lists all species in this genus that occur in the study area as invasive.

Species richness and abundance

At the site level, non-native species richness and cover varied between site classes (Table 3). Non-native species richness ranged from 5 to 13 species, 7 to 15

Table 2 List of the 25 non-native species observed in the vegetation surveys as well as the number of sites in each site class in which each species was observed

Scientific name	Number of recorded occurrences			
	10-year	5-year	Control	Total
<i>n</i>	14	16	14	44
<i>Agropyron cristatum</i> (crested wheatgrass) g	12	11	12	35
<i>Arctium minus</i> (lesser burdock) f	0	1	0	1
<i>Artemisia absinthium</i> (absinthe wormwood) ^b f	0	3	1	4
<i>Brassica</i> (unknown mustard species) f	1	1	0	2
<i>Bromus arvensis</i> (field or Japanese brome) g	12	9	5	26
<i>Bromus inermis</i> (smooth brome) g	9	13	5	27
<i>Bromus tectorum</i> (cheatgrass) ^{b,c} g	1	0	0	1
<i>Carduus nutans</i> (nodding plumeless thistle) ^b f	1	0	0	1
<i>Cirsium arvense</i> (Canada thistle) ^{a,b} f	5	11	0	16
<i>Cirsium vulgare</i> (bull thistle) ^b f	3	5	1	9
<i>Convolvulus arvensis</i> (field bindweed) ^{a,b} f	4	8	2	14
<i>Descurainia sophia</i> (herb sophia) f	4	0	0	4
<i>Elymus repens</i> (quackgrass) g	0	4	1	5
<i>Euphorbia esula</i> (leafy spurge) ^{a,b} f	6	2	1	9
<i>Kochia scoparia</i> (kochia) ^b f	8	12	0	20
<i>Lactuca serriola</i> (prickly lettuce) f	7	10	5	22
<i>Lythrum salicaria</i> (purple loosestrife) ^{a,b} f	1	0	0	1
<i>Medicago sativa</i> (alfalfa) f	2	7	4	13
<i>Melilotus albus</i> (honey clover) f	0	3	0	3
<i>Melilotus officinalis</i> (yellow sweet clover) f	4	9	0	13
<i>Poa pratensis</i> (Kentucky bluegrass) g	14	16	12	42
<i>Salsola kali</i> (Russian thistle) f	5	8	0	13
<i>Sonchus arvensis</i> (field sowthistle) ^b f	3	5	0	8
<i>Thinopyrum intermedium</i> (intermediate wheatgrass) g	2	6	0	8
<i>Tragopogon dubius</i> (yellow salsify) f	13	15	13	41

Growth habit identified by the single letter at the end of the common name: *f* forb, *g* graminoid

^a Montana state noxious weed list

^b North Dakota state or county noxious weed list

^c Montana regulated species

Table 3 The mean total, forb, and graminoid non-native species richness and mean total, forb, and graminoid non-native cover (1 SE in parenthesis) for each site class

Study sites	10-year	5-year	Control
Non-native species richness (total)	8.4 ^a (0.7)	9.9 ^a (0.6)	4.4 ^b (0.5)
Non-native species richness (forbs)	4.8 ^a (0.6)	6.3 ^a (0.5)	1.9 ^b (0.3)
Non-native species richness (graminoids)	3.6 ^a (0.2)	3.7 ^a (0.3)	2.5 ^b (0.3)
Non-native cover (total)	21.8 ^a (4.8)	35.5 ^a (4.4)	20.9 ^a (5.9)
Non-native cover (forbs)	3.0 ^a (0.6)	7.1 ^a (1.4)	1.5 ^b (0.9)
Non-native cover (graminoids)	18.8 ^a (4.4)	28.4 ^a (4.4)	19.4 ^a (5.2)

Superscript letters a and b denote significant differences at the 0.05 level in mean values between site classes (Tukey multiple comparison test)

species, and 2 to 8 species at the 10-year, 5-year, and control sites, respectively, while non-native cover ranged from 0.8 to 89.5, 15.2 to 71.2, and 1.7 to 79.4 %. Total non-native species richness was significantly greater at the 10-year and 5-year sites compared to control sites. Non-native forb species richness was significantly greater at the 10-year and 5-year sites compared to control sites and suggestive at the 5-year sites compared to the 10-year sites. Non-native graminoid species richness was significantly greater at the 10-year and 5-year sites compared to control sites. No differences existed in total or graminoid non-native cover between the 10-year, 5-year, and control sites; however, non-native forb cover was significantly greater at the 10-year and 5-year sites relative to control sites and suggestive at the 5-year sites compared to the 10-year sites. Since both forbs and graminoids were significantly contributing to non-native species richness, additional analyses were done on total non-native species richness for simplicity; however, since the significant differences in non-native cover were dependent on growth habit, additional analyses continued to examine potential differences in the cover of non-native forbs and graminoids.

Combining data by transect direction yielded no significant differences in total non-native species richness between the different transects at the 10-year (range 4.1 to 5.1±0.5 to 0.6 (mean±1 SE)), 5-year (5.0 to 6.4±0.3 to 0.7), or control sites (2.6 to 2.9±0.3 to 0.4). Similarly, there were no significant differences in total non-native forb cover between the four transects at the 10-year (range 1.8 to 4.3 %±0.8 to 1.4), 5-year (5.1 to 9.4 %±1.4 to 2.3), or control sites (1.1 to 1.9 %±0.6 to 1.3).

There were also no significant differences in non-native graminoid cover between the different transects at the 10-year (15.6 to 22.5 %±4.9 to 5.3), 5-year (21.7 to 34.9 %±4.9 to 6.4), or control sites (14.9 to 22.0 %±5.0 to 6.9); however, at the 5-year sites, greater non-native graminoid cover in the west transect was suggestive compared to the south transect.

Combining data for each set of concentric quadrats provided evidence that the presence and abundance of non-native species varied by distance (Fig. 2). Although mean non-native species richness was greatest near the well pad and decreased with distance from the well pad at the 10-year sites, these differences were non-significant (plot 1, Fig. 2). At the 5-year sites, total non-native species richness in quadrat 1 (0 m) was significantly greater than quadrats 2 (40 m), 3 (80 m), and 4 (120 m). Additionally, total non-native species richness in quadrat 2 was significantly greater than quadrat 4 (plot 2, Fig. 2). No differences in total non-native species richness existed between the four sets of concentric quadrats at the control sites (plot 3, Fig. 2). Non-native forb cover in quadrat 1 was significantly greater than quadrat 2 and quadrat 4 at the 10-year sites (plot 4, Fig. 2). At the 5 year sites, non-native forb cover was significantly greater in quadrat 1 compared to all other quadrats (plot 5, Fig. 2). No differences existed in non-native forb cover between the four sets of concentric quadrats at the control sites (plot 6, Fig. 2). Finally, no differences existed in non-native graminoid cover between the four sets of concentric quadrats at the 10-year and control sites (plots 7 and 9, respectively, Fig. 2); however, non-native graminoid cover was significantly greater in quadrats 1 and 2 compared to quadrats 3 and 4 at the 5-year sites (plot 8, Fig. 2).

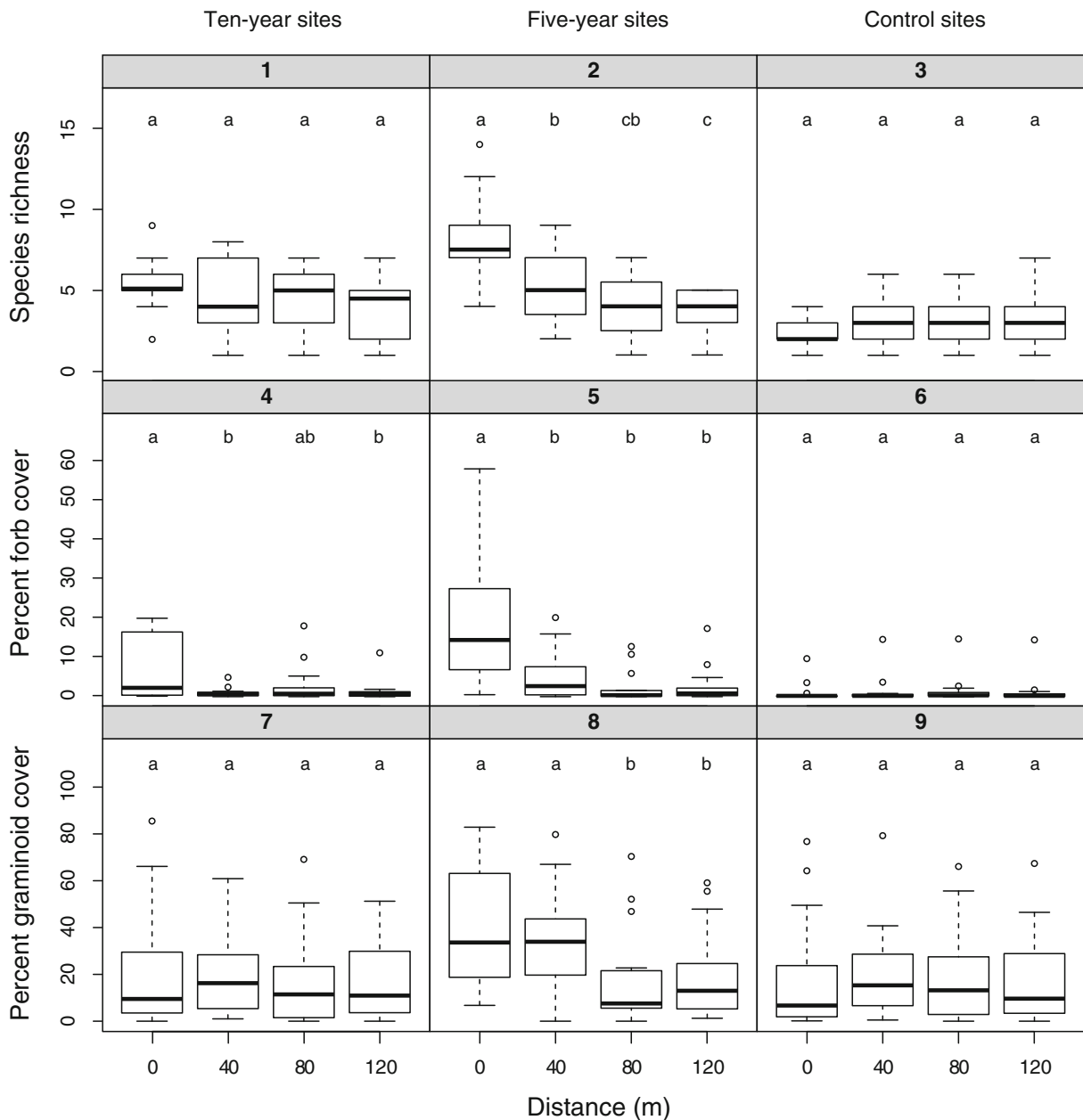


Fig. 2 Boxplots showing total non-native species richness (*first row*) and non-native forb (*second row*) and graminoid (*third row*) cover by distance for the three site classes. *Distance* refers to the starting position of concentric quadrats along the transects: quadrat

1, 0 m; quadrat 2, 40 m; quadrat 3, 80 m; and quadrat 4, 120 m. *a*, *b*, and *c* denote significant differences in mean values at the 0.05 level between distances (Tukey multiple comparison test)

Comparing the combined concentric quadrat data between site classes further illustrated the differences in non-native species richness and abundance between the oil well and control sites (Table 4). Total non-native species richness was significantly greater in quadrat 1 at both the 10-year and 5-year sites compared to control

sites and at the 5-year sites relative to the 10-year sites. Additionally, total non-native species richness was significantly greater in quadrat 2 at the 5-year sites compared to control sites. Non-native forb cover was significantly greater in quadrat 1 at both the 10-year and 5-year sites compared to control sites and at the 5-year

Table 4 Mean non- and forb and graminoid cover for each set of concentric quadrats at each of the three site classes. Values in this table are the mean values of boxplots in Fig. 2

	10-year	5-year	Control
Non-native species richness			
Quadrat 1 (0–10 m)	5.2 ^a (0.5)	8.1 ^b (0.6)	2.5 ^c (0.2)
Quadrat 2 (40–50 m)	4.6 ^{a,b} (0.6)	5.3 ^b (0.6)	3.0 ^a (0.4)
Quadrat 3 (80–90 m)	4.6 ^a (0.5)	4.0 ^a (0.5)	3.3 ^a (0.4)
Quadrat 4 (120–130 m)	3.9 ^a (0.5)	3.6 ^a (0.3)	3.1 ^a (0.5)
Non-native forb cover			
Quadrat 1 (0–10 m)	6.5 ^a (2.1)	18.4 ^b (4.0)	1.2 ^c (0.7)
Quadrat 2 (40–50 m)	1.0 ^a (0.4)	4.8 ^b (1.5)	1.6 ^a (1.1)
Quadrat 3 (80–90 m)	2.9 ^a (1.4)	2.3 ^a (1.0)	1.7 ^a (1.1)
Quadrat 4 (120–130 m)	1.4 ^a (0.8)	2.6 ^a (1.1)	1.5 ^a (1.0)
Non-native graminoid cover			
Quadrat 1 (0–10 m)	20.6 ^a (7.0)	40.1 ^a (6.3)	19.0 ^a (6.8)
Quadrat 2 (40–50 m)	21.3 ^a (5.1)	33.6 ^a (5.3)	20.4 ^a (5.6)
Quadrat 3 (80–90 m)	17.4 ^a (5.5)	18.3 ^a (5.2)	19.5 ^a (5.4)
Quadrat 4 (120–130 m)	16.0 ^a (4.1)	19.2 ^a (4.8)	18.9 ^a (5.5)

Superscript letters a, b, and c denote significant differences in mean values at the 0.05 level between site classes (Tukey multiple comparison test)

sites relative to the 10-year sites. Additionally, non-native forb cover was significantly greater in quadrat 2 at the 5-year sites compared to the 10-year sites and control sites. No significant differences existed in non-native graminoid cover in any set of concentric quadrats between the three site classes; however, greater non-native graminoid cover in quadrat 1 was suggestive at the 5-year sites compared to the 10-year sites and control sites.

Furthermore, average non-native species richness and non-native forb and graminoid cover varied in quadrats disturbed from energy development compared to those without disturbance at the oil well sites. At the 10-year and 5-year sites, average non-native species richness in the disturbed quadrats (1.1±0.1 and 1.6±0.1, respectively (mean±1 SE)) was significantly greater than the undisturbed quadrats (0.6±0.07 and 0.5±0.04, respectively). There was suggestive evidence for greater non-native forb cover between the disturbed quadrats (5.2±1.6 %) and undisturbed quadrats (1.9±0.6 %) at the 10-year sites, while non-native forb cover was significantly greater in the disturbed quadrats (14.7±3.1 %) compared to the undisturbed quadrats (2.6±0.8 %) at the 5-year sites. No significant difference

existed in average non-native graminoid cover between the disturbed quadrats (20.0±6.1 %) and undisturbed quadrats (17.3±4.8 %) at the 10-year sites; however, disturbed quadrats (40.2±5.6 %) had significantly greater average non-native graminoid cover than undisturbed quadrats (20.8±5.0 %) at the 5-year sites.

Several non-native plant species occurred at a significantly greater proportion of oil well sites relative to control sites (Fig. 3). Three species, *Cirsium arvense* (Canada thistle), *Kochia scoparia* (kochia), and *Salsola kali* (Russian thistle), occurred in a significantly greater proportion of both the 10-year and 5-year sites compared to control sites. Additionally, relative to control sites, *Bromus arvensis* (field brome) and *E. esula* occurred in a significantly greater proportion of 10-year sites, while *Bromus inermis* (smooth brome), *Convolvulus arvensis* (field bindweed), *Melilotus officinalis* (yellow sweet clover), *Sonchus arvensis* (field sowthistle), and *Thinopyrum intermedium* (intermediate wheatgrass) occurred in a significantly greater proportion of 5-year sites. Finally, there was suggestive evidence that *Descurainia sophia* (herb sophia) and *M. officinalis* occurred in a greater proportion of 10-year sites compared to control sites.

Furthermore, the abundance of several non-native species in the first set of concentric quadrats varied between the site classes (Table 5). Differences in non-native cover were greatest between the 5-year and control sites, with six species having significantly greater cover at the 5-year sites: *C. arvense*, *K. scoparia*, *Lactuca serriola* (prickly lettuce), *M. officinalis*, *S. arvensis*, and *T. intermedium*. Additionally, greater cover of *B. inermis*, *Elymus repens* (quackgrass), and *S. kali* at the 5-year sites compared to control sites was suggestive. The cover of *M. officinalis* was also significantly greater at the 5-year sites compared to the 10-year sites, while greater cover of *C. arvense*, *E. repens*, *K. scoparia*, *L. serriola*, *S. arvensis*, and *T. intermedium* was suggestive. Although no non-native species had significantly greater cover at the 10-year sites compared to control sites, there was suggestive evidence for greater cover of *D. sophia* at the 10-year sites compared to the 5-year sites. Finally, greater cover of *P. pratensis* was suggestive at the control sites compared to the 10-year sites.

Finally, the species accumulation curves demonstrated greater non-native species richness near oil well sites compared to control sites at the landscape level (Fig. 4). Specifically, non-native species richness near the oil well sites was greatest in the 5-year disturbed quadrats

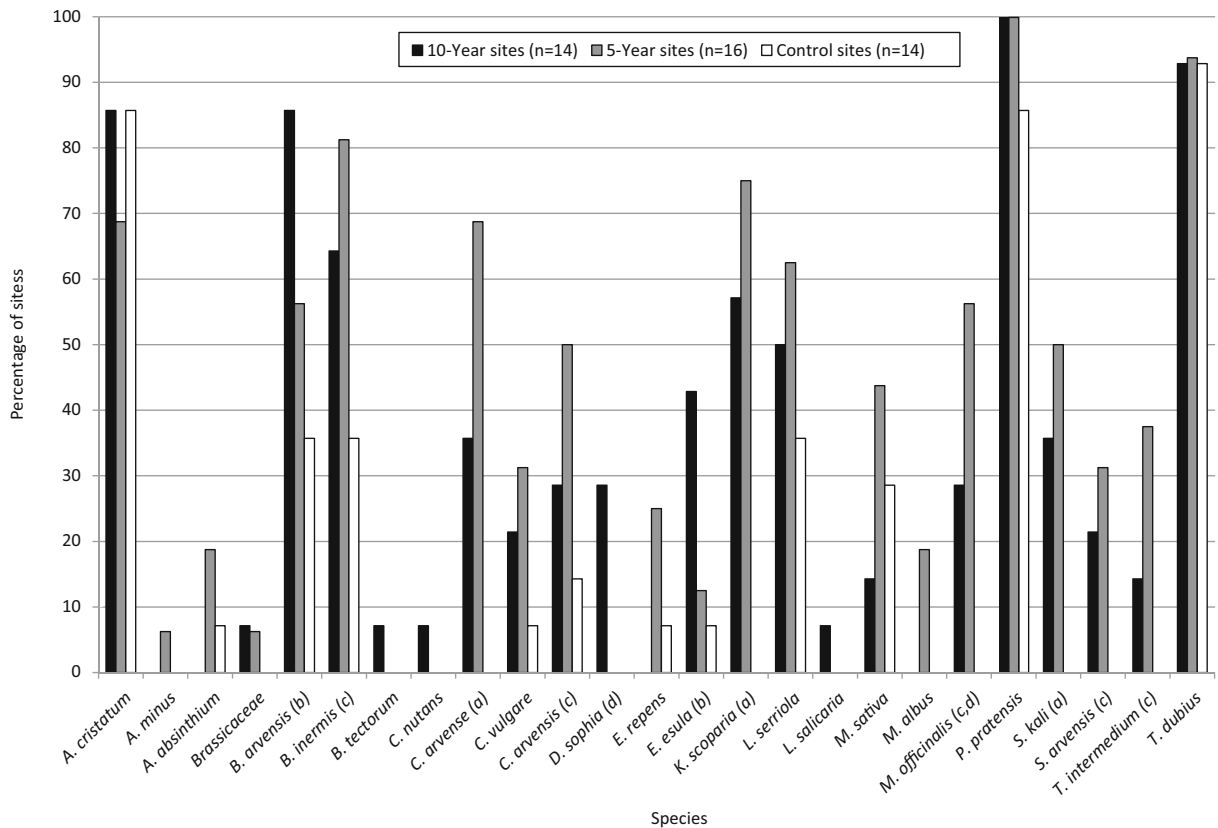


Fig. 3 Bar chart showing the percentage of sites in the different site classes at which each non-native species was observed. Letters in parenthesis following species name are as follows: a, species occurred in a significantly ($p < 0.05$) greater proportion of both 10-year and 5-year sites compared to control sites; b and c, species

occurred in a significantly ($p < 0.05$) greater proportion of 10-year or 5-year sites, respectively, compared to control sites; and d, suggestive ($p < 0.1$) evidence that species occurred in a greater proportion of 10-year sites compared to control sites

and decreased through the 10-year disturbed, 10-year undisturbed, and 5-year undisturbed quadrats. Control quadrats exhibited the lowest non-native species richness. As expected, the species accumulation

curves all exhibit a steep rise at the start of the curve; however, there are differences in the slope of this initial part of the curve with the steepest slopes observed in the 10-year and 5-year

Table 5 Mean cover values (1 SE in parenthesis) for the six non-native species with significant differences in cover between site classes within the first set of concentric quadrats

Scientific name	10-year	5-year	Control
<i>n</i>	14	16	14
<i>Cirsium arvensis</i> (Canada thistle)	0.7 ^{a,b} (0.5)	2.1 ^a (0.8)	0.0 ^b (0.0)
<i>Kochia scoparia</i> (kochia)	1.9 ^{a,b} (1.4)	6.3 ^a (2.8)	0.0 ^b (0.0)
<i>Lactuca serriola</i> (prickly lettuce)	0.03 ^{a,b} (0.01)	0.16 ^b (0.07)	0.00 ^a (0.00)
<i>Melilotus officinalis</i> (yellow sweet clover)	0.03 ^a (0.01)	1.06 ^b (0.69)	0.00 ^a (0.00)
<i>Sonchus arvensis</i> (field sowthistle)	0.07 ^{a,b} (0.07)	0.95 ^a (0.44)	0.00 ^b (0.00)
<i>Thinopyrum intermedium</i> (intermediate wheatgrass)	1.5 ^{a,b} (1.4)	11.6 ^a (5.2)	0.0 ^b (0.0)

Superscript letters a and b denote significant differences in mean values at the 0.05 level between site classes (Tukey multiple comparison test)

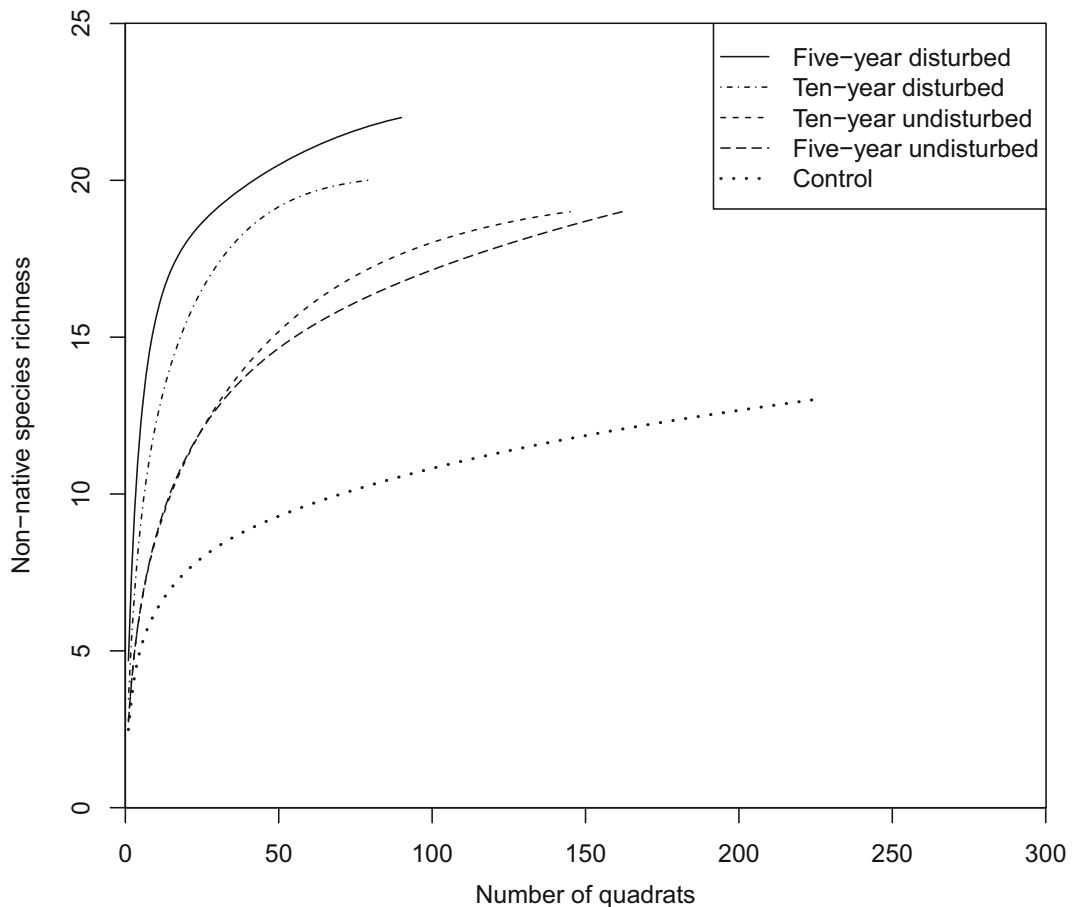


Fig. 4 Species accumulation curves calculated from the vegetation survey results from the 10-year disturbed, 10-year undisturbed, 5-year disturbed, 5-year undisturbed, and control quadrats

disturbed quadrats. Additionally, the initial curves are steeper for the 10-year and 5-year undisturbed quadrats relative to control quadrats. Although all curves continue to rise, indicating that additional non-native species likely existed in the landscape, they appear to level off, implying that the sampling effort was sufficient to capture most of the non-native species richness. Lastly, it should be noted that the entire dataset was used to generate the species accumulation curves and the different lengths are due to different sample sizes for each curve.

Discussion

Non-native species were recorded at all 44 study sites. Control sites for this study were located at least one mile

from the nearest oil well so the presence of non-natives at these sites likely cannot be attributed to energy development. Therefore, these results show that the invasion of non-native species in the Williston Basin has been occurring irrespective of energy development (for example, see DeKeyser et al. 2013); however, areas adjacent to oil wells have significantly greater non-native species richness and non-native forb cover relative to areas without these facilities. While this study did not collect data on the presence and abundance of native species, previous studies have shown that the changes observed in vegetation communities from energy development are predominantly the result of increases in non-native species as opposed to decreases in native species. For example, Nasen et al. (2011) reported that despite increased abundance and diversity of undesirable (non-native) species, namely rhizomatous and tufted grasses and perennial forbs, adjacent to oil and natural gas wells in Saskatchewan grasslands, these sites had similar

compositions of desirable (native) species compared to control sites. Similarly, in the Powder River Basin of Wyoming, Bergquist et al. (2007) only found significant differences in native species richness and cover between control sites and the actual coal bed methane well pads, but not between control sites and areas adjacent to well pads. Therefore, it is likely that the primary changes in vegetation communities in the Williston Basin related to energy development are the result of the increases in non-native species described here.

Total non-native species richness was significantly greater at both the 10-year and 5-year sites compared to control sites. Indeed, the oil well sites had approximately twice as many non-native species as control sites. The increase in total non-native species richness was driven by increases in forb and graminoid species richness, both of which were significantly greater at the oil well sites compared to control sites. These results are similar to other studies examining non-native species richness adjacent to energy development. For example, Bergquist et al. (2007) reported significantly greater non-native species richness in areas disturbed from energy development in Wyoming's Powder River Basin, and Manier et al. (2011) reported that areas adjacent to active well pads had greater non-native species richness relative to ten other anthropogenic features in southwestern Wyoming.

Additionally, non-native forb cover was significantly greater at both the 10-year and 5-year sites compared to control sites; however, no differences existed in total or graminoid non-native cover at the site level. The increase in non-native forb cover is likely due to greater non-native species richness as Stohlgren et al. (2002) concluded that areas where several non-native species have become established, non-native species cover can substantially increase. Although this logic would suggest increased non-native graminoid cover as well, non-native graminoids comprised approximately 20 % of the vegetative cover in the control sites and the increase in cover near the well pads was not sufficient to produce significant increases at the site level. Since the habitat characteristics for several wildlife species are a function of vegetation structure and composition (Rotenberry 1985), increased dominance by non-native plants that create monotypic stands decrease the heterogeneity of native vegetation structure and diversity resulting in loss of suitable habitat (Martin and Murray 2011).

Many non-native species present in the Williston Basin utilize anemochory (wind dispersal of seeds);

therefore, this study examined differences in non-native species richness and non-native forb and graminoid cover between transects to determine if the invasion dynamics are directional. Annual wind directions reported at Sloulin Field International Airport (Williston, North Dakota) are from the north (15 % of the time), west (13 %), and northwest (12 %); however, winds from the south (13 %) and southwest (12 %) are also common (<http://weatherspark.com/averages/30611/Williston-North-Dakota-United-States>). Based on the annual wind data, it would seem possible that the invasion of non-natives could be greater in the downwind transects (south or east) relative to the upwind transects (north or west). However, the only difference between transects within site classes was at the 5-year sites, where there was suggestive results for greater non-native graminoid cover in the western transect compared to the southern transect. This result is contrary to what would be expected from the wind data and also appears not to be related to differences in the number of disturbed quadrats (which also had greater non-native graminoid cover relative to undisturbed quadrats at the 5-year sites) between the western (23), northern (21), southern (21), or eastern (25) transects. Therefore, it appears that the spread of non-natives near oil well pads is not strongly directional, and, where a directional component does exist, the average annual wind data may not be the best indicator of directionality.

However, examining the differences in non-native species richness and cover by distance from the well pads as well as between the oil well sites and control sites provides a better understanding of invasion dynamics in the Williston Basin. Within the oil well sites, significant differences in the presence and abundance of non-native species were the result of greater values in the first (10-year and 5-year sites) and second (5-year sites) quadrats compared to quadrats located at further distances from the well pad. Similarly, the comparison of oil well sites to the control sites demonstrated that the significant differences in non-native species presence and abundance existed in the first quadrat at the 10-year sites and in the first two quadrats at the 5-year sites; however, no significant differences existed between the oil well sites and control sites in the third or fourth quadrats. Taken together, these results demonstrate that the increase in non-native species richness and cover at the oil well sites is predominately localized near the well pad and allows for the distance of invasion to be calculated. At the 10-year sites, the distance of invasion is at

least 10 m and possibly as great as 40 m, while the distance of invasion is at least 50 m and possibly as great as 80 m at the 5-year sites. These results are similar to research by Nasen et al. (2011) that examined petroleum and natural gas wells installed over the previous 50 years in Saskatchewan grasslands. They estimated that the impacts to vegetation communities from oil and gas development extended 25 m from the well pad; however, they also noted that range health was reduced at least 40 m (as far as they surveyed) from the well pad.

Revegetated quadrats that were disturbed during well pad construction had greater non-native species richness and cover compared to undisturbed quadrats. Average non-native species richness was significantly greater in disturbed quadrats compared to undisturbed quadrats at the 10-year sites, while average non-native species richness and forb and graminoid cover were significantly greater in disturbed quadrats relative to undisturbed quadrats at the 5-year sites. According to the North Dakota Petroleum Council, the surface footprint of oil wells targeting the Bakken Formation requires the construction of a large (4–6 acres for single wells and 5–7 acres for multiple wells) pad during the drilling phase, with up to 25 % of the initial pad reclaimed after production starts. During interim reclamation, the land is contoured to blend with the surrounding topography, covered by topsoil removed during well pad construction, and revegetated with native perennial species or other plant materials as specified by the surface owner (North Dakota Petroleum Council 2014). Several studies have documented positive correlations between the invasion of non-native species and increased amount of bare ground (i.e., Burke and Grime 1996; Watkins et al. 2003). While vegetation growth on well pads (bare ground) is kept to a minimum per operating requirements, Bergquist et al. (2007) reported that approximately half of the cover observed on oil well pads in the Powder River Basin was comprised non-native species. Additionally, enhanced recruitment of non-native species compared to native species in disturbed areas following revegetation was reported at grassland sites in western Montana (Maron et al. 2012). Therefore, the creation of large areas of bare ground for the well pad and revegetation of disturbed areas adjacent to the producing well pad (halo) likely provides a pathway for the introduction and establishment of non-native species which can then act as a source of propagules for non-native species to establish in undisturbed areas (D'Antonio et al. 2001). This is supported by the species

accumulation curves which clearly show that the disturbed quadrats adjacent to the well pads had the greatest non-native species richness; however, the undisturbed quadrats at the oil well sites also exhibited greater non-native species richness relative to control sites.

Several non-native species occurred at a greater proportion of oil well sites relative to control sites. None of the three species (*C. arvensis*, *K. scoparia*, and *S. kali*) that occurred in a significantly greater proportion of both the 10-year and 5-year sites relative to control sites were observed at any of the control sites. Similarly, seven other species occurred at a significantly greater proportion of either the 10-year sites (*B. arvensis* and *E. esula*) or 5-year sites (*B. inermis*, *C. arvensis*, *M. officinalis*, *S. arvensis*, and *T. intermedium*) compared to control sites; however, only *B. arvensis*, *B. inermis*, and *C. arvensis* occurred at more than one control site. Nielsen et al. (2011) documented a significant increase in the occurrence of common non-native plant species near oil and gas wells in Wyoming; however, these results show that several non-native species that commonly occur near oil well pads in the Williston Basin do not appear to be pervasive in areas lacking energy development. Therefore, the presence of these non-pervasive species near oil well pads may increase the potential for their introduction and establishment in native prairie environments across the Williston Basin.

The list of species with significantly greater cover at the oil well sites compared to control sites included five of the ten species that occurred at a significantly greater proportion of oil well sites. Combining these two lists produced 11 non-native species that exhibited greater presence and/or abundance near oil well pads compared to control sites in native prairie environments within the Williston Basin: *B. inermis*, *B. arvensis*, *C. arvensis*, *C. arvensis*, *E. esula*, *K. scoparia*, *L. serriola*, *M. officinalis*, *S. kali*, *S. arvensis*, and *T. intermedium*. Due to the timing of the vegetation surveys (July–August), it is possible this list is missing some early-season non-native species that were no longer present. While the effects on native plant communities of each of the 11 non-native species listed above likely vary across the Williston Basin due to differences in soil type, vegetation type, land use, etc., five of these species (*C. arvensis*, *C. arvensis*, *E. esula*, *K. scoparia*, *S. arvensis*) are of

serious concern to land managers due to their listing on either the state of Montana noxious weed list or the state and county noxious weed lists of North Dakota.

Although the most pronounced differences were between the oil well and control sites, the presence and abundance of non-native species also varied between the oil well sites with the 5-year sites generally having greater non-native species richness and cover relative to the 10-year sites as well as a greater number of more common and/or abundant species. The differences between the oil well sites are likely due to differences in plant dynamics between the observed non-native species. Certain species are capable of establishing within, and even dominating, native communities. For example, areas with high soil displacement can lead to the establishment of persistent forb-rich communities including *C. arvensis* (Jensen 1991), removal of top soil can result in *S. kali* dominance for up to a decade (Allen 1989), and *K. scoparia* has been documented a decade after disturbance in mixed prairie (Samuel and Hart 1994). These three species occurred at a greater proportion of both the 10-year and 5-year sites compared to control sites indicating they have likely become established at the oil well sites. Other species, however, are early successional species and/or annual or biennial and it is possible these species rapidly colonized the disturbed areas adjacent to the well pad but were then unable to persist, leading to the drop in non-native species richness and cover near the well pad with increasing time. For example, reduced sunlight from shading by other plants can force *C. arvensis* into dormancy (Holm et al. 1977), reductions in the occurrence of *L. serriola* were reported 3 to 5 years after initial disturbance (Ferguson and Craig 2010), and *M. officinalis* rapidly colonizes bare ground, but rarely persists as a dominant (Gucker 2009). Relative to control sites, these three species occurred at a significantly greater proportion of and/or had significantly greater cover at the 5-year sites, but not the 10-year sites; therefore, these species, if initially present at the 10-year sites, may have failed to become established. Although these results demonstrate that the presence and abundance of non-native species decreases with time, non-native forb and graminoid species richness as well as non-native forb cover at the 10-year sites was still significantly greater than control sites. Thus, the effects to vegetation communities of

energy development within native prairie environments in the Williston Basin are still clearly visible a decade after well pad construction.

Conclusions

This study examined non-native species richness and cover near oil well pads constructed 10- and 5-years ago, as well as similar control sites, in native prairie environments. At the site level, total, forb, and graminoid non-native species richness, as well as non-native forb cover, were significantly greater at both the 10-year and 5-year sites compared to control sites. Non-native species richness and forb cover were greatest adjacent to the well pad and decreased with distance. Non-native species richness and forb cover returned to levels similar to control sites by 40 m at the 10-year sites and 80 m at the 5-year sites. Finally, relative to undisturbed areas, the disturbed and revegetated areas had significantly greater non-native species richness at both the 10-year and 5-year sites and significantly greater forb and graminoid cover at the 5-year sites.

Based on these results and previous studies, much of the increase in non-native species richness and forb and graminoid cover near oil well pads is likely the result of disturbance and subsequent interim reclamation of areas adjacent to the producing well pad. Increased non-native species richness and cover in these disturbed and revegetated areas then act as sources of propagules into undisturbed areas. The most recent update on producing counties in North Dakota predicted that full well capacity in the state would be 58,485 wells (North Dakota Industrial Commission 2014). Assuming these wells are all installed on a single, 5-acre, square well pad, this would equate to approximately 292,000 acres of disturbed land in North Dakota alone. Greater non-native species richness and forb cover were documented at least 50 m from the edge of the well pads at the 5-year sites, and using this buffer around the idealized well pad produces a zone of impact that covers an additional 555,000 acres. This estimate is likely high as it does not account for factors such as multiple boreholes on larger well pads; however, it also does not include additional oil field infrastructure such as access roads or pipelines, both of which have large “edge” areas and significantly contribute to the total area disturbed for energy development. The introduction of non-native species in such a large and geographically expansive

area could allow for their establishment across the Williston Basin. Therefore, reducing the initial footprint of the well pad during the drilling phase and better suppression efforts in revegetated areas after interim reclamation would likely have the greatest effects in minimizing the establishment of non-native species in native prairie environments across the Williston Basin.

To that end, this study identified several non-native species that were more common near oil well sites and/or had greater cover immediately adjacent (0–10 m) to the well pads compared to control sites. Ten non-native species occurred in a significantly greater proportion of the 10-year, 5-year, or both well site classes relative to control sites with suggestive results for an additional three species. Similarly, six non-native species had significantly greater cover immediately adjacent to the well pad at the 5-year sites compared to control sites, with greater cover of one additional species at the 10-year sites being suggestive. Five of the non-native species on these two lists overlapped. Therefore, these results could be used by land managers to enhance current suppression efforts by placing additional emphasis on the more common and abundant non-native species associated with oil and gas development in the Williston Basin.

Acknowledgments The author wishes to thank the following individuals for their contributions: Tara Chesley-Preston (Montana State University Institute on Ecosystems) assisted in identifying study sites; Karen Newlon (Montana Natural Heritage Program) conducted oversight of the vegetation surveys performed by Nick Smith, Isabel Beavers, and Luke Obermeyer; Joseph Washington (U.S. Forest Service Medora Ranger Station) provided logistical support; and Kathryn Irvine and Robert Diehl (U.S. Geological Survey Northern Rocky Mountain Science Center) provided statistical assistance and general counsel, respectively.

Compliance with ethical standards The author declares there are no conflicts of interest. This project was fully funded by the U.S. Fish and Wildlife Service Plains and Prairie Potholes Landscape Conservation Cooperative (grant number CFDA 15.669). Manuscript contents have been reviewed by the U.S. Geological Survey and approved for publication. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

- Allen, M. F. (1989). Mycorrhizae and rehabilitation of disturbed arid soils: processes and practices. *Arid Soil Research*, 3, 229–241.
- Bergquist, E., Evangelista, P., Stohlgren, T. J., & Alley, N. (2007). Invasive species and coal bed methane development in the Powder River Basin. *Wyoming Environmental Monitoring Assessments*, 128, 381–394.
- Burke, M. J. W., & Grime, J. P. (1996). An experimental study of community invasibility. *Ecology*, 77, 776–790.
- Cully, A. C., Cully, J. F., Jr., & Hiebert, R. D. (2003). Invasion of exotic plants species in tallgrass prairie fragments. *Conservation Biology*, 17, 900–998.
- D’Antonio, C. M., & Vitousek, P. A. (1992). Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology and Systematics*, 23, 63–87.
- D’Antonio, C. M., Levine, J. M., & Thomsen, M. (2001). Ecosystem resistance to invasion and the role of propagule supply: a California perspective. *Journal of Mediterranean Ecology*, 2, 233–245.
- Daubenmire, R. (1959). A canopy-cover method of vegetational analysis. *Northwest Science*, 33(1), 43–64.
- Davies, K. W., & Sheley, R. L. (2007). A conceptual framework for preventing the spatial dispersal of invasive plants. *Weed Science*, 55(2), 178–184.
- DeKeyser, E. S., Meehan, M., Clambey, G., & Krabbenhoft, K. K. (2013). Cool season invasive grasses in the Northern Great Plains natural areas. *Natural Areas Journal*, 33(1), 81–090.
- Duncan, C. (2008). *Montana weed management plan: Montana noxious weed summit advisory council* (p. 100). Helena: Montana Department of Transportation.
- Ellstrand, N., & Schierenbeck, K. A. (2000). Hybridization as a stimulus for the evolution of invasiveness in plants? *Proceedings from the National Academy of Sciences*, 97, 7043–7050.
- Ferguson, D.E., & Craig, C.L. (2010). Response of six non-native plant species to wildfires in the northern Rocky Mountains, USA. *Research Paper RMRSRP-78*, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 12.
- Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., & Wickham, J. (2011). Completion of the 2006 national land cover database for the conterminous United States. *Photogrammetric Engineering and Remote Sensing*, 77(9), 858–864.
- Gaswirth, S.B., Marra, K.R., Cook, T.A, Charpentier, R.R., Gautier, D.L., Higley, D.K., Klett, T.R., Lewan, M.D., Lillis, P.G., Schenk, C.J., Tennyson, M.E., & Whidden, K.J. (2013). Assessment of undiscovered oil resources in the Bakken and Three Forks Formations, Williston Basin Province, Montana, North Dakota, and South Dakota, 2013. *U.S. Geological Survey Fact Sheet 2013–3013*, 4. <http://pubs.usgs.gov/fs/2013/3013/>.
- Gelbard, J. L., & Belnap, J. (2003). Roads as conduits for exotic plant invasions in a semiarid landscape. *Conservation Biology*, 17(2), 420–432.
- Gibson, J. W. (2013). Bombing North Dakota. *Earth Island Journal*, 27(4), 4.
- Gucker, C.L. (2009). *Melilotus alba*, *M. officinalis*. In Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: <http://www.fs.fed.us/database/feis/> [2014, September 26].

- Holm, L. G., Plucknett, D. L., Pancho, J. V., & Herberger, J. P. (1977). *The world's worst weeds: distribution and biology* (p. 609). Honolulu: University Press of Hawaii.
- Jensen, M.E. (1991). Ecological classification and cumulative soil effects. In Harvey, A.E., Neuenschwander, L.F., compilers. Proceedings—management and productivity of western-montane forest soils; 1990 April 10–12; Boise, ID. *General Technical Report INT-280* (pp. 218–223). Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.
- Kurz, G. L., Olson, R.A., & Whitson, T. D. (1995). Ecological implications of Russian knapweed (*Centaurea repens* L.) infestation: small mammal and habitat associations. *Proceedings of the Western Society of Weed Science*, 56.
- Larson, D. L., Anderson, P. J., & Newton, W. (2001). Alien plant invasion in mixed-grass prairie: effects of vegetation type and anthropogenic disturbance. *Ecological Applications*, 11(1), 128–141.
- Litt, A. R., & Pearson, D. E. (2013). Non-native plants and wildlife in the intermountain west. *Wildlife Society Bulletin*, 37, 517–526.
- Lonsdale, W. M., & Lane, L. A. (1994). Tourist vehicles as vectors of weed seeds in Kakadu National Park, Northern Australia. *Biological Conservation*, 69, 277–283.
- Manier, D. J., Aldridge, C., Anderson, P., Chong, G., & Homer, C. (2011). Land use and habitat conditions across the southwestern Wyoming sagebrush steppe: development impacts, management effectiveness and the distribution of invasive plants. *Natural Resources and Environmental Issues*, 17, 15–27.
- Manier, D. J., Aldridge, C. L., & Schell, S. J. (2014). Human infrastructure and invasive plant occurrence across rangelands of southwestern Wyoming, USA. *Rangeland Ecology & Management*, 67, 160–172.
- Maron, J. L., Pearson, D. E., Potter, T., & Ortega, Y. K. (2012). Seed size and provenance mediate the joint effects of disturbance and seed predation on community assembly. *Journal of Ecology*, 100, 1492–1500.
- Martin, L. J., & Murray, B. R. (2011). A predictive framework and review of the ecological impacts of exotic plant invasions on reptiles and amphibians. *Biological Reviews*, 86, 407–419.
- Nasen, L. C., Noble, B. F., & Johnstone, J. F. (2011). Environmental effects of oil and gas lease sites in a grassland ecosystem. *Journal of Environmental Management*, 92, 195–204.
- Nielsen, S. E., Aldridge, C. L., Hanser, S. E., Leau, M., & Knick, S. T. (2011). Chapter 10: occurrence of non-native plants: the role of anthropogenic features. In S. E. Hanser, M. Leu, S. T. Knick, & C. L. Aldridge (Eds.), *Sagebrush ecosystem conservation and management: ecoregional assessment tools and models for the Wyoming Basins* (pp. 357–386). Kansas: Allen Press.
- North Dakota Department of Agriculture. (2014). Weed survey report: <http://agdepartment.vision-technology.com/weedsurvey/report.asp>, accessed 9/15/2014.
- North Dakota Industrial Commission. (2014). ND producing counties update: <https://www.dmr.nd.gov/oilgas/presentations/NDOGCPC091814.pdf>, accessed 2/17/2015.
- North Dakota Petroleum Council. (2014). Surface Owner Information Center: <http://www.ndoil.org/?id=184>, accessed 9/15/2014.
- Pimentel, D., Zuniga, R., & Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, 52, 273–288.
- Rice, P.M. (2012). INVADERS database system. University of Montana, Division of Biological Sciences, Missoula, Montana, USA. <<http://invader.dbs.umt.edu>>. Accessed December 10, 2013.
- Ringwall, K., Biondini, M., & Grugiel, C. (2000). Effects of nitrogen fertilization in leafy spurge architecture. *Journal of Range Management*, 53, 228–232.
- Rotenberry, J. T. (1985). The role of habitat in avian community composition: physiognomy or floristics? *Oecologia*, 67, 213–217.
- Samuel, M. J., & Hart, R. H. (1994). Sixty-one years of secondary succession on rangelands of the Wyoming high plains. *Journal of Range Management*, 47, 184–191.
- Sinkins, P. A., & Oftinowski, R. (2012). Invasion or retreat? The fate of exotic invaders on the northern prairies, 40 years after cattle grazing. *Plant Ecology*, 213, 1251–1262.
- Sonnenberg, S. A., & Pramudito, A. (2010). Petroleum geology of the giant Elm Coulee field, Williston Basin. *American Association of Petroleum Geologists*, 93(9), 1127–1156.
- Stohlgren, T. J., Chong, G. W., Schell, L. D., Rimar, K. A., Otsuki, Y., Lee, M., Kalkhan, M. A., & Villa, C. A. (2002). Assessing vulnerability to invasion by nonnative plant species at multiple spatial scales. *Environmental Management*, 9(4), 566–577.
- Thompson, M. J. (1996). Winter foraging response to elk to spotted knapweed removal. *Northwest Science*, 70(1), 10–19.
- Thompson, G. G., Withers, P. C., Pianka, E. R., & Thompson, S. A. (2003). Assessing biodiversity with species accumulation curves; inventories of small reptiles by pit-trapping in Western Australia. *Austral Ecology*, 28, 361–383.
- Trammel, M. A., & Butler, J. L. (1995). Effects of exotic plants on native ungulate use of habitat. *The Journal of Wildlife Management*, 59(4), 808–816.
- Ugland, K. I., Gray, J. S., & Ellingsen, K. E. (2003). The species-accumulation curve and estimation of species richness. *Journal of Animal Ecology*, 72, 888–897.
- US Department of Agriculture, National Resources Conservation Service. (2014). The PLANTS database (<http://plants.usda.gov>), 1 April 2014), National Plant Data Team, Greensboro, NC 27401–4901 USA.
- von der Lippe, M., & Kowarik, I. (2007). Long-distance dispersal of plants by vehicles as a driver of plant invasions. *Conservation Biology*, 21(4), 986–996.
- Watkins, R. Z., Chen, J., Pickens, J., & Brosofske, K. D. (2003). Effects of forest roads on understory plants in a managed hardwood landscape. *Conservation Biology*, 17(2), 411–419.
- Wilcove, D. S., Rothstein, D., Phillips, A., & Losos, E. (1998). Quantifying threats to imperiled species in the United States. *BioScience*, 48, 607–615.