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Diversifying monoculture crops by incorporating prairie buffer strips

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ABSTRACT

Monoculture crop production and prevailing farming practices have greatly reduced perennial plants on the landscape and nearly eliminated native Iowa prairie vegetation. The STRIPs (Science-based Trials of Row crops Integrated with Prairies) project is a watershed-scale experiment at the Neal Smith National Wildlife Refuge, in Jasper County, Iowa, US, in which strips of prairie vegetation were planted within watersheds of corn (*Zea mays*) and soybean (*Glycine max*) production to aid in soil and water conservation. The project includes 12 0.5- to 3.2-ha watersheds. Nine watersheds included buffer strips in one of three design treatments that varied the number and position of strips and/or the proportion of the watershed converted to buffer and three watersheds were 100% crop. The present study investigated: (1) If the design of prairie buffer strips influenced their vegetation; (2) If the vegetation of prairie buffer strips shifted over time; (3) If prairie buffer strips caused a weed problem in adjacent crop fields. From 2008-2011, the identity and percent cover of plant species within the buffer strips were surveyed, and from 2009-2011, the identity and percent cover of weed species within the cropped areas of the watersheds were surveyed. Differences among treatments and among years in plant species diversity, percent cover, and composition were analyzed using ANOVA and NMS. The design of buffer strips did not influence plant species diversity or composition; however, buffer strip vegetation did shift over time. In 2008, the strips had 38 species (in 6 m^2) with 37% of the total plant cover composed of perennial species and 22% composed of native perennial species. By 2011, the strips had 55 species (in 6 m^2) with 90% of the total plant cover composed of perennial species and 58% composed of native perennial species. In addition, NMS analyses indicated that the buffer strip plant community shifted from annual to perennial species. Within the crop, weed species richness and percent cover did not differ among watershed treatments, regardless of whether watersheds contained buffer strips or not. Prairie buffer strips greatly increased plant diversity in the watersheds; 380% more species were found in 6 m^2 of prairie buffer than in 6 m^2 of cropland. Within four years of establishment, the buffer strip vegetation was predominantly perennial and native species, the target vegetation for both ecohydrological functions (i.e., erosion control) and for conservation. Furthermore, weed species richness or prevalence did not differ between watersheds that incorporated prairie buffer strips versus

100% crop watersheds. Therefore, converting 10-20% of arable cropland to prairie buffer strips successfully reintroduced perennial species and conserved native Iowa prairie without causing a weed problem in adjacent crops.

CHAPTER 1. INTRODUCTION

Agriculture has contributed to the worldwide loss of biodiversity due to land transformation from native vegetation such as forests or prairies to cropland. Worldwide, the most productive and fertile land tends to be modified most heavily (Fischer et al. 2006). Crop monocultures, in which a single crop is produced in a field during the growing season, have replaced and simplified natural ecosystems, which once contained up to thousands of plant species. Four previously rare plants, barley, maize, rice, and wheat, now occupy 39.8% of global cropland (Tilman 1999). In Iowa, before Euro-American settlement, prairie covered approximately 85% of the state (> 12 million hectares), but by the 1990s, prairie covered only 0.01% of the state's land area (Eilers & Roosa 1994; Samson & Knopf 1994).

Iowa farmers typically practice a two-crop rotation of corn and soybean, which replaced previously more complex, diverse crop rotations that included perennial plants in hay fields and pastures (Bullock 1992; Bultena et al. 1996; Brummer 1998). Furthermore, modern agricultural techniques tend to simplify ecosystems by adding inputs such as herbicides (McLaughlin & Mineau 1995). In the 1940s, due to large farm equipment becoming available and pressure during World War II to cultivate as much land as possible, farms began shifting from small farms surrounded with brushy, perennial fencerows to larger expanses of uninterrupted row crops (Bultena et al. 1996). The loss of diversity can be detrimental to agriculture, as reducing biodiversity on the land negatively influences ecological processes that agriculture is dependent upon, including soil formation, erosion control, water retention, and nutrient cycling (Giliomee 2006; Schulte et al. 2006).

Incorporating prairie buffer strips in monoculture row crops offers an opportunity to re-introduce native plant diversity on the land and provide ecological services to the agricultural system. Buffer strips, intentional areas of non-crop vegetation within crop fields, serve to conserve water, soil, and nutrients, and to prevent these materials from leaving the field and entering the water supply (Lovell & Sullivan 2006). Buffer strips have the potential to promote the diversity of several taxa, such as birds, insects, spiders, mammals, and plants, and can conserve native species on the land (Benton et al. 2003). The STRIPs (Science-based Trials of Row crops Integrated with Prairies) project, located within the Neal Smith National Wildlife Refuge in Iowa, US, is a watershed-scale experiment initiated in 2007, which includes 12 0.5- to 3.2- ha watersheds. The project was established to investigate how prairie buffer strips placed within catchments used for corn and soybean production affected ecohydrology, biodiversity, and socioeconomic dynamics. The present study specifically investigated the effects of integrating prairie buffer strips on plant diversity and composition within the watersheds, both within the buffer strips and adjacent row crops.

The ability of buffer strips to conserve water, soil, and nutrients and to promote diversity and native species is largely determined by their vegetation. Boubakari and Morgan (1999) found that the type of grass used in contour grass strips was more important than the slope of the hill in affecting soil loss. For trapping sediment and reducing erosion, grasses and forbs that are tall, dense, deeply rooted, sturdy, and resistant to bending in flowing water are superior to grasses and forbs that are short, clumped, sparsely rooted, flexible, and susceptible to bending in run-off water (Tadesse & Morgan 1996; Melville & Morgan 2001; Liu et al. 2008). Tall, stiff, dense plants are more able to resist flooding and can slow water runoff through ponding water behind them, thus allowing sediment to settle (Meyer et al. 1995; Boubakari & Morgan 1999).

In central Iowa, prairie vegetation is diverse, perennial, and native, and could encourage optimal performance and multi-functionality of buffer strips. Functionally diverse species tend to increase ecosystem stability in terms of resistance (remaining unchanged during stress), resilience (returning to the original state after stress or disturbance), and persistence (remaining relatively unchanged over time) (Phelan 2009). Diverse plant communities encourage the conservation of nutrients and water. Diverse prairie plant communities can also increase nitrogen (N) utilization and reduce soil N leaching losses (Tilman et al. 1996; Bingham & Biondini 2011). In the BIODEPTH project (BioDiversity and Ecological Processes in Terrestrial Herbaceous Ecosystems), in which the effects of declines in plant diversity were examined in European grasslands, more diverse communities had less water loss to evaporation after rain events, and generally, photosynthesis in more diverse communities was less limited by water shortages (Minns et al. 2001). Beneficial effects of biodiversity arise due to properties of individual species and the increased likelihood that particular species will be present in diverse communities (e.g., the increased likelihood that drought tolerant species will be present in diverse communities). In addition, benefits of biodiversity arise due to positive interactions between species or due to diverse communities being able to utilize more completely all of the niche resources (Minns et al. 2001). Perennial plants are ideal vegetation for buffer strips as they have extensive root systems that hold soil in place, trap sediment, reduce soil compaction, and enhance water infiltration (Anon 2003; Lovell & Sullivan 2006).

In addition, native, diverse vegetation in buffer strips may encourage pollination in crops, control disease, and promote natural enemies of insect pests (Anon 2003; Bianchi et al. 2006; Giliomee 2006). Non-crop habitats such as hedgerows or herbaceous field margins provide natural enemies with resources such as pollen and nectar sources and suitable areas for hibernation, and can therefore increase the diversity and abundance of natural enemies within the agricultural landscape. In a review of 24 studies, Bianchi et al. (2006) found that in 74% of the cases, landscape complexity enhanced natural enemy populations in crop fields; however, more studies are needed to determine if this ensures effective pest control in crop fields. Native plant species in field borders in Iowa provide ecological advantages such as providing diverse pollen and nectar sources to promote local pollinator populations. In addition, incorporating native plant species in field borders in Iowa can provide habitat for local wildlife (NRCS 2007).

Buffer strip design

The vegetation of prairie buffer strips may be influenced by the design of buffer strips (shape, size and/or position in the watershed). Vegetation spread over a larger surface area (elongated or multiple buffer strips) may encounter heterogeneous environments that favor different species, and buffer strips with large edge to area ratios may have more undesirable species that grow on the border between vegetation types (Diamond & May 1981; Kunin 1997). The position of the buffer strip within the watershed may affect buffer vegetation due to various parts of the watershed having different water, soil, and nutrient patterns. For example, buffer strips that are predominately run-on versus run-off may have different vegetation (Saunder et al. 1991). Including buffer strips in a watershed is expected to increase plant diversity; however, the amount of plant diversity and composition of plant species in the watershed due to the buffer strips may depend on the position of the buffer strips within the watershed or the proportion of the watershed converted to buffer. In addition, factors such as the prairie seed mix, soil seed bank and seed dispersal from neighboring land may influence the number and composition of plant species in the buffer strips. To test the influence of buffer strip design on plant diversity and composition, the current study varied the number and position of buffer strips within the watershed (one strip at the bottom of the slope or one strip at the bottom of the slope and two to three strips upslope) and the proportion of the watershed converted to prairie buffer strips (10% or 20% of the watershed). The first objective of this study was to determine if the design of the buffer strips influenced the vegetation growing in them.

Buffer strip succession

Plant communities often follow succession patterns, shifting from annual, weedy vegetation to perennial vegetation (Schwartz & Whitson 1987; Rothrock & Squiers 2003; Camill et al. 2004; Critchley et al. 2006). Initially, a few weedy, r-selected species rapidly grow and occupy available space (May 1981). The first plant species to colonize a community take up similar fractions of remaining available growing space, such that the log of relative abundance versus the rank abundance of species will form a straight line (Bazzaz 1975; May 1981). As the plant community develops, typically there will be a lognormal distribution of the relative abundances of species, such that the log of relative abundance versus the rank abundance of species will form an S-shaped curve.

Fallow cropland that naturally regenerates is initially dominated by annual or other short-lived species, next by perennial non-woody species, and lastly by shrubs and trees (Hodgson 1989). A 21-farm study across the Netherlands established crop field margins ≥ two meters wide that were sown with grass or a grass/forb mixture. While there were differences between farms, overall, field margin plant species richness increased and cover of agriculturally harmful weeds decreased in the years following establishment (Musters et al. 2009). A study of 116 sites in eight regions of England found that sown grass margins around cropland followed early successional patterns, as by the third year after establishment, annual weedy vegetation had substantially declined and perennial species dominated the field margins (Critchley et al. 2006).

Reconstructed tallgrass prairies in the US shifted within four years from annual, weedy vegetation to perennial vegetation (Schwartz & Whitson 1987; Rothrock & Squiers

2003; Camill et al. 2004). A reconstructed tallgrass prairie near Cedar Falls, Iowa that had been plowed and seeded with a prairie grass and forb mix was dominated for the first three years by weedy species including *Setaria* spp., *Ambrosia artemisiifolia* L., *Trifolium pratense* L., *Conyza canadensis* (L.) Cronq., and *Polygonum* spp. (Schwartz & Whitson 1987). The prairie then shifted for the next five years to perennial cool-season grasses including *Bromus inermis* Leyss, *Agropyron smithii* Rybd. and *Elymus canadensis* L.. Finally, nine years after the prairie was seeded, the vegetation shifted to be dominated by prairie grasses (Schwartz & Whitson 1987). Similarly, Camill et al. found that agricultural land restored to tallgrass prairie in southern Minnesota was dominated by weedy, non-native annual and biennial species during the first growing season. By the second growing season, perennial native composites were dominant, and by the third growing season 38-57% of the vegetation was warm-season C_4 prairie grasses, which remained the dominant functional group during growing seasons three to eight (Camill et al. 2004). Rothrock and Squiers (2003) found in a tallgrass prairie restoration in Upland, Indiana that annual weeds dominated during the first two growing seasons, including *Hibiscus trionum* and *Setaria glauca*, although prairie species seedlings were present. By the third growing season until the end of the five-year study, the prevalence of annual weed density declined and the prevalence of prairie grasses and forbs increased, including *Rudbeckia hirta*, *Andropogon gerardii*, and *Sorghastrum nutans*. Mowing, burning, or grazing practices can be used to eliminate woody or weedy plant species and enhance native plant species (Axelrod 1985; Schwartz & Whitson 1987).

Polluted or over fertilized communities may retain annual weeds and not shift to perennial species. In the "Park Grass Experiment" at the Rothamsted Experimental Station in England, plots that were over fertilized became more like an early succession community with time (May 1981). Nitrogen fertilized areas in a prairie restoration on former agricultural land in Indiana, US retained annual weeds, including *Ambrosia trifida*, *Ambrosia artemisiifolia*, *Setaria faberi*, *Chenopodium album*, and *Polygonum* spp., and did not shift to perennial prairie species (Rothrock & Squiers 2003). Furthermore, in five of the six experimental blocks, prairie species had below 6% cover, whereas control plots had 50% cover (Rothrock & Squiers 2003). In the present study, although the prairie buffer strips were not intentionally altered, fertilizers or herbicides applied to the surrounding crops may move into the buffer strips and alter their succession. Thus, while succession patterns in plant communities have been well studied, patterns specific to prairies that are serving as buffer strips (in small areas, surrounded by conventional cropland) are unknown. The second objective of this study was to determine how prairie buffer strips developed through time.

Weeds in cropland

Farmers may be concerned that plants from prairie buffer strips will spread into crops and cause a weed problem. However, previous studies indicate that most species present in crop field boundaries were not present in the crop, many of the species found in both the field boundary and crop were only in the first 2-5 meters of the crop (Marshall 1989), and most shared species between the field boundary and crop were annual and originated in the crop (Marshall & Arnold 1995). Musters et al. (2009) also found uncropped field margins did not increase weeds within the crop field. Furthermore, managing field edges to increase biodiversity did not seem to affect weed levels in the neighboring crop, particularly when the margin contained non-invasive perennial species (Smith et al. 1999). The third objective of this study was to determine if prairie buffer strips caused a weed problem in adjacent crops.

Hypotheses

We hypothesized that the age of the prairie buffers but not the buffer strip design will influence their vegetation. The watersheds in all design treatments had similar vegetation prior to seeding, are surrounded by similar vegetation, were sown with the same seed-mix, and were seeded at the same time and thus are in the same successional stage. Therefore, these common factors are expected to supersede any differences that may result from the buffer design. Specifically, we hypothesized that the prairie buffer strips in different design treatments will not differ in species richness (total, perennial, native, or native perennial), percent plant cover (total, perennial, native, or native perennial), relative percent plant cover (perennial, native, or native perennial), or species composition. However, based on patterns in fallow cropland, sown grass/forb field margins, and reconstructed prairies, we hypothesized that during the first years of the experiment (2008-2011) while the prairie is establishing, the prairie buffer strips will have increased species richness (total, perennial, native, or native perennial), increased relative percent plant cover (perennial, native, and native perennial), and will shift in species composition.

Based on previous studies, we hypothesized that within the crop, the number of species or total percent cover of weeds will not differ among any of the watersheds, regardless of whether they contain buffer strips or not, and will not differ among years 2009-2011. Additionally, the weed species composition within the crop areas will not change among design treatments or among years 2009-2011.

Thesis organization

The present research study is organized as five chapters and three appendices. Chapter 2 describes the methods of the study. This chapter presents the study site and experimental set-up, and explains how the watersheds were established and managed, how the vegetation was surveyed, identified, and classified, and how the data were analyzed. Chapter 3 describes and illustrates the results of the analysis of the vegetation sampling method and the results of the buffer strip and crop surveys. Chapter 4 discusses the adequacy of the vegetation sampling method and the results of the hypothesis tests and their implications, and reviews additional possible explanations for findings of this study. Finally, Chapter 5 summarizes the main results of the study, mentions areas of interest for future studies, and reiterates the importance of the present study. Appendix A lists detailed management activities for the crop and buffer strips. Appendix B reports how conservative species in the prairie buffer strips were, in terms of the Iowa coefficients of conservatism. Appendix C discusses the alpha, beta, and gamma diversity within the study.

CHAPTER 2. METHODS

Study site and experimental set-up

The study was located within the Neal Smith National Wildlife Refuge in Jasper County, Iowa, US (41°32′ N, 93°15′ W). Within the last 9,000 years, this region was primarily covered by tallgrass prairie, oak savannas and woodland (Eilers & Roosa 1994); however, the area is now primarily row crop agriculture (corn and soybean) outside of the national refuge. The study was conducted on 12 0.5- to 3.2-ha watersheds, based on topographic boundaries, with an average size of 1.3 ha. A watershed was defined as the land area in which precipitation would drain to a collection point at the bottom of the slope (i.e., a catchment). The watersheds were used for corn or soybean production (in an alternate year rotation). Prairie grasses and forbs native to central Iowa were planted in strips in portions of nine of the watersheds. These buffer strips were planted in three designs: (1) one buffer strip at the bottom of the watershed slope, comprising 10% of the watershed area (treatment 1); (2) two to three buffer strips at the bottom of the watershed slope and upslope, comprising 10% of the watershed area (treatment 2); (3) two to three buffer strips at the bottom of the watershed slope and upslope, comprising 20% of the watershed area (treatment 3). Treatment 4 was 100% row crop with no buffer strips (Fig. 1). In watersheds that contained two to three buffer strips, each buffer strip within a watershed was an equal area. There were three replicate watersheds for each of the four treatments, and the 12 watershed were arranged in four blocks. Each block contained three watersheds and therefore contained three of the four treatments (Fig. 2). For statistical analysis, this constituted a balanced incomplete-block design, as there were not enough experimental units (watersheds) in a block to accommodate all treatments. It is considered balanced because all treatments are in the same number of blocks and because every pair of treatments is together in the same number of blocks (Littell et al. 2002).

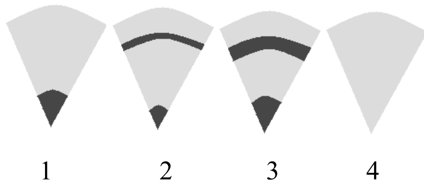

Fig. 1. Experimental treatments: (1) 90% of the watershed as crop and 10% as one buffer strip at the bottom of the watershed slope; (2) 90% of the watershed as crop and 10% as two to three buffer strips at the bottom of the watershed slope and upslope; (3) 80% of the watershed as crop and 20% as two to three buffer strips at the bottom of the watershed slope and upslope; (4) 100% of the watershed as crop.

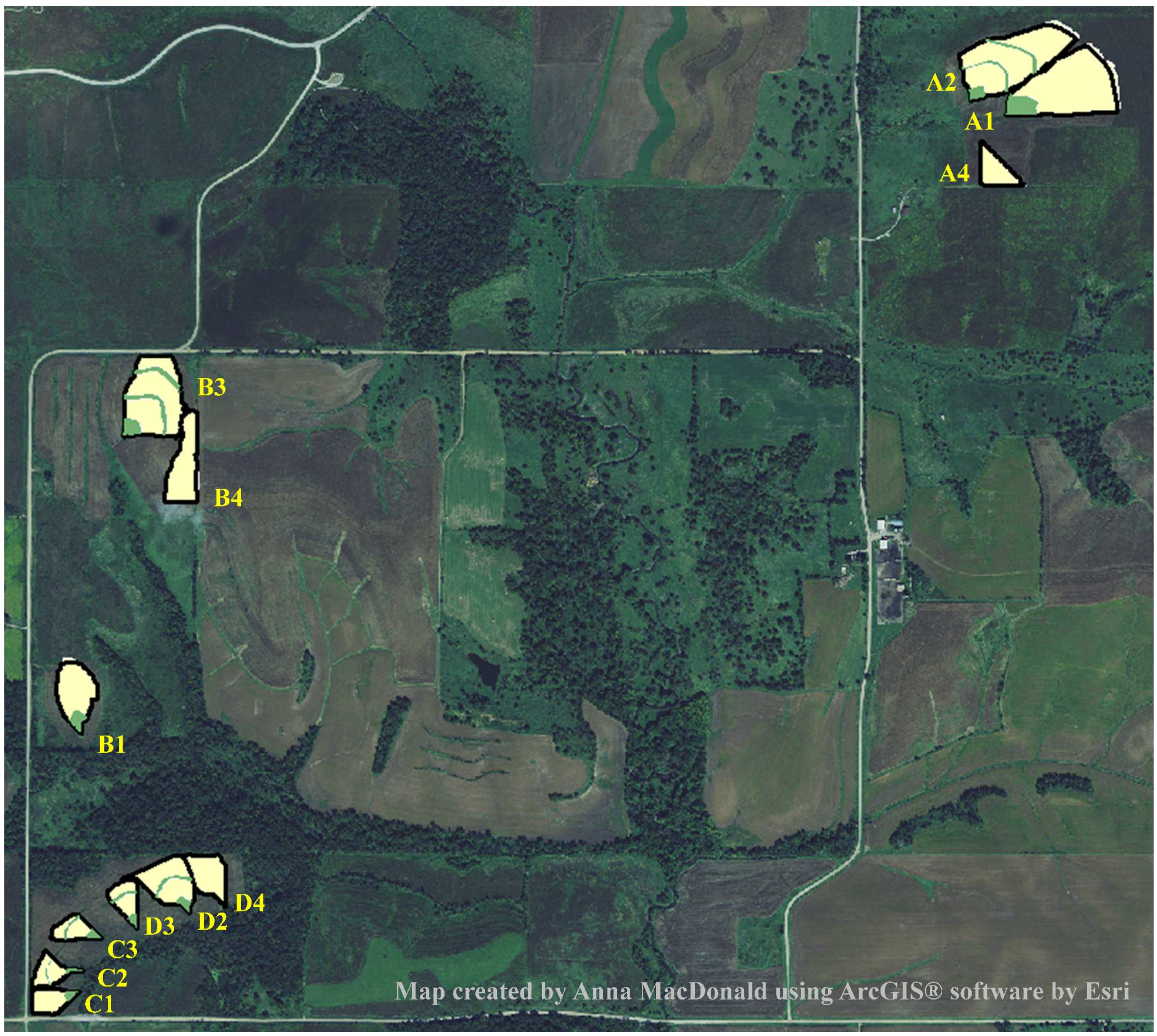

Fig. 2. Location of study. Watersheds within Neal Smith National Wildlife Refuge. Blocks and treatments of each watershed are labeled by block A-D followed by treatment 1-4.

Watershed management

The watersheds in block A and block B were dominated by *Bromus inermis* prior to the experiment, and the watersheds in block C and block D were planted in prairie in 2005, but heavily dominated by *Bromus inermis* before the start of the experiment. All watersheds were plowed prior to being planted at the start of the experiment. Since 2007 watersheds have been farmed in a no-till alternate year corn-soybean rotation using synthetic fertilizers (anhydrous ammonia, potassium chloride, monoammonium phosphate) and glyphosate herbicide; soybean was planted in 2007. The buffer strips were tilled and broadcast seeded with a tallgrass prairie seed mix containing 32 species on 6 July 2007 (Table 1). The strips were mowed to slow the growth of weedy species 19-21 June 2008, late August 2008, and 25 June 2009. The strips were further mowed with removal of cuttings 30-31 October 2010 and 8-19 November 2011. *Cirsium arvense* in the buffer strips was spot treated with aminopyralid in 2009 and with glyphosate in 2010 and 2011. (See Appendix A for more details on cropland and buffer strip management.)

Table 1. Species present in the tallgrass prairie seed mix. Percentages of seed mix components by weight were 27% grasses (G), 24% forbs (F), 5% weedy forbs (WF) and weedy grasses (WG), and 44% inert matter. Buffer strips were sown on 6 Jul 2007, with the exception of *Anemone canadensis*, which was sown on 22 Apr 2008.

Latin binomial	Group
Andropogon gerardii	G
Bouteloua curtipendula	G
Elymus canadensis	G
Elymus virginicus	G
Schizachyrium scoparium	G
Sorghastrum nutans	G
Sporobolus spp.	G
Amorpha spp.	F
Anemone canadensis	F
Asclepias spp.	F
Aster spp.	F
Chamaecrista fasciculata	F
Coreopsis spp.	F
Heliopsis helianthoides	F
Lespedeza capitata	F
Liatris spp.	F
Monarda fistulosa	F
Ratibida spp.	F
Solidago rigida	F
Ambrosia artemisiifolia	WF
Ambrosia trifida	WF
Bidens polylepis	WF
Brickellia eupatorioides	WF
Chenopodium album	WF
Daucus carota	WF
Lactuca serriola	WF
Trifolium repens	WF
Polygonum convolvulus	WF
Polygonum pensylvanicum	WF
Rumex crispus	WF
Setaria faberi	WG
Muhlenbergia spp.	WG

Vegetation sampling method

Buffer strip vegetation was surveyed 15-19 August 2008, 20-23 July 2009, 7-28 July 2010, and 5-26 July 2011. Survey timing was intended to capture the peak of the flowering vegetation. Twelve 0.5-m^2 quadrats (50 x 100 cm) were surveyed in the buffers of each of the nine watersheds. Quadrats were placed equidistant along a straight transect in each buffer strip. In watersheds with one buffer strip, all 12 quadrats were surveyed along a single transect; in watersheds with two or three buffer strips, six or four quadrats, respectively, were surveyed along each transect. The first and last quadrats were surveyed two meters from the crop edge on both transect ends. In addition, from 2009-2011, 12 quadrats were surveyed within the corn or soybean crop of each of the twelve watersheds. The number (species richness) and identity of plant species and percent cover of each species were determined within the quadrats. Percent cover is the percentage of ground area covered by a species when it is vertically projected onto the ground, as viewed from above (Bonham 1989). The percent cover of the species within a quadrat was estimated to be 0-1%, 1-5%, 5-25%, 25-50%, 50-75%, 75-95%, or 95-100%. Midpoints of the percent cover classes were used for analyses (0.5%, 3%, 15%, 37.5%, 62.5%, 85%, and 97.5%) (Bonham 1989). The percent cover of each plant species was observed independently in order to adequately sample vegetation of varying heights. For example, two plant species could have each covered 75-95% of the quadrat if one was underneath the other. Therefore, quadrats with multiple layers of vegetation may have contained >100% cover of all species summed.

Species identification and classification

Plants were identified to the species level, with the following exceptions identified to the genus level due to the small size or lack of flowers and fruits: *Acer*, *Cerastium*, *Cornus*, *Crataegus*, *Helianthus*, *Lepidium*, *Lonicera*, *Melilotus*, *Morus*, *Rosa*, *Rubus*, *Salix*, *Sanicula*, *Sonchus*, *Tilia*, *Viola*, *Juncus*, *Muhlenbergia*, and *Setaria*. In addition, the following pairs of species were grouped due to difficulty in distinguishing between them: *Acalypha virginica* and *A. rhomboidea*, *Vernonia baldwinii* and *V. fasciculata*, and *Tradescantia ohiensis* and *T. bracteata*. Furthermore, *Poa compressa* and *P. pratensis* were grouped due to difficulty differentiating the percent cover of each. Plants were characterized as native or non-native to Iowa (Eilers & Roosa 1994), as perennial, biennial, or annual, and as a dicot or monocot (USDA, NRCS 2012). Plants listed under two or three life span categories were categorized as the longer-lived category (e.g., a plant listed as annual/biennial was characterized as biennial). Plants were categorized into 10 life-history groups: native perennial monocot (NPM), native annual monocot (NAM), non-native perennial monocot (XPM), non-native annual monocot (XAM), native perennial dicot (NPD), native biennial dicot (NBD), native annual dicot (NAD), non-native perennial dicot (XPD), non-native biennial dicot (XBD), and non-native annual dicot (XAD). In situations when plants were identified to the genus level rather than the species level, they were still grouped into a life-history group based on the dominant characteristics of the species in that genus (e.g., all of the *Juncus* spp. in Iowa are native and perennial except for one rare species, so *Juncus* spp. was grouped as a NPM).

Analysis of vegetation sampling method

Analyses were conducted to assess the adequacy of the buffer strip sampling method and to determine if doubling the buffer strip sampling area would have changed the overall results of the study. In 2010 and 2011, 24 0.5-m^2 quadrats, rather than the typical 12 0.5-m^2 quadrats, were surveyed in the buffer strip of the three replicate watersheds of treatment 1 (one buffer strip at the bottom of the watershed slope, comprising 10% of the watershed area). Species accumulation curves, rank abundance curves, and species richness estimates were calculated for the 12 quadrats and for the 24 quadrats sampled in the buffer strip of the three watersheds. Treatment 1 was chosen because it covered the least geographic spread, and therefore was expected to have the least environmental heterogeneity and to be the most thorough sample.

Species accumulation curves depict the number of new species found versus the quadrat number, showing how many new species are added with each additional quadrat sampled. A curve that does not approach an asymptote indicates new species continue to be found, and more species are present in the buffer strip than those represented in the survey. In contrast, a curve that approaches an asymptote indicates the surveyed quadrats contain almost all of the species present in the buffer strip. Species accumulation curves of the 12 quadrats and 24 quadrats of the same watershed buffer strip were visually examined to see if they approached an asymptote and compared to see if the 24-quadrat curve was closer to approaching an asymptote than the 12-quadrat curve. In addition, if species accumulation curves did not approach an asymptote, first-order jackknife[1] (Heltshe & Forrester 1983; Palmer 1990), second-order jackknife[2] (Burnham & Overton 1979; Palmer 1991), and Chao2 bias corrected[3] (Chao 1987; Colwell & Coddington 1994; Colwell 2009) species richness estimates were calculated to estimate the actual number of species present in the buffer strip.

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[1] Jack1 = $S + r1(n\text{-}1) / n$, where S = observed species richness; $r1$ = number of species that occurred in one experimental unit; n = number of experimental units

[2] Jack2 = $S + r1(2n\text{-}3)/n - r2(n\text{-}2)^2 / (n(n\text{-}1))$, where $r2$ = number of species that occurred in exactly two experimental units

[3] Chao2 = $S + r1(r1\text{-}1)(n\text{-}1) / (2n(r2 + 1))$

The number of species that occurred in only one (singleton) or in only two (doubleton) of the 12 quadrats also was recorded.

Rank abundance curves depict the mean percent cover of species versus their rank order, illustrating the mean percent cover of all species, from the most prevalent to the least prevalent. They show the number of species that dominate and the number that cover very little ground (the 'tail' of the curve). If the 24-quadrat rank abundance curve looked similar to the 12-quadrat rank abundance curve, except for the length of the tail (the number of species with low percent cover values), then sampling more than 12 quadrats likely served only to capture more sparse species (species with less than 3% cover). For the present study, it was considered acceptable not to capture all of the sparse species during sampling.

Buffer strip vegetation analyses

Species richness in the buffer strips of a watershed was calculated as the total number of different species in the 12 0.5-m^2 quadrats (6 m^2 total sample area). Species diversity in the buffer strips of a watershed was calculated as Simpson's diversity index ($1/D$) in the 12 0.5-m^2 quadrats ($D = \sum_i^s p_i^2$; p_i = the proportion of individuals belonging to species i; S = the number of species). $1/D$ represents the number of species if all species were equally abundant. Simpson's diversity was used because it slightly favors common species (in comparison to Shannon's diversity) and is independent of N, the number of individuals. Species were categorized into life-history groups. The percent cover and the relative percent cover of each life-history group were calculated for the buffer strip vegetation. The percent cover of a life-history group (sum of the percent cover of each species in a life-history group) has functional implications, as it indicates the amount of ground covered by plants. However, differences in percent cover values among years could have resulted from differences in buffer strip management (e.g., timing of mowing in relation to sampling) or weather among years rather than shifts in plant community composition. Therefore, relative percent cover (proportion of total percent cover of a particular life-history group) is essential to make comparisons among years (Bonham 1989).

Perennial, native, and native perennial species are of particular interest, due to their functional and conservational benefits. Therefore, the effects of treatment and year on the dependent variables of total, perennial, native, and native perennial species richness and percent cover, and perennial, native, and native perennial relative percent cover (arcsine-square root transformed) were analyzed using a repeated measures analysis of variance (ANOVA) (SAS 9.2, proc mixed; SAS Institute, Cary, NC, US). The relative percent cover values were arcsine-square root transformed because the values were not between 30 and 70, and were therefore constrained by upper and lower limits, and the variance of the values was dependent on the mean (Gomez & Gomez 1984; Gotelli & Ellison 2004). An ANOVA model for repeated measures was appropriate as each experimental unit (watershed) was measured each year. Blocks were treated as a fixed effect. Least square means (LSMs) were calculated for treatments and for years, using the Tukey-Kramer multiple comparison adjustment. Differences of LSMs (Tukey-Kramer adjusted) of years were analyzed to determine which years were significantly different.

For treatment one watersheds, plots were constructed of the log mean percent cover of species versus their rank abundance from 2008-2011 in order to illustrate how this relation may change over the years as the vegetation develops, and to see if succession stages are evident by a shift from a straight line to a more S-shaped curve.

The species data were summarized to deduce important patterns in species composition of the buffers among years or treatments. As described above, data were summarized by classifying the large number of species into a smaller number of discrete life-history groups. Alternatively, data were summarized through ordination, which created fewer continuous composite variables (axes) from the original variables (species) as a result of the original variables (species) covarying. Watersheds were arranged along the axes (composite variables) according to the species they contained. The non-metric multidimensional scaling (NMS) technique (Kruskal 1964; Mather 1976) was used, which is appropriate for ecological community data and for data that is non-normally distributed (McCune & Grace 2002). Non-metric multidimensional scaling was performed on the 175 species found in the buffer strips. Additionally, the species were grouped into the 10 life-history groups, and NMS was performed on these. Rare species were not deleted before performed NMS to avoid losing valuable information and because deleting rare species is not biologically justified (Cao et al. 1998). By including all of the species, the whole-community structure can be analyzed (McCune & Grace 2002). The original, unreduced space had a dimension (axis) for each variable (i.e., 175 dimensions for species analysis or 10 dimensions for life-history group analysis), whereas NMS reduced the space to contain only two dimensions for the life-history group analysis or two dimensions for the species analysis. Watersheds were arranged along the two axes according to their buffer strip species composition, with dissimilar watersheds plotted farther apart and similar watersheds plotted closer together, preserving only the rank ordering of the original distances (Gotelli & Ellison 2004). The distance between points in the ordination space (measured with Euclidean distance) should represent the distance between points in the original, unreduced space (measured with Sorensen/Bray-Curtis distance). Therefore, the distance between watersheds in the ordination space was proportional to the dissimilarity between the watersheds in terms of their species composition. Non-metric multidimensional scaling iteratively searched for the best positions of the watersheds on the axes to minimize the stress of the ordination on those axes (Gotelli & Ellison 2004). 'Stress' measures how different the reduced dimension arrangement is from the original, unreduced dimension arrangement; stress values between 10 and 15 are satisfactory for ecological community data (McCune & Grace 2002). A coefficient of determination (r^2) between the original space distance and ordination space distance evaluates the quality of data reduction, and r^2 x 100 provides a measure of the percentage of variance represented by each axis in the ordination. However, the r^2 values can be biased by outliers in a data set. Generally, data sets with > 20 species should explain > 50% of the variation with two axes (McCune & Grace 2002).

Non-metric multidimensional scaling was performed using the PC-ORD software version 6.04 (MjM Software, Gleneden Beach, OR, US) autopilot 'slow and thorough' mode, which is recommended for community data. The autopilot mode uses random starting configurations. It performs 250 runs with the real data (series of solutions stepping down from the highest number of axes to one axis), and 250 runs with randomized data. Randomization of data shuffles the species present within watersheds. A randomization (Monte Carlo) test is run to compare final stress in the real data to final stress in the randomized data and to evaluate how strong patterns are in the data and if NMS is extracting stronger axes than expected by chance. The autopilot mode selects a best solution for each dimensionality and chooses the optimal dimensionality by choosing the lowest dimension in which the stress would not be reduced by at least five had the dimensionality been one dimension higher. In addition, the dimension must have a final stress lower than 95% of the randomized runs ($p \leq 0.05$ on the Monte Carlo test) (McCune & Grace 2002). The 'slow and thorough' autopilot mode attempts to find a solution until instability (the standard deviation in stress over the preceding ten iterations) is 0.0000001 or a maximum of 500 runs have been performed.

Joint plots of the NMS ordinations show how the positions of the watersheds in ordination space relate to their species/life-history groups. They illustrate species/ life-history group shifts and highlight important species/ life-history groups by depicting them with vector lines. The angle and length of a vector line radiating from the center of the ordination space shows the direction and the strength of the relationship between that vector (a particular species or life-history group) and the watersheds. Vectors represent species/life-history groups with greater than a set r^2 value. The correlation coefficient (r) compares the position of the watersheds in ordination space to the abundance of the species/life-history group, and r^2 is the proportion of variation in position on the ordination axis explained by the species/life-history group. The r and r^2 values must be interpreted with care as they can be influenced by outliers and misrepresent nonlinear relationships within the data (McCune & Grace 2002). The r^2 value determining which vectors are plotted in the joint plot (e.g., $r^2 > 0.3$) is calculated relative to the combination of axis one and axis two (McCune & Mefford 2011). Convex hulls outline the watersheds of each year. Convex hulls can be visually compared to see if years appear separated, indicating that species/life-history group composition is different among years.

Alternatively, the abundance of life-history groups of interest in the buffer strips was illustrated using overlay plots. In overlay plots, watershed symbols are scaled to represent the abundance of a particular life-history group (McCune & Grace 2002). This allows non-linear relationships (i.e., 'hump-shaped' responses along ordination axes) to be interpreted more accurately than with joint plots. However, in contrast to the joint plot, overlay plots can show only one life-history group at a time. Again, convex hulls outline the watersheds of each year and can be visually compared to determine if the symbol sizes of watersheds seem to vary among years.

Differences among years and/or treatments in the species/life-history group composition of the buffers were also quantitatively assessed based on the position of each watershed in the ordination space. The effect of treatment and year on the dependent variables of the position (coordinate value) of each watershed on axis one and axis two in the ordination space was analyzed using repeated-measures ANOVA (SAS 9.2, proc mixed; SAS Institute, Cary, NC, US). Since the axes of the NMS ordinations are orthogonal, scores on axis one are not influenced by scores on axis two and each axis can be analyzed separately. This analysis may not capture all effects since the ordination could be rotated and additional axes be analyzed. However, by rotating to orthogonal principal axes (standard practice in PC-ORD autopilot mode), the NMS axes tend to be ordered by decreasing importance, with axis one being the strongest axis. Least square means were calculated for treatments and years, using the Tukey-Kramer adjustment. Differences of LSMs (Tukey-Kramer adjusted) of years were analyzed to determine which years had different species/ life-history group composition.

In addition, Adonis in the VEGAN R package (Oksanen et al. 2011) was used to analyze differences in the buffer strip species composition among years and/or treatments in order to verify that significant effects were not being missed due to the rotation of the ordination. Adonis is an appropriate function to analyze ecological multivariate data. It uses a non-parametric method based on repeated permutations for multivariate analysis of variance (Anderson 2001). The Adonis analysis used the Bray-Curtis distance measure and 999 permutations. The Adonis test is not dependent upon rotation. However, this analysis cannot indicate which years and/or treatments were different from others. Adonis cannot account for repeated measures so the species abundances were summed across years to test for treatment effects.

Crop vegetation analyses

The number of weed species and total percent cover of weeds in the crop were calculated based on the 12 0.5-m^2 quadrats (6 m^2 total sample area). The effect of treatment and year on the dependent variables of weed species richness and percent cover was analyzed using a repeated measures ANOVA (SAS 9.2, proc mixed; SAS Institute, Cary, NC, US). Least square means were calculated for treatments and years, using the Tukey-Kramer adjustment. Differences of LSMs (Tukey-Kramer adjusted) of years were analyzed to determine which years were different.

Non-metric multidimensional scaling was performed using the PC-ORD software – Version 6.04 (MjM Software, Gleneden Beach, OR, US) on the 89 species found in the crop. The NMS solution for two dimensions was found using Sorensen/Bray-Curtis distance measure (random starting configuration, 250 runs with real data compared to 250 runs with randomized data). The effect of treatment and year on the position of each watershed on axis one and axis two in the ordination space was analyzed using repeated-measures ANOVA (SAS 9.2, proc mixed; SAS Institute, Cary, NC, US). Differences of LSMs (Tukey-Kramer adjusted) of years were computed to determine which years had different weed species composition. In addition, Adonis in the VEGAN R package (Oksanen et al. 2011) was used to analyze differences in the crop weed species composition among years and/or treatments.

CHAPTER 3. RESULTS

Analysis of vegetation sampling method

Species accumulation curves of both 12 quadrats and 24 quadrats from the buffer strip of watersheds in treatment 1 did not approach an asymptote, indicating that the number of species encountered continued to increase even when the sampling area was doubled (Fig. 3). Therefore, first-order Jackknife, second-order Jackknife, and Chao2 bias corrected species richness estimates were calculated to estimate the total species richness in the buffer strips. There was no consistent pattern between the estimated species richness based on the 24-quadrat sampling versus the 12-quadrat sampling (Table 2). For example, for watershed A1 in 2010, the estimates predicted 80-92 species when based on the 24-quadrat sampling, but only 56-64 species when based on the 12-quadrat sampling. However, for watershed B1 in 2010, the estimates predicted roughly the same number of species regardless of whether they were based on the 12-quadrat sampling or the 24-quadrat sampling (predictions of 83-96 species based on 12 quadrats and predictions of 81-95 species based on 24 quadrats). Rank abundance curves of 12 quadrats and 24 quadrats from the buffer strip of watersheds in treatment 1 appeared similar except the 24-quadrat curves had longer tails. Thus, sampling with 24 quadrats included more sparse species (with $< 3\%$ cover) than sampling with 12 quadrats (Fig. 4). Importantly, the identity of the species that made up $> 3\%$ cover was similar whether 12 or 24 quadrats were sampled (Fig. 4).

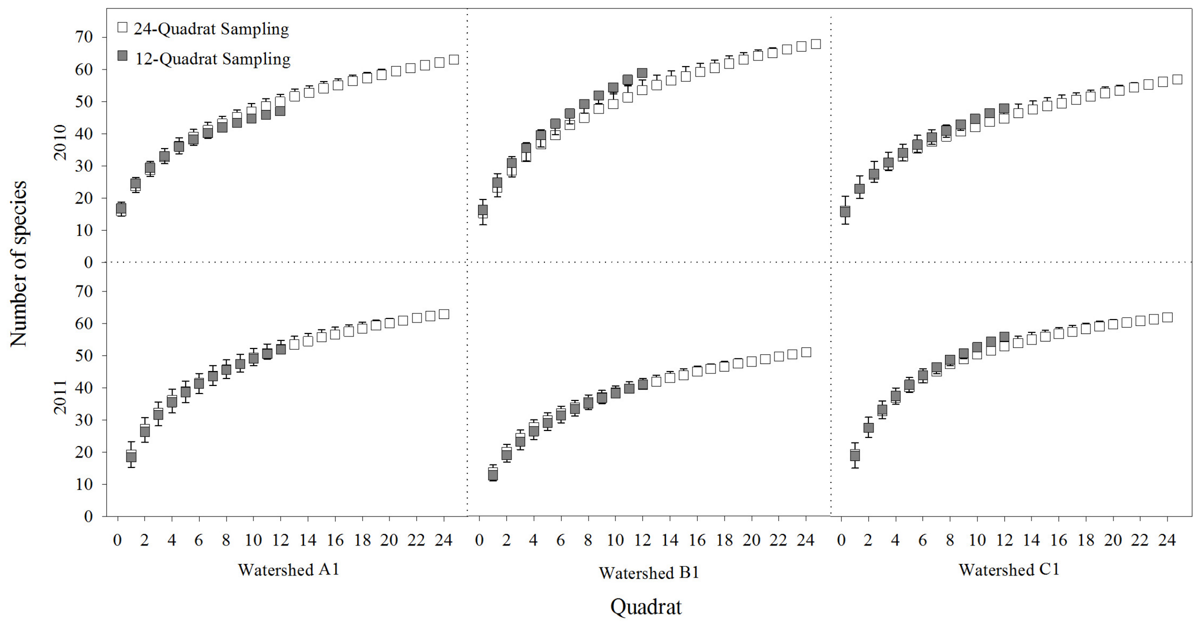

Fig. 3. Comparison between sampling 12 quadrats and sampling 24 quadrats. Species accumulation curves of the buffer strip in each treatment 1 watershed (A1, B1, and C1) in 2010 and 2011 sampled with 12 quadrats versus 24 quadrats. Error bars indicate 1 positive standard deviation for the 24-quadrat sampling and 1 negative standard deviation for the 12-quadrat sampling.

Table 2. Comparison between sampling 12 quadrats and sampling 24 quadrats. Species richness (in 6 m^2); first-order jackknife (Jack1), second-order jackknife (Jack2), Chao2 bias corrected form (Chao2) species richness estimates; and number of species present in only 1 of the 12 quadrats (singletons) and in only 2 of the 12 quadrats (doubletons) of the buffer strip in each treatment 1 watershed (A1, B1, and C1) in 2010 and 2011.

Watershed	Quadrats sampled	Species observed	Jack1	Jack2	Chao2	Singletons	Doubletons
2010							
A1	12	47	58.9	64.4	55.9	13	7
	24	63	82.2	91.7	79.6	20	10
B1	12	59	82.8	96.2	83.8	26	11
	24	68	88.1	95.1	81.4	21	14
C1	12	48	65.4	76.7	70.4	19	6
	24	57	76.2	89.2	83.0	20	6
2011							
A1	12	52	67.6	76.4	67.6	17	7
	24	63	77.4	80.6	70.7	15	12
B1	12	41	55.7	64.5	56.7	16	6
	24	51	66.3	75.7	67.4	16	6
C1	12	56	73.4	82.4	71.7	19	9
	24	62	74.5	81.1	72.7	13	6

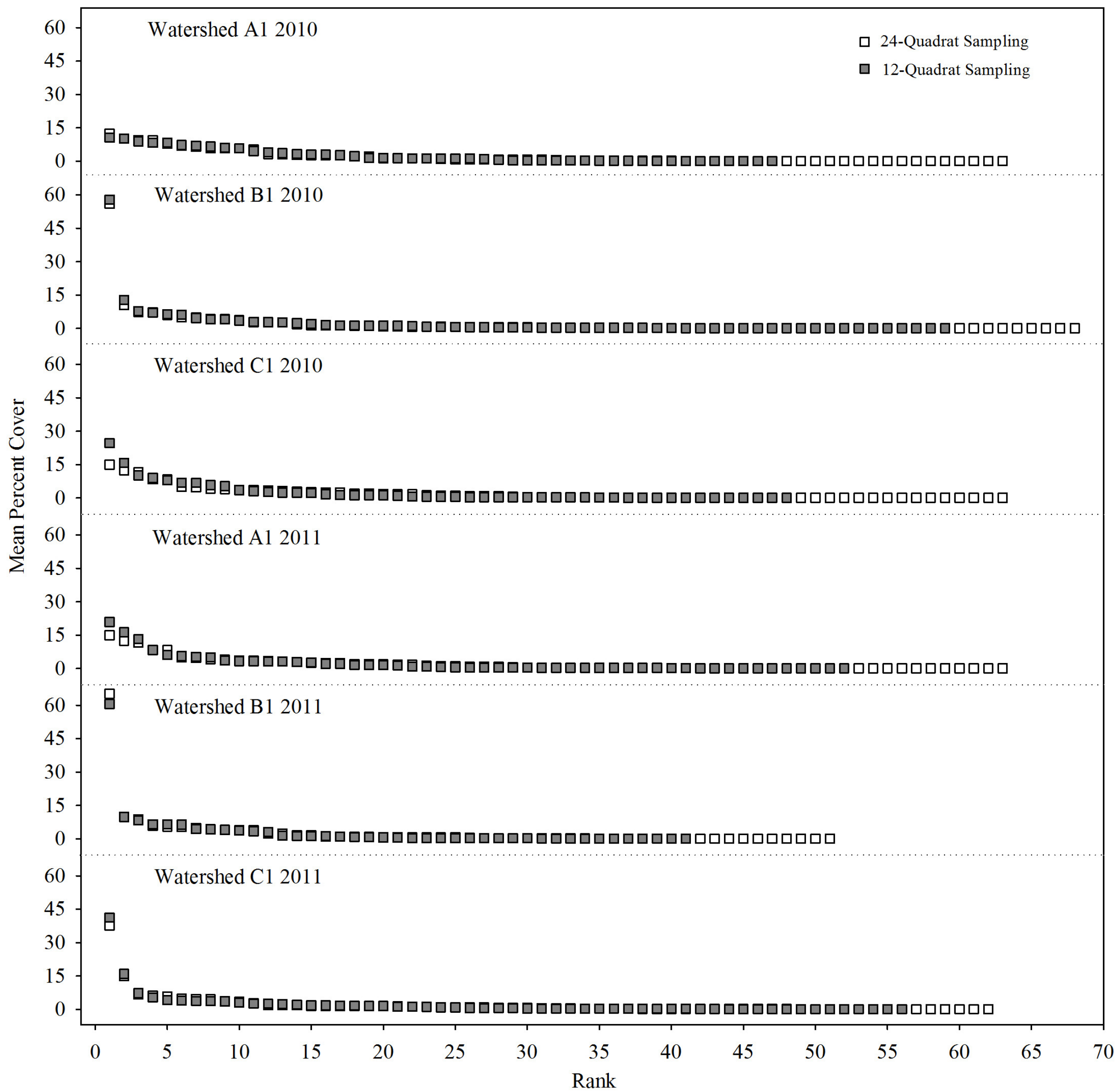

Fig. 4. Comparison between sampling 12 quadrats and sampling 24 quadrats. Rank abundance curves of the buffer strip in each treatment 1 watershed (A1, B1, and C1) in 2010 and 2011 sampled with 12 quadrats (12Q) versus 24 quadrats (24Q). Species with > 3% cover from the most dominant to least dominant:

2010 A1 12Q: 1. *Andropogon gerardii,* 2. *Bromus inermis*, 3. *Monarda fistulosa,* 4. *Setaria* spp., 5. *Calystegia sepium,* 6. *Bouteloua curtipendula,* 7. *Elymus canadensis,* 8. *Daucus carota*, 9. *Aster pilosus,* 10. *Solidago canadensis,* 11. *Ratibida pinnata,* 12. *Heliopsis helianthoides*, 13. *Sorghastrum nutans,* 14. *Pastinaca sativa*

2010 A1 24Q: 1. *Monarda fistulosa,* 2. *Bromus inermis,* 3. *Solidago canadensis,* 4. *Setaria* spp., 5. *Calystegia sepium,* 6. *Andropogon gerardii,* 7. *Bouteloua curtipendula,* 8. *Elymus canadensis,* 9. *Daucus carota,* 10. *Ratibida pinnata,* 11. *Aster pilosus,* 12. *Sorghastrum nutans,* 13. *Poa compressa/P. pratensis*

2010 B1 12Q: 1. *Poa compressa/P. pratensis,* 2. *Solidago canadensis,* 3. *Ratibida pinnata*, 4. *Sorghastrum nutans*, 5. *Setaria* spp., 6. *Daucus carota*, 7. *Aster pilosus,* 8. *Monarda fistulosa*, 9. *Plantago rugelii*, 10. *Elymus canadensis*

2010 B1 24Q: 1. *Poa compressa/P. pratensis,* 2. *Solidago canadensis,* 3. *Sorghastrum nutans,* 4. *Ratibida pinnata,* 5. *Setaria* spp., 6. *Daucus carota,* 7. *Aster pilosus,* 8. *Elymus canadensis,* 9. *Bouteloua curtipendula,* 10. *Monarda fistulosa*

2010 C1 12Q: 1. *Poa compressa/P. pratensis,* 2. *Lotus corniculatus*, 3. *Ratibida pinnata,* 4. *Aster pilosus,* 5. *Cyperus esculentus,* 6. *Daucus carota,* 7. *Andropogon gerardii,* 8. *Sorghastrum nutans*, 9. *Trifolium repens,* 10. *Solidago canadensis*
2010 C1 24Q: 1. *Poa compressa/P. pratensis,* 2. *Lotus corniculatus,* 3. *Ratibida pinnata,* 4. *Aster pilosus,* 5. *Sorghastrum nutans,* 6. *Daucus carota,* 7. *Andropogon gerardii,* 8. *Cyperus esculentus,* 9. *Trifolium repens,* 10. *Rumex crispus*
2011 A1 12Q: 1. *Monarda fistulosa,* 2. *Solidago canadensis,* 3. *Daucus carota,* 4. *Phalaris arundinacea,* 5. *Bromus inermis,* 6. *Calystegia sepium,* 7. *Muhlenbergia* spp., 8. *Asclepias syriaca,* 9. *Bouteloua curtipendula,* 10. *Elymus canadensis,* 11. *Sorghastrum nutans,* 12. *Setaria* spp., 13. *Andropogon gerardii*
2011 A1 24Q: 1. *Monarda fistulosa,* 2. *Solidago canadensis,* 3. *Daucus carota,* 4. *Phalaris arundinacea,* 5. *Bromus inermis,* 6. *Calystegia sepium,* 7. *Bouteloua curtipendula,* 8. *Ambrosia trifida,* 9. *Aster pilosus,* 10. *Cirsium arvense,* 11. *Andropogon gerardii,* 12. *Sorghastrum nutans,* 13. *Setaria* spp.
2011 B1 12Q: 1. *Poa compressa/P. pratensis,* 2. *Toxicodendron radicans,* 3. *Phalaris arundinacea,* 4. *Sorghastrum nutans,* 5. *Solidago canadensis,* 6. *Monarda fistulosa,* 7. *Cyperus esculentus,* 8. *Andropogon gerardii,* 9. *Aster pilosus,* 10. *Bromus inermis,* 11. *Setaria* spp., 12. *Tradescantia ohiensis/T. bracteata*
2011 B1 24Q: 1. *Poa compressa/P. pratensis,* 2. *Solidago canadensis,* 3. *Toxicodendron radicans,* 4. *Monarda fistulosa,* 5. *Sorghastrum nutans,* 6. *Andropogon gerardii,* 7. *Phalaris arundinacea,* 8. *Bromus inermis,* 9. *Setaria* spp., 10. *Tradescantia ohiensis/T. bracteata,* 11. *Aster pilosus*
2011 C1 12Q: 1. *Poa compressa/P. pratensis,* 2. *Ratibida pinnata,* 3. *Andropogon gerardii,* 4. *Daucus carota,* 5. *Aster pilosus,* 6. *Monarda fistulosa,* 7. *Cyperus esculentus,* 8. *Sorghastrum nutans,* 9. *Solidago canadensis*
2011 C1 24Q: 1. *Poa compressa/P. pratensis,* 2. *Ratibida pinnata,* 3. *Sorghastrum nutans,* 4. *Andropogon gerardii,* 5. *Monarda fistulosa,* 6. *Cyperus esculentus,* 7. *Daucus carota,* 8. *Aster pilosus,* 9. *Solidago canadensis,* 10. *Toxicodendron radicans*

Buffer strips

Buffer strip vegetation surveys recorded a total of 82 species in 2008, 103 species in 2009, 122 species in 2010, and 118 species in 2011 (in 54 m^2). On average, the buffer strip(s) of a watershed contained 37.8 species providing 82.1% cover in 2008, 45.3 species providing 74.9% cover in 2009, 51.4 species providing 105.0% cover in 2010, and 55.1 species providing 115.0% cover in 2011 (in 6 m^2) (Table 3). Many of these species were rare, however, and 90% of the total percent cover in the buffer strips was composed of 26 species in 2008, 27 species in 2009, 29 species in 2010, and 30 species in 2011 (Table 4).

There were no differences among treatments 1, 2, and 3 for the mean species richness of all species ($P = 0.3696$), perennial species ($P = 0.4516$), native species ($P = 0.6348$), or native perennial species ($P = 0.6720$); mean Simpson's diversity ($P = 0.1937$); mean total percent cover ($P = 0.3050$), perennial percent cover ($P = 0.4854$), native percent cover ($P = 0.8149$), or native perennial percent cover ($P = 0.9132$); and arcsine-square root transformed value of the mean relative perennial percent cover ($P = 0.8993$), native percent cover ($P = 0.3938$), or native perennial percent cover ($P = 0.5244$) in the buffer strip(s) of a watershed.

However, there were differences among years for the mean species richness of all species ($P < 0.0001$), perennial species ($P < 0.0001$), native species ($P = 0.0001$), and native perennial species (*P* < 0.0001); mean Simpson's diversity (*P* = 0.0016); mean total percent cover (*P* < 0.0001), perennial percent cover (*P* < 0.0001), native percent cover (*P* < 0.0001), and native perennial percent cover (*P* < 0.0001); and arcsine-square root transformed value of the mean relative perennial percent cover (*P* < 0.0001), native percent cover (*P* < 0.0001), and native perennial percent cover (*P* < 0.0001) in the buffer strip(s) of a watershed (Table 3). Plots showing the log mean percent cover of species in the buffer strip versus their rank abundance illustrate that curves generally became less steep from 2008 to 2011 (Fig. 5).

Table 3. Vegetation of the buffer strip(s) in watersheds from 2008-2011. Analysis of variance results (*F* statistics, *P* values) for the effect of year on the dependent variables of total, perennial, native, and native perennial (NP) species richness and percent plant cover; perennial, native, and native perennial relative percent plant cover; Simpson's diversity; and positions of the watersheds on axis one and axis two in the NMS ordination space for species and life-history group (LHG) composition analyses. 2008-2011 least square mean (LSM) values indicate the mean value of nine watersheds (12 0.5-m^2 quadrats sampled per watershed) with standard errors (SE). Numerator degrees of freedom = 3; denominator degrees of freedom = 18; different letters within rows indicate significant differences among years (*P* < 0.05, Tukey-Kramer adjusted). Relative percent cover values are arcsine-square root transformed; untransformed values are in parentheses.

	F	*P*	2008 LSM	2009 LSM	2010 LSM	2011 LSM	SE
Species richness							
All species	14.8	<0.0001	37.8 a	45.3 b	51.4 c	55.1 c	2.0
Perennial species	32.6	<0.0001	25.0 a	33.7 b	40.1 c	44.8 d	1.5
Native species	12.0	0.0001	25.2 a	30.4 b	35.1 c	38.5 c	1.8
NP species	24.3	<0.0001	17.8 a	24.2 b	28.8 c	33.0 d	1.4
Percent cover							
All species	17.0	<0.0001	82.1 a	74.9 a	105.0 b	115.0 b	4.7
Perennial species	36.9	<0.0001	30.1 a	58.4 b	93.7 c	103.6 c	5.5
Native species	25.8	<0.0001	38.4 a	24.6 b	57.3 c	68.8 c	3.9
NP species	51.6	<0.0001	18.0 a	21.8 a	55.6 b	66.7 b	3.3
Relative percent cover							
Perennial species	39.6	<0.0001	0.64 a (36.5)	1.08 b (77.0)	1.24 bc (88.8)	1.26 c (90.0)	0.05 (3.6)
Native species	15.9	<0.0001	0.77 a (48.4)	0.61 b (32.9)	0.83 a (54.4)	0.89 a (60.1)	0.04 (3.4)
NP species	55.6	<0.0001	0.49 a (22.2)	0.57 b (29.2)	0.81 c (52.8)	0.87 c (58.4)	0.03 (2.3)
Simpson's diversity	7.7	0.0016	5.9 a	8.5 ab	11.8 c	10.5 bc	0.9
Species composition							
Axis one	67.1	<0.0001	-1.22 a	-0.31 b	0.66 c	0.87 c	0.12
Axis two	12.3	0.0001	0.21 a	-0.33 b	0.07 a	0.22 a	0.08
LHG composition							
Axis one	55.6	<0.0001	-1.24 a	-0.48 b	0.64 c	0.89 c	0.15
Axis two	7.9	0.0015	-0.20 a	0.48 b	-0.05 a	-0.28 a	0.12

Table 4. Dominant species in the buffer strips from 2008-2011. Species composing 90% of the mean relative percent plant cover, indicating least square mean (LSM) percent cover and standard errors (SE).

2008		2009		2010		2011	
Latin binomial	LSM % cover (± SE)	Latin binomial	LSM % cover (± SE)	Latin binomial	LSM % cover (± SE)	Latin binomial	LSM % cover (± SE)
Setaria spp.	27.13 ± 1.84	*Trifolium hybridum*	11.80 ± 1.77	*Poa compressa/ P. pratensis*	21.31 ± 4.90	*Poa compressa/ P. pratensis*	25.14 ± 4.90
Panicum capillare	12.91 ± 2.31	*Poa compressa/ P. pratensis*	10.95 ± 4.90	*Solidago canadensis*	8.37 ± 1.34	*Solidago canadensis*	11.59 ± 1.34
Rumex crispus	4.07 ± 0.82	*Setaria* spp.	10.71 ± 1.84	*Ratibida pinnata*	6.48 ± 1.33	*Ratibida pinnata*	6.52 ± 1.33
Ratibida pinnata	3.32 ± 1.33	*Taraxacum officinale*	3.41 ± 0.65	*Daucus carota*	5.80 ± 1.22	*Daucus carota*	6.41 ± 1.22
Poa compressa/ P. pratensis	2.63 ± 4.90	*Rumex crispus*	2.75 ± 0.82	*Aster pilosus*	5.55 ± 0.67	*Sorghastrum nutans*	5.63 ± 0.75
Daucus carota	2.36 ± 1.22	*Cyperus esculentus*	2.53 ± 0.50	*Sorghastrum nutans*	4.49 ± 0.75	*Monarda fistulosa*	4.47 ± 1.01
Medicago sativa	2.13 ± 0.60	*Ratibida pinnata*	2.35 ± 1.33	*Andropogon gerardii*	3.70 ± 0.80	*Andropogon gerardii*	4.27 ± 0.80
Bouteloua curtipendula	1.71 ± 0.63	*Daucus carota*	2.23 ± 1.22	*Elymus canadensis*	3.60 ± 0.56	*Bromus inermis*	4.03 ± 0.74
Polygonum pensylvanicum	1.67 ± 0.43	*Bouteloua curtipendula*	1.85 ± 0.63	*Taraxacum officinale*	3.24 ± 0.65	*Aster pilosus*	3.68 ± 0.67
Cyperus esculentus	1.42 ± 0.50	*Cirsium arvense*	1.77 ± 0.50	*Setaria* spp.	3.16 ± 1.84	*Phalaris arundinacea*	3.13 ± 0.71
Calystegia sepium	1.27 ± 0.36	*Trifolium repens*	1.68 ± 0.83	*Bromus inermis*	3.03 ± 0.74	*Heliopsis helianthoides*	3.07 ± 0.38
Chamaecrista fasciculata	1.27 ± 0.40	*Elymus canadensis*	1.52 ± 0.56	*Bouteloua curtipendula*	2.76 ± 0.63	*Cyperus esculentus*	2.66 ± 0.50
Potentilla norvegica	1.16 ± 0.28	*Solidago canadensis*	1.47 ± 1.34	*Monarda fistulosa*	2.74 ± 1.01	*Setaria* spp.	2.40 ± 1.84
Conyza canadensis	1.10 ± 0.28	*Bromus inermis*	1.36 ± 0.74	*Lotus corniculatus*	2.69 ± 0.70	*Schizachyrium scoparium*	2.18 ± 0.42
Rudbeckia hirta	1.02 ± 0.37	*Calystegia sepium*	1.30 ± 0.36	*Trifolium repens*	2.16 ± 0.83	*Elymus canadensis*	2.18 ± 0.56
Solidago canadensis	0.97 ± 1.34	*Euthamia graminifolia*	0.98 ± 0.28	*Cyperus esculentus*	2.13 ± 0.50	*Calystegia sepium*	2.10 ± 0.36
Chenopodium album	0.91 ± 0.19	*Schizachyrium scoparium*	0.97 ± 0.42	*Schizachyrium scoparium*	1.97 ± 0.42	*Taraxacum officinale*	1.86 ± 0.65
Monarda fistulosa	0.89 ± 1.01	*Sorghastrum nutans*	0.88 ± 0.75	*Scirpus atrovirens*	1.69 ± 0.67	*Tradescantia ohiensis/ T. bracteata*	1.63 ± 0.23
Oxalis stricta	0.83 ± 0.13	*Solidago speciosa*	0.80 ± 0.08	*Rumex crispus*	1.51 ± 0.82	*Bouteloua curtipendula*	1.62 ± 0.63
Juncus spp.	0.81 ± 0.38	*Scirpus atrovirens*	0.78 ± 0.67	*Calystegia sepium*	1.39 ± 0.36	*Toxicodendron radicans*	1.39 ± 0.54
Ambrosia artemisiifolia	0.79 ± 0.38	*Polygonum pensylvanicum*	0.77 ± 0.43	*Heliopsis helianthoides*	1.22 ± 0.38	*Cirsium arvense*	1.30 ± 0.50
Pastinaca sativa	0.78 ± 0.30	*Andropogon gerardii*	0.77 ± 0.80	*Pastinaca sativa*	0.86 ± 0.30	*Carex vulpinoidea*	1.15 ± 0.41
Cirsium arvense	0.78 ± 0.50	*Potentilla norvegica*	0.76 ± 0.28	*Agrostis gigantea*	0.81 ± 0.31	*Pastinaca sativa*	0.92 ± 0.30
Elymus canadensis	0.72 ± 0.56	*Rudbeckia hirta*	0.76 ± 0.37	*Rudbeckia hirta*	0.81 ± 0.37	*Juncus* spp.	0.90 ± 0.38
Andropogon gerardii	0.64 ± 0.80	*Lotus corniculatus*	0.73 ± 0.70	*Phalaris arundinacea*	0.76 ± 0.71	*Carex frankii*	0.82 ± 0.42
Trifolium hybridum	0.45 ± 1.77	*Monarda fistulosa*	0.70± 1.01	*Potentilla norvegica*	0.73 ± 0.28	*Chamaecrista fasciculata*	0.72 ± 0.40
		Heliopsis helianthoides	0.57 ± 0.38	*Verbena urticifolia*	0.72 ± 0.23	*Aster lateriflorus*	0.62± 0.29
				Tradescantia ohiensis/ T. bracteata	0.69 ± 0.23	*Lotus corniculatus*	0.55 ± 0.70
				Juncus spp.	0.60 ± 0.38	*Scirpus atrovirens*	0.51 ± 0.67
						Trifolium repens	0.51 ± 0.83

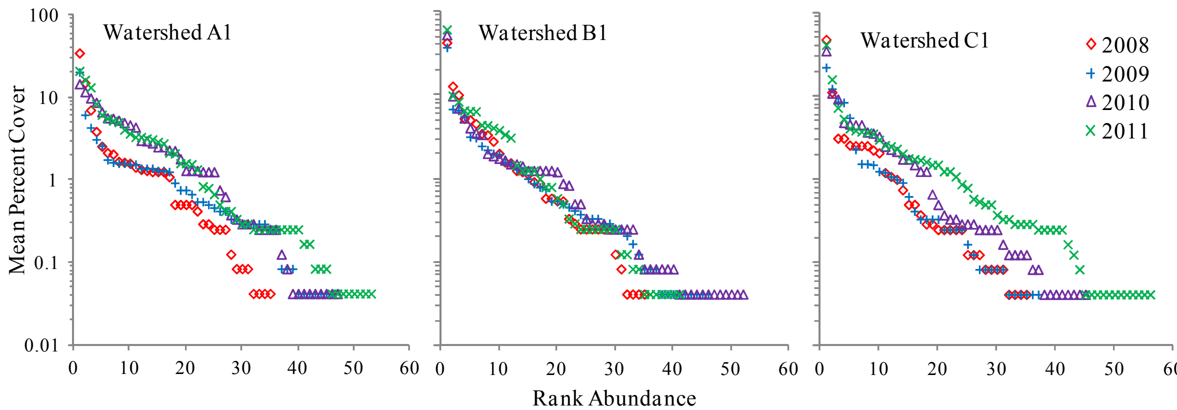

Fig. 5. Watershed A1, B1, and C1 buffers. Plot of log mean percent cover of species in 12 quadrats versus their rank abundance in 2008, 2009, 2010, and 2011.

The NMS species analysis had an optimal dimensionality of two with a final stress of 12.0. Monte Carlo test results of 250 randomized runs indicated that there was a 0.004 probability of obtaining a similar final stress by chance. There were 41 iterations for the final NMS solution. The proportion of variance represented by axis one and axis two were 0.716 and 0.152, respectively, based on the r^2 between distance in the ordination space (Euclidean distance measure) and distance in the original space (Sorensen/Bray-Curtis distance measure). The NMS joint plot depicted the watersheds positioned according to their buffer strip species composition and illustrated that species strongly related to watersheds in 2008 were different from species strongly related to watersheds in 2010 and 2011. For example, the annual grasses *Setaria* spp. and *Panicum capillare* had strong vectors pointed toward watersheds from 2008, while the perennial species *Poa compressa/ P. pratensis*, *Sorghastrum nutans*, and *Solidago canadensis* had strong vectors pointed toward watersheds from 2010 and 2011 (Fig. 6).

The convex hulls in the NMS joint plot of buffer species composition illustrated clear separation between watersheds in 2008, 2009, and 2010/2011; however, the convex hulls of 2010 and 2011 were partially overlapping (Fig. 6). Therefore, an NMS species analysis for just these two years was performed. For this analysis, optimal dimensionality was two with a final stress of 11.4. Monte Carlo test results of 250 randomized runs indicated that there was a 0.004 probability that a similar final stress could have been obtained by chance. There were 44 iterations for the final NMS solution. The proportion of variance represented by axis one was 0.599 and axis two was 0.295, based on the r^2 between distance in the ordination space

(Euclidean distance measure) and distance in the original space (Sorensen/Bray-Curtis distance measure). The joint plot of these two years illustrated that the convex hulls surrounding watersheds in 2010 and watersheds in 2011 were highly overlapping, and therefore buffer strips in 2010 and 2011 do not appear to have different species composition (Fig. 7).

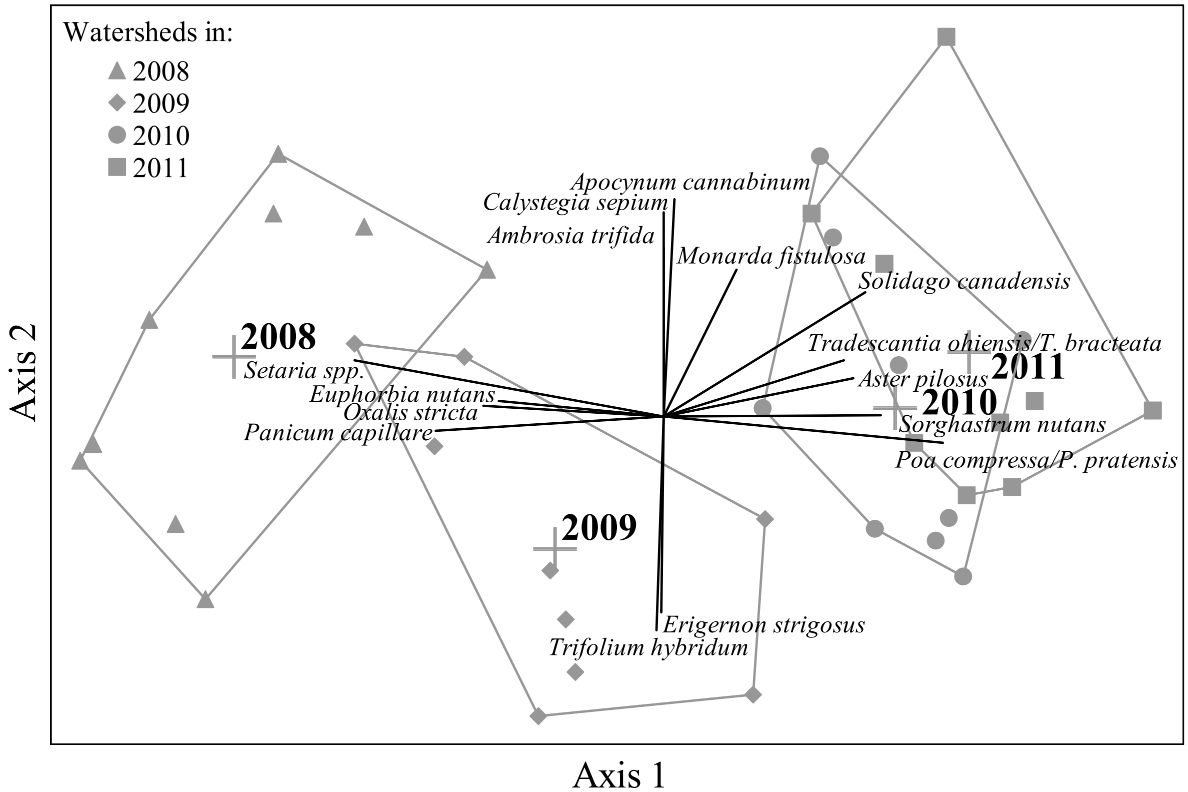

Fig. 6. Non-metric multidimensional scaling (NMS) joint plot of the buffer strips in the nine watersheds in each year, positioned according to their species composition. The proportion of variance represented by axis one and axis two was 0.716 and 0.152, respectively, based on the r^2 between distance in the ordination space (Euclidean distance measure) and distance in the original space (Sorensen/Bray-Curtis distance measure). Distance between watersheds in the ordination space approximates the amount of dissimilarity between watersheds in terms of their buffer species composition. Watersheds of each year enclosed by convex hulls; dominant species depicted with vectors; r^2= 0.3 vector cut-off.

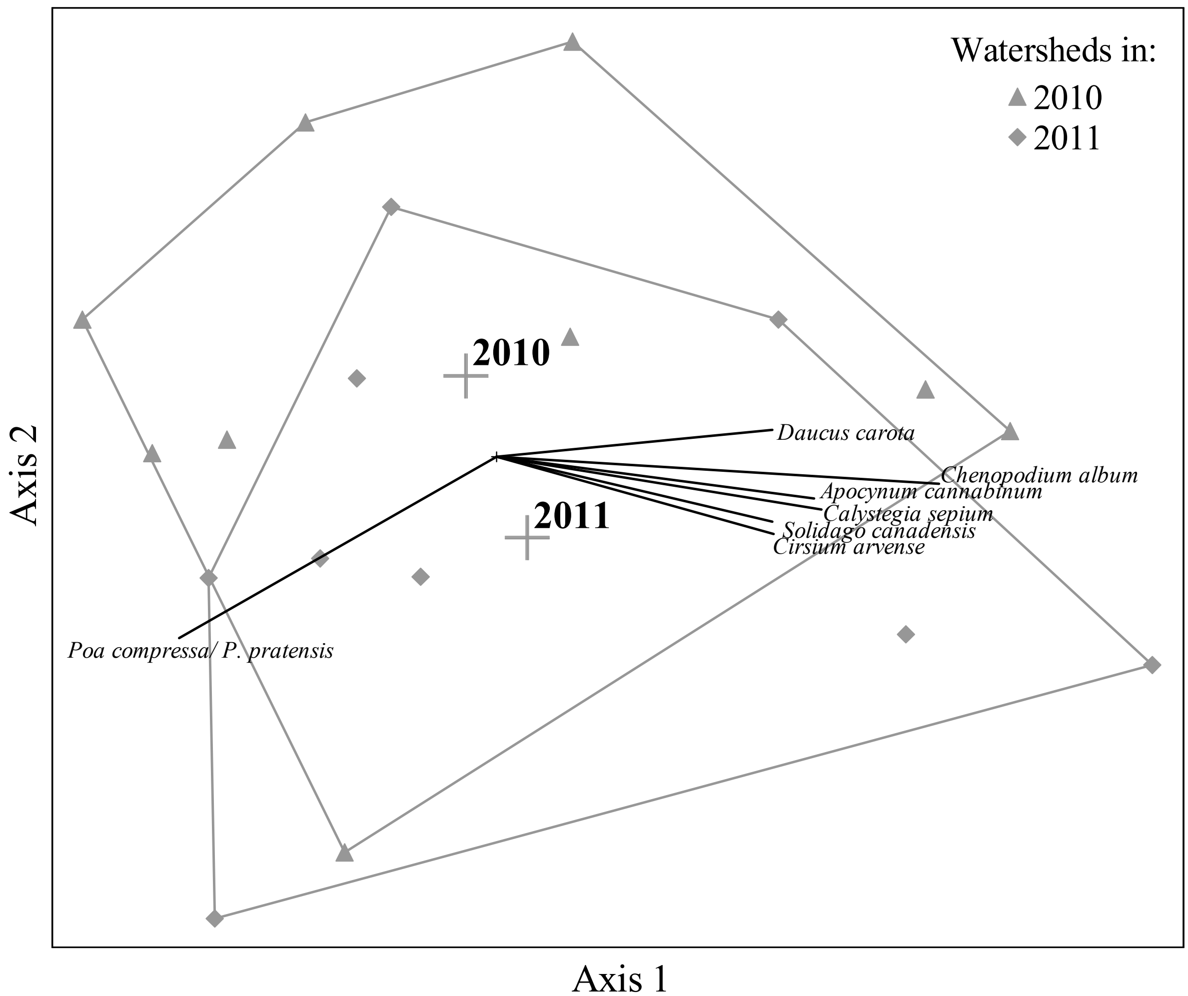

Fig. 7. Non-metric multidimensional scaling (NMS) joint plot of the buffer strips in the nine watersheds in 2010 and 2011, positioned according to their species composition. The proportion of variance represented by axis one and axis two was 0.599 and 0.295, respectively, based on the r^2 between distance in the ordination space (Euclidean distance measure) and distance in the original space (Sorensen/Bray-Curtis distance measure). Distance between watersheds in the ordination space approximates the amount of dissimilarity between watersheds in terms of their buffer species composition. Watersheds of 2010 and 2011 enclosed by convex hulls; dominant species depicted with vectors; r^2= 0.5 vector cut-off.

Analysis of variance of the coordinate values of the watersheds on the NMS ordination axes indicated that the species composition of the buffer strips did not differ among treatments 1, 2, and 3 (axis one, $P = 0.7474$; axis two, $P = 0.7706$), but the species composition did differ over time (axis one, $P < 0.0001$; axis two, $P = 0.0001$) (Table 3). Furthermore, the appearance of 2010 and 2011 having highly overlapping convex hulls in the NMS joint plot (Fig. 7), signifying similar buffer strip species communities, is quantitatively reinforced, as differences of LSMs (Tukey-Kramer adjusted) of the axes coordinate values between 2010 and 2011 were not significant.

The Adonis analysis in the VEGAN R package (Oksanen et al. 2011), which was used to analyze differences among years and/or treatments in the buffer strip species composition, found that there were differences among years ($p = 0.001$), but there were no differences among treatments ($p = 0.491$). There was also no interaction between years and treatments ($p = 0.659$).

The NMS life-history group analysis had an optimal dimensionality of two with a final stress of 11.1. Monte Carlo test results with 250 randomized runs indicated there was a 0.004 probability of obtaining a similar final stress by chance. There were 70 iterations for the final solution. The proportion of variance represented by axis one and axis two was 0.813 and 0.106, respectively, based on the r^2 between distance in the ordination space (Euclidean distance measure) and distance in the original space (Sorensen/Bray-Curtis distance measure). The NMS joint plot depicted the watersheds positioned according to their life-history group composition and illustrated that XAM and NAM species had a strong vectors pointed toward 2008, XPD species had a strong vector pointed toward 2009, and XPM, NPM, and NPD species had strong vectors pointed toward 2010 and 2011 (Fig. 8). Again, ANOVA of the NMS axis one and axis two coordinate values of the watersheds indicated that the life-history group composition of the buffer strips did not differ among treatments 1, 2, and 3 (axis one, $P = 0.9632$; axis two, $P = 0.5395$), but the life-history group composition did differ over time (axis one, $P < 0.0001$; axis two, $P = 0.0015$) (Table 3). Furthermore, overlay plots of the life-history groups of most interest, NPD and NPM, indicate much greater prevalence of NPD and NPM species in 2010 and 2011 than in 2008 and 2009 (Fig. 9).

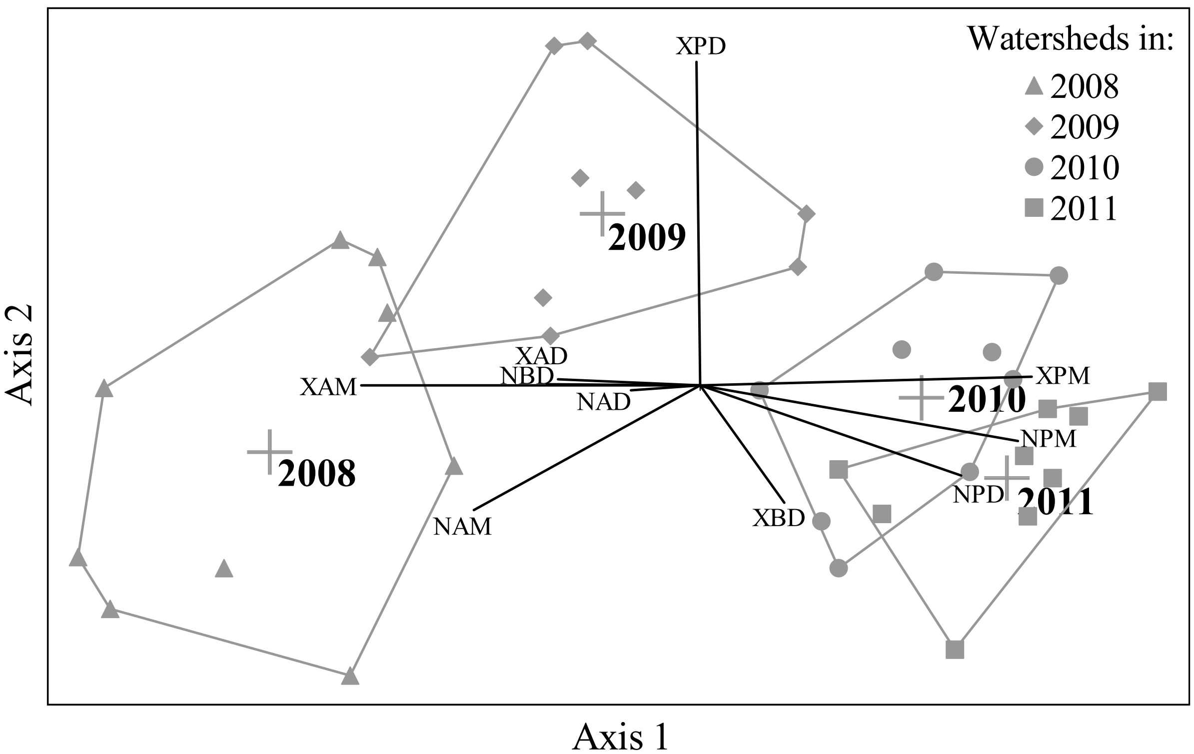

Fig. 8. Non-metric multidimensional scaling (NMS) joint plot of the buffer strips in the nine watersheds in each year, positioned according to their life-history group (LHG) composition. The proportion of variance represented by axis one and axis two was 0.813 and 0.106, respectively, based on the r^2 between distance in the ordination space (Euclidean distance measure) and original space (Sorensen/Bray-Curtis distance measure). Distance between watersheds in the ordination space approximates the amount of dissimilarity between watersheds in terms of their LHG composition. Watersheds of each year enclosed by convex hulls; all LHGs depicted with a vector; $r^2 = 0.1$ vector cut-off. NPM - native perennial monocot, NAM - native annual monocot, XPM - non-native perennial monocot, XAM - non-native annual monocot, NPD - native perennial dicot, NBD - native biennial dicot, NAD - native annual dicot, XPD - non-native perennial dicot, XBD - non-native biennial dicot, XAD - non-native annual dicot.

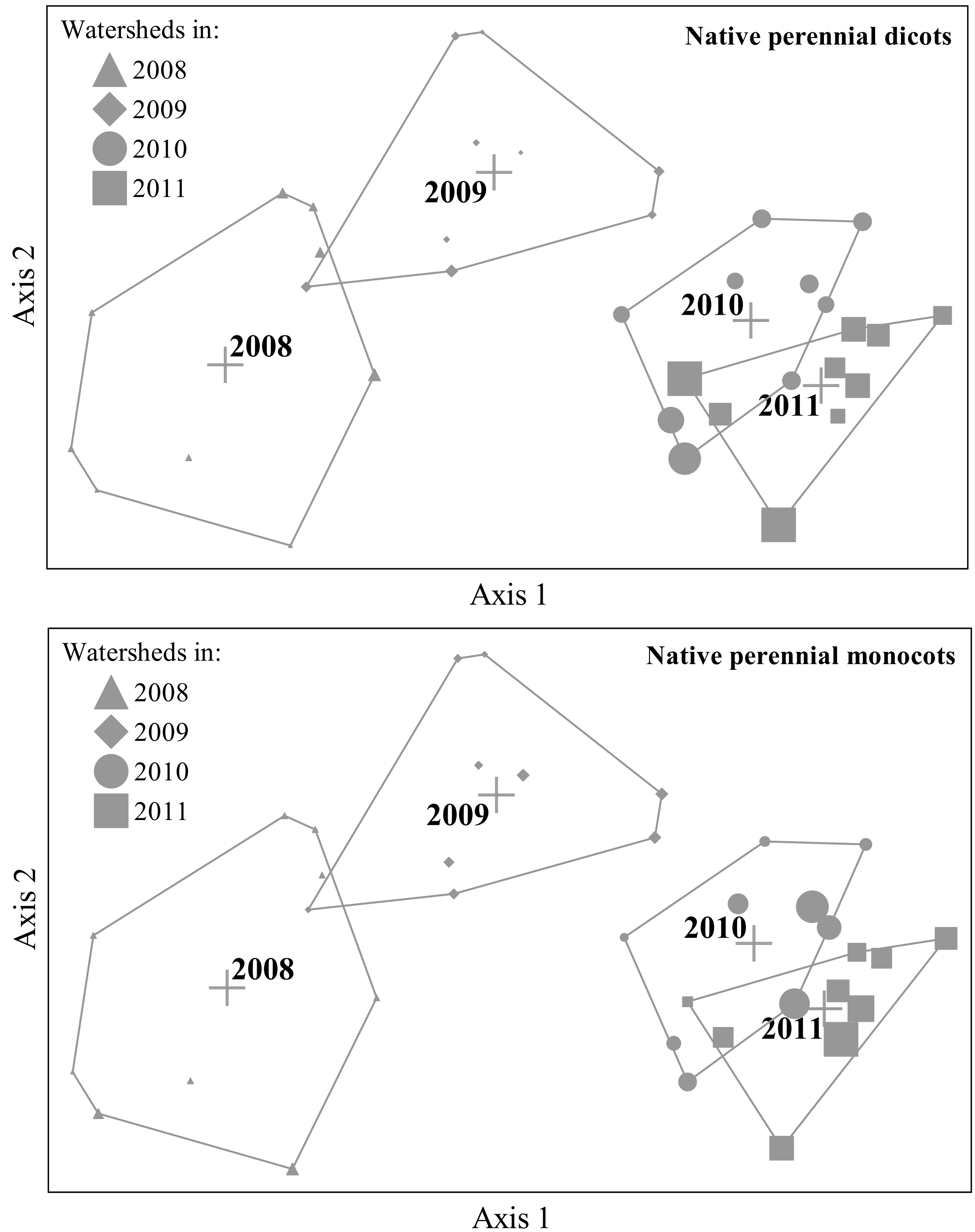

Fig. 9. Overlay plots indicating the abundance of native perennial dicot (NPD) species and native perennial monocot (NPM) species in the buffer strips of the watersheds in all years. The size of the shape represents the prevalence of NPD or NPM species (i.e., small shapes indicate less percent cover whereas large shapes represent more percent cover).

Weeds in crop

Crop vegetation surveys recorded a total of 40 species in 2009, 49 species in 2010, and 54 species in 2011 (in 72 m^2). On average, the crop of a watershed contained 8.4 species providing 2.4% cover in 2009, 15.4 species, providing 6.5% cover in 2010, and 15.1 species providing 7.7% cover in 2011 (in 6 m^2) (Table 5). There were no differences among treatments 1, 2, 3, and 4 for the mean number of weed species ($P = 0.3417$) or for the mean percent cover of weeds ($P = 0.5984$) in the crop, regardless of whether the watershed contained buffer strips or not. However, there were differences among years for the mean number of weed species ($P < 0.0001$) and mean percent cover of weeds ($P = 0.0075$) in the crop (Table 5). Weed species richness and percent cover significantly increased from 2009 (8.4 species; 2.4 percent cover) to 2010 (15.4 species; 6.5 percent cover), but did not significantly increase from 2010 to 2011 (15.1 species; 7.7 percent cover). Dominant weed species were similar among years (Table 6).

Table 5. Non-crop vegetation (weeds) in the crop watersheds from 2009-2011. Analysis of variance results (*F* statistics, *P* values) for the effect of year on the dependent variables of species richness, percent plant cover, and positions of the watersheds on axis one and axis two in the NMS ordination space for the weed species composition analysis. 2009-2011 least square mean (LSM) values indicate the mean value of 12 watersheds (12 0.5-m^2 quadrats sampled per watershed) with standard errors (SE). Numerator degrees of freedom = 2; denominator degrees of freedom = 16; different letters within rows indicate significant differences among years ($P < 0.05$, Tukey-Kramer adjusted).

	F	*P*	2009 LSM	2010 LSM	2011 LSM	SE
Species richness	24.0	<0.0001	8.4 a	15.4 b	15.1 b	0.9
Percent cover	6.7	0.0075	2.4 a	6.5 b	7.7 b	1.1
Species composition (axis 1)	15.87	0.0002	-0.07 a	-0.59 a	0.65 b	0.15
Species composition (axis 2)	60.90	<0.0001	-0.75 a	0.44 b	0.30 b	0.08

Table 6. Ten most prevalent weed species in the crop fields from 2009-2011. Indicating the life-history group (LHG) of the species, least square mean (LSM) percent cover, and standard errors (SE). NPM - native perennial monocot, NAM - native annual monocot, XPM - non-native perennial monocot, XAM - non-native annual monocot, NPD - native perennial dicot, NBD - native biennial dicot, NAD - native annual dicot, XPD - non-native perennial dicot, XBD - non-native biennial dicot, XAD - non-native annual dicot.

2009			**2010**			**2011**		
Latin binomial	LHG	LSM % cover (± SE)	Latin binomial	LHG	LSM % cover (± SE)	Latin binomial	LHG	LSM % cover (± SE)
Taraxacum officinale	XPD	1.23 ± 0.79	*Amaranthus rudis*	NAD	1.55 ± 0.29	*Taraxacum officinale*	XPD	4.03 ± 0.79
Potentilla norvegica	NPD	0.34 ± 0.09	*Panicum capillare*	NAM	0.98 ± 0.15	*Amaranthus rudis*	NAD	0.97 ± 0.29
Cyperus esculentus	NPM	0.19 ± 0.08	*Daucus carota*	XBD	0.67 ± 0.13	*Daucus carota*	XBD	0.55 ± 0.13
Zea mays	XAM	0.11 ± 0.02	*Setaria* spp.	XAM	0.61 ± 0.15	*Setaria* spp.	XAM	0.39 ± 0.15
Panicum capillare	NAM	0.07 ± 0.15	*Taraxacum officinale*	XPD	0.59 ± 0.79	*Panicum capillare*	NAM	0.25 ± 0.15
Daucus carota	XBD	0.06 ± 0.13	*Glycine max*	XAD	0.48 ± 0.09	*Potentilla norvegica*	NPD	0.21 ± 0.09
Abutilon theophrasti	XAD	0.06 ± 0.08	*Abutilon theophrasti*	XAD	0.31 ± 0.08	*Oenothera biennis*	NBD	0.18 ± 0.08
Amaranthus rudis	NAD	0.04 ± 0.29	*Medicago lupulina*	XPD	0.19 ± 0.04	*Aster pilosus*	NPD	0.11 ± 0.02
Sida spinosa	XPD	0.03 ± 0.06	*Rumex crispus*	XPD	0.11 ± 0.06	*Trifolium hybridum*	XPD	0.07 ± 0.02
Juncus spp.	NPM	0.03 ± 0.02	*Sida spinosa*	XPD	0.11 ± 0.06	*Chenopodium album*	XAD	0.06 ± 0.02

The NMS weed species analysis had an optimal dimensionality of two with a final stress of 13.6. Monte Carlo test results with 250 randomized runs indicated there was a 0.004 probability of obtaining a similar final stress by chance. There were 63 iterations for the final solution. The proportion of variance represented by axis one and axis two was 0.569 and 0.303, respectively, based on the r^2 between distance in the ordination space (Euclidean distance measure) and distance in the original space (Sorensen/Bray-Curtis distance measure). The NMS joint plot depicted the watersheds positioned according to their weed species composition in the crop and illustrated that watersheds had a different composition of weeds in different years (Fig. 10). Analysis of variance of the axis one and axis two coordinate values of the watersheds indicated that the weed species composition of the crop did not differ among treatments, regardless of whether the watershed contained buffer strips or not (axis one, $P = 0.0810$; axis two, $P = 0.8125$), but the weed species composition did differ over time (axis one, $P = 0.0002$; axis two, $P < 0.0001$) (Table 5).

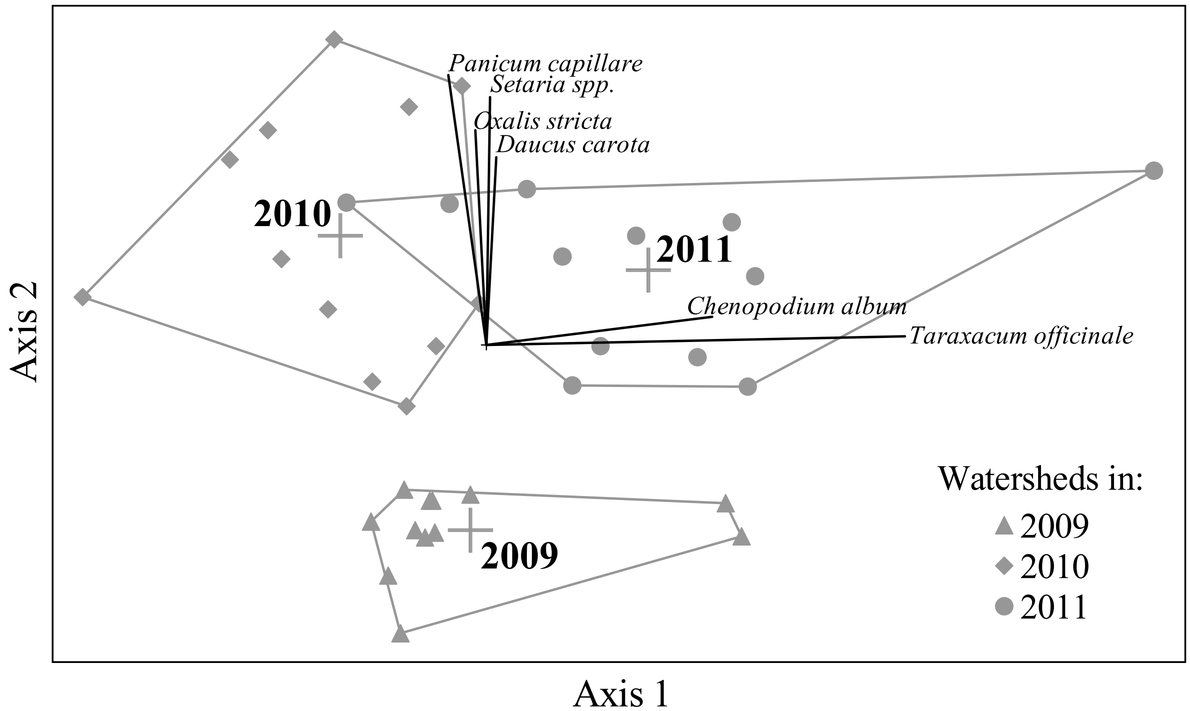

Fig. 10. Non-metric multidimensional scaling (NMS) joint plot of the crop portions in the 12 watersheds in each year, positioned according to their weed species composition. The proportion of variance represented by axis one and axis two was 0.569 and 0.303, respectively, based on the r^2 between distance in the ordination space (Euclidean distance measure) and distance in the original space (Sorensen/Bray-Curtis distance measure). Distance between watersheds in the ordination space approximates the amount of dissimilarity between watersheds in terms of their weed species composition. Watersheds of each year enclosed by convex hulls; dominant species depicted with vectors; r^2= 0.35 vector cut-off.

The Adonis analysis in the VEGAN R package (Oksanen et al. 2011), which was used to analyze differences among years and/or treatments in the buffer strip species composition, found that there were differences among years (p = 0.001), but there were no differences among treatments (p = 0.498). There was also no interaction between years and treatments (p = 0.981).

CHAPTER 4. DISCUSSION

Sampling method

Sampling 12 quadrats within the buffer strip(s) of a watershed was adequate for the purposes of the present study. Species accumulation curves of both 12 and 24 quadrats did not approach an asymptote, indicating more species were present in the buffer strips than found in the area surveyed. However, rank abundance curves of 12 and 24 quadrats from the same buffer strip indicated that when the sample area was doubled, the dominant species (comprising > 3% cover on average) were relatively consistent, and sampling 24 quadrats served mainly to include more species with very low mean percent cover. Therefore, enough quadrats were surveyed in the buffer strips to assess accurately the dominant species and the proportions of species in various life-history groups. The addition of sparse species would not change overall vegetation patterns and therefore would not be expected to change the overall function of the buffer strips.

However, when considering the overall diversity in the buffer strips, the species richness recorded from 12 quadrats is likely an underestimate of the true number of species. Species accumulation and rank abundance curves indicated that there were more sparse species present in the buffer strips than indicated by 12 quadrats, and first-order Jackknife, second-order Jackknife, and Chao2 bias corrected species estimates reinforced this finding. While these species are not expected to change the overall function of the system, they do contribute to the diversity supported, thereby reinforcing the conclusion that by establishing buffer strips in the watershed, biodiversity was greatly increased.

Prairie buffer strips

Incorporating prairie buffer strips in monoculture crop watersheds greatly increased plant species diversity in the watersheds. From 2009-2011, on average 6 m^2 of crop had 13.3 species whereas 6 m^2 of prairie buffer had 50.6 species. Buffer strip design did not influence the species diversity or composition, nor did it influence the total vegetation percent cover or percent cover of particular life-history groups. Therefore, the present study offered no evidence that environmental heterogeneity or edge effects influenced species composition.

However, three replicates per treatment may be too few to find significant differences. Confidence intervals for the species richness LSM differences of the treatments were very wide and not centered on zero (treatment 1 versus treatment 2: -20.1 to 9.1; treatment 1 versus treatment 3: -19.2 to 10.0; treatment 2 versus treatment 3: -13.7 to 15.5), indicating more replicates per treatment may have led to significant effects (assuming that the level of variability across watersheds remained the same with more replicates).

During the first four years of establishment, the prairie buffer strips increased in overall, perennial, native, and native perennial species richness. The dominant species in the buffer strips shifted from annual, weedier species, such as *Setaria*, to perennial species. This may be attributable to perennial species becoming established and, with time, having competitive advantages over annual species. The development of the prairie buffer strip community was consistent with development of reconstructed prairies, sown grass/forb field margins, and fallow cropland (Schwartz & Whitson 1987; Hodgson 1989; Rothrock & Squiers 2003; Camill et al. 2004; Critchley et al. 2006; Musters et al. 2009). The plots of the log mean percent cover of species versus their rank abundance show some indication that the plant community was following a succession pattern, as the plots appear to be shifting from a more linear line to an S-shaped curve over time (Fig. 5). In other words, the plant community is shifting from having one or few dominant species with high percent cover to having a larger number of co-dominant species with high percent cover. The prairie community will likely continue to develop in subsequent years and to have more native and perennial prairie species (Schwartz & Whitson 1987; Rothrock & Squiers 2003; Camill et al. 2004). The lag time from planting prairie buffer strips to having the desired plant species in the buffer strips is noteworthy from a management standpoint, as establishing prairie buffer strips would not be practical if the land manager did not anticipate keeping the buffer strips for several years.

There was some concern that the buffer strips proximity to the crop would make them susceptible to disturbance (Marshall & Moonen 2002). However, the prairie buffer strips did not follow patterns found in some polluted communities. The shift from an S-shaped curve to a straight line, which was found in the Park-grass experiment plots that were over-fertilized (May 1981), was not evident in the prairie buffer strips, which may be an indication that the prairie buffer strips were not being degraded by their proximity to the surrounding conventionally managed crop.

Buffer strips can serve to both reduce soil and nutrient loss from watersheds and to conserve native plant species. The identity and life-history group of dominant species, occupying the majority of ground cover, were of interest when evaluating the soil and nutrient loss potential. The relative percent cover of native perennial species (likely the species most desirable to landowners for both functional and conservational interests) increased substantially from 2008 (22%) to 2010 (54%) and remained high in 2011 (60%). In the experimental watersheds, transforming 10-20% of the crop to prairie buffer strips served to reduce sediment and nutrient loss. Watersheds with buffer strips compared to 100% crop watersheds reduced sediment loss by 95% on average in both 2008 (a year with intense flooding) and in 2009 (Liebman et al. 2011). In addition, N and phosphorus (P) losses in surface run-off were greatly reduced (Liebman et al. 2011).

Furthermore, the prairie buffer strips greatly increased the number and percent cover of native Iowa species in the watersheds. During 2009-2011, 6 m^2 of crop had on average 5.9 native species[4], whereas 6 m^2 of prairie buffer had on average 34.8 native species[5]. See appendix B for information on the conservativeness of native species in the buffer strips.

Moreover, many plants in the prairie buffer strips were aesthetically pleasing. Marshall and Moonen (2002) found that flower strips around crop fields improved the aesthetic value of the land. The prairie buffer strips added to the landscape many colorful prairie species, which people often enjoy viewing (i.e., *Asclepias tuberosa*, *Echinacea pallida*, *Eryngium yuccifolium*, and *Silphium integrifolium*) (Fig. 11). Shimek (1911, p. 169) summarized the aesthetic attributes of the Iowa prairie through the seasons:

> …by day the sun-lit sea of snow sparkled with countless ice-crystals which covered its surface, or formed filmy festoons on every projecting culm and blade…and the hills and higher prairies were dotted with the early pasque-flower, the prairie violet and a variety of rapidly succeeding spring flowers… Soon the grasses covered the surface with a great carpet of green painted with puccoons, prairie phlox and other flowers of late spring. But the real rich beauty of the prairie was developed only after mid-summer when myriads of flowers of most varied hues were everywhere massed

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[4] This value is the average based on the crop areas of 36 watersheds sampled (12 watersheds each year).
[5] This value is the average based on the buffer strip(s) of 27 watersheds sampled (nine watersheds each year).

into one great painting… In the fall this in turn was followed by the rusty-red or brown expanse of drying grasses…

Fig. 11. Aesthetically pleasing prairie plants found within prairie buffer strips. Left to right: *Asclepias tuberosa, Echinacea pallida*, *Eryngium yuccifolium*, and *Silphium integrifolium*

Landscape and management effects

Many more species were found in the buffer strips than were planted. While the seed mix contained only 32 species, 82 species were recorded in 2008, and by 2010, 122 species were recorded during the vegetation surveys. Out of the 19 prairie species in the seed mix, all seven grasses and nine of the 12 forbs were identified during the vegetation surveys. In addition, 11 of the 13 weed species present in the seed mix were identified during the vegetation surveys. Thus, over 130 additional species not in the seed mix were identified during sampling. In 2011, 19 native species recorded during the vegetation surveys were present in the seed mix, whereas an additional 63 native species recorded were not present in the seed mix.

The buffer strip vegetation may have differed from the seed mix due to the land-use history and the soil seed bank, as well as the watershed locations and the surrounding landscape. Unsown species may have originated from viable propagules in the soil at the site. Seeds are able to persist in the soil for varying amounts of time; however, generally, the re-establishment of plant species from the soil seed bank is poor if communities have been degraded for a few decades (van Diggelen & Marrs 2003).

Furthermore, unsown species that were locally present may have drifted into the buffer strips. Rabinowitz and Rapp (1980) found in a tallgrass prairie in Missouri, the species composition of the flowering plant community was much more similar to the seed rain than to the soil seed pool. Prairie buffer strips that are closer to other prairie vegetation will have more opportunity for species colonization (Saunders et al. 1991). Since watersheds in the present study are surrounded by prairie in the Neal Smith National Wildlife Refuge, there are ample opportunities for seeds to move into the study sites. Generally, seed dispersal distance is negatively correlated with seed size and positively correlated with fecundity (Clark et al. 2002). Moreover, the ability for species to colonize depends on their dispersal mode or vector and how readily they are transported. Additional species could have moved into the buffer strips through water runoff, wind (e.g., *Taraxacum*), and through animals dispersing seeds by caching, ingesting fruits and later passing or regurgitating intact seeds, and transporting seeds in their fur or feathers (Saunders et al. 1991; Bakker et al. 1996; Clark et al. 2002; van Diggelen & Mars 2003). While species composition is influenced by large-scale processes (i.e., dispersal), species must also be suited to the biotic and abiotic entities in the area to survive (Zobel 1997). For example, even if a wetland species drifted into a site, it would not establish if the soil was too dry.

There were over 130 species identified during sampling that were not planted. In 2011, unplanted species present in the buffer strips had seed that could have been wind dispersed, animal internally dispersed (e.g., through birds eating fruits), animal externally dispersed (i.e., through barbs sticking to animal fur), dispersed through rhizomes, or passively dispersed (Table 7). While many species were present in the buffer strips that were not in the seed mix, most of the dominant species were present in the seed mix. Six of the eight most dominant native species in 2011 were sown, with the two exceptions being *Solidago canadensis* and *Phalaris arundinacea* (Table 7). Therefore, even when surrounded by prairie, sowing buffer strips is likely necessary.

Table 7. Species present in 2011, their life-history group (LHG), percent cover, Iowa coefficient of conservatism (IA CC), and their dispersal mechanism. Iowa coefficients of conservatism are values from 0-10 assigned to native plant species according to whether the species is a generalist species, which may come from a range of sites including degraded sites (0) versus a conservative species, which come from an intact natural community (10). Non-native species are indicated by an asterisk. NPM - native perennial monocot, NAM - native annual monocot, XPM - non-native perennial monocot, XAM - non-native annual monocot, NPD - native perennial dicot, NBD - native biennial dicot, NAD - native annual dicot, XPD - non-native perennial dicot, XBD - non-native biennial dicot, XAD - non-native annual dicot.

Latin binomial	LHG	Percent cover	IA CC	Dispersal mechanism
Poa compressa/ P. pratensis	XPM	25.65	*	Rhizome[1]
Solidago canadensis	NPD	11.49	0	Wind dispersed seed[1]
Ratibida pinnata	NPD	6.63	4	Seed mix
Daucus carota	XBD	6.33	*	Seed mix
Sorghastrum nutans	NPM	5.57	4	Seed mix
Monarda fistulosa	NPD	4.33	2	Seed mix
Andropogon gerardii	NPM	4.30	4	Seed mix
Bromus inermis	XPM	3.89	*	Passive and rhizome[2]
Aster pilosus	NPD	3.59	0	Seed mix; Wind dispersed seed[2]
Phalaris arundinacea	NPM	3.09	**	Passive seed dispersal; Rhizome[2]
Heliopsis helianthoides	NPD	3.07	4	Seed mix
Cyperus esculentus	NPM	2.71	0	Passive seed dispersal[2]
Setaria spp.	XAM	2.19	*	Seed mix
Schizachyrium scoparium	NPM	2.16	5	Seed mix
Elymus canadensis	NPM	2.11	5	Seed mix
Calystegia sepium	NPD	1.98	0	Passive seed dispersal[3]
Taraxacum officinale	XPD	1.79	*	Wind dispersed seed[2]
Tradescantia ohiensis/ T. bracteata	NPM	1.62	4	Passive seed dispersal[2]
Bouteloua curtipendula	NPM	1.51	6	Seed mix
Toxicodendron radicans	NPD	1.38	0	Bird dispersed fruit[2]
Carex vulpinoidea	NPM	1.20	3	Passive seed dispersal[2]
Cirsium arvense	XPD	1.19	*	Wind dispersed seed[2]
Juncus spp.	NPM	0.95	-	Passive seed dispersal[2]
Pastinaca sativa	XPD	0.86	*	Passive seed dispersal[2]
Carex frankii	NPM	0.79	8	Passive seed dispersal[2]
Chamaecrista fasciculata	NAD	0.75	1	Seed mix
Trifolium repens	XPD	0.69	*	Seed mix
Scirpus atrovirens	NPM	0.66	1	Passive seed dispersal[2]
aster lateriflorus	NPD	0.65	4	Seed mix; Wind dispersed seed[2]
Lotus corniculatus	XPD	0.63	*	Passive seed dispersal[2]
Rumex crispus	XPD	0.63	*	Seed mix
Trifolium hybridum	XPD	0.61	*	Passive seed dispersal[2]
Apocynum cannabinum	NPD	0.59	1	Wind dispersed seed[2]
Muhlenbergia spp.	NPM	0.59	-	Seed mix
Asclepias syriaca	NPD	0.55	0	Seed mix
Ambrosia trifida	NAD	0.55	0	Seed mix
Trifolium pratense	XPD	0.48	*	Passive seed dispersal[2]
Erigeron annuus	NAD	0.38	0	Wind dispersed seed[2]
Verbena urticifolia	NPD	0.36	2	Passive seed dispersal[2]
Vernonia baldwinii/ V. fasciculata	NPD	0.35	-	Wind dispersed seed[2]

Table 7. (continued)

Latin binomial	LHG	Percent cover	IA CC	Dispersal mechanism
Cirsium discolor	NPD	0.34	1	Wind dispersed seed[2]
Teucrium canadense	NPD	0.33	4	Passive seed dispersal[2]
Medicago sativa	XPD	0.28	*	Passive seed dispersal[2]
Lespedeza capitata	NPD	0.25	3	Seed mix
Morus spp.	PD	0.23	-	Bird dispersed fruit[2]
Silphium perfoliatum	NPD	0.23	1	Passive seed dispersal[2]
Melilotus spp.	XPD	0.21	*	Passive seed dispersal[3]
Aster novae-angliae	NPD	0.20	3	Seed mix; Wind dispersed seed[2]
Festuca arundinacea	XPM	0.19	*	Passive seed dispersal[2]
Sporobolus heterolepis	NPM	0.19	9	Seed mix
Potentilla norvegica	NPD	0.18	2	Passive seed dispersal[2]
Rudbeckia hirta	NPD	0.17	2	Passive seed dispersal[2]
Oxalis stricta	NPD	0.17	0	Passive seed dispersal[2]
Solanum americanum	NPD	0.16	0	Animals consume?[2]
Polygonum pensylvanicum	NAD	0.15	0	Seed mix
Penstemon digitalis	NPD	0.14	4	Passive seed dispersal[2]
Vitis riparia	NPD	0.14	1	Bird dispersed fruit[2]
Erechtites hieracifolia	NAD	0.14	0	Wind dispersed seed[2]
Aster lanceolatus	NPD	0.14	4	Seed mix; Wind dispersed seed[2]
Physalis heterophylla	NPD	0.14	2	Animals consume?[2]
Salix spp.	NPD	0.14	-	Wind dispersed seed[2]
Abutilon theophrasti	XAD	0.13	*	Passive seed dispersal[2]
Cornus spp.	NPD	0.12	-	Bird dispersed fruit[2]
Geum canadense	NPD	0.12	2	Animal attach external[2]
Brickellia eupatorioides	NPD	0.12	5	Seed mix
Acalypha virginica/ A. rhomboidea	NAD	0.11	-	Passive seed dispersal[2]
Chenopodium album	XAD	0.11	*	Seed mix
epilobium coloratum	NPD	0.11	3	Wind dispersed seed[2]
Tridens flavus	NPM	0.08	0	Passive seed dispersal[2]
Plantago rugelii	NPD	0.07	0	Passive seed dispersal[2]
Conyza canadensis	NBD	0.07	0	Wind dispersed seed[2]
Agrostis gigantea	XPM	0.07	*	Passive seed dispersal[2]
Solanum carolinense	NPD	0.06	0	Animals consume?[2]
Gleditsia triacanthos	NPD	0.06	0	Passive seed dispersal[2]
Potentilla arguta	NPD	0.06	8	Passive seed dispersal[2]
Rumex altissimus	NPD	0.06	0	Passive seed dispersal[2]
Acer spp.	NPD	0.05	-	Wind dispersed seed[2]
Ambrosia artemisiifolia	NAD	0.05	0	Seed mix
Barbarea vulgaris	XBD	0.05	*	Passive seed dispersal[2]
Physalis virginiana	NPD	0.04	4	Animals consume?[2]
Medicago lupulina	XPD	0.04	*	Passive seed dispersal[2]
Pediomelum argophyllum	NPD	0.04	5	Passive seed dispersal[2]
Ulmus rubra	NPD	0.04	2	Wind dispersed seed[2]
Verbena hastata	NPD	0.04	3	Passive seed dispersal[2]
Aster ontarionis	NPD	0.03	3	Seed mix; Wind dispersed seed[2]
Sida spinosa	XPD	0.03	*	Animal attach external[3]

Table 7. (continued)

Latin binomial	LHG	Percent cover	IA CC	Dispersal mechanism
Oenothera biennis	NBD	0.03	0	Passive seed dispersal[2]
Achillea millefolium	NPD	0.03	0	Passive seed dispersal[2]
Symphoricarpos orbiculatus	NPD	0.03	0	Bird dispersed fruit[2]
Convolvulus arvensis	XPD	0.03	*	Passive seed dispersal[3]
Agropyron repens	XPM	0.03	*	Passive seed dispersal[2]
Sanicula spp.	NB/PD	0.03	-	Animal attach external[2]
Lactuca serriola	XBD	0.02	*	Seed mix
Anemone canadensis	NPD	0.01	2	Seed mix
Erigeron strigosus	NPD	0.01	2	Wind dispersed seed[2]
Rubus spp.	NPD	0.01	-	Bird dispersed fruit[2]
Hibiscus trionum	XAD	0.01	*	Passive seed dispersal[4]
Poa annua	XAM	0.01	*	Passive seed dispersal[2]
Antennaria spp.	NPD	0.01	2	Wind dispersed seed[5]
Crataegus spp.	NPD	0.01	-	Bird dispersed fruit[2]
Eryngium yuccifolium	NPD	0.01	8	Wind dispersed seed[5]
Parthenocissus quinquefolia	NPD	0.01	2	Bird dispersed fruit[2]
Prunus serotina	NPD	0.01	3	Bird dispersed fruit[2]
Lepidium spp.	BD	0.01	-	Passive seed dispersal[2]
Lonicera spp.	PD	0.01	-	Bird dispersed fruit[2]
Amaranthus rudis	NAD	< 0.01	0	Passive seed dispersal[2]
Veronica peregrina	NAD	< 0.01	0	Passive seed dispersal[2]
Agrimonia gryposepala	NPD	< 0.01	3	Animal attach external[2]
Asclepias verticillata	NPD	< 0.01	0	Wind dispersed seed[2]
Euphorbia nutans	NPD	< 0.01	0	Passive seed dispersal[2]
Fraxinus pennsylvanica	NPD	< 0.01	3	Wind dispersed seed[2]
Ludwigia palustris	NPD	< 0.01	4	Passive seed dispersal[2]
Potentilla simplex	NPD	< 0.01	3	Passive seed dispersal[3]
Viola spp.	NPD	< 0.01	-	Many are ant dispersed
Dichanthelium oligosanthes	NPM	< 0.01	7	Passive seed dispersal[2]
Echinochloa crusgalli	XAM	< 0.01	*	Passive seed dispersal[2]
Agrostis stolonifera	XPM	< 0.01	*	Passive seed dispersal[2]
Dactylis glomerata	XPM	< 0.01	*	Passive seed dispersal[2]

[1]PLANTS database. Available at: http://plants.usda.gov/java/ (accessed 4 April 2012)
[2]Personal communication Dr. Catherine Mabry McMullen
[3]Seed ID workshop. Department of Horticulture and Crop Science, The Ohio State University. Available at: http://www.oardc.ohio-state.edu/seedid/ (accessed 4 April 2012)
[4]Tenaglia, D. Missouriplants.com. Available at: http://www.missouriplants.com/index.html (accessed 4 April 2012)
[5]Minnesota Wildflowers. Available at: http://www.minnesotawildflowers.info/ (accessed 4 April 2012)

Prairie buffer strip establishment technique and timing of sowing (July) may have influenced diversity and composition (Kleijn et al. 1998; De Cauwer et al. 2008). In addition, buffer strip management (i.e., mowing) or pressure from invasive species could have influenced vegetation. Mowing, burning, or grazing can reduce competition from invasive exotic species while encouraging native grasses and forbs (Paine & Ribic 2002; De Cauwer et al. 2008). Differences observed among years may have resulted partially from mowing timing; in 2008 and 2009, the buffer strips were mowed approximately one month prior to the vegetation surveys, whereas in 2010 and 2011 the buffer strips were not mowed in the summer prior to surveys. The mowing schedule was intended to enhance desirable species and suppress weeds in the buffer strips and was a realistic scenario for land managers. In addition, mowing increases the spatial homogeneity of the landscape, as all the vegetation is at the same height (van Diggelen & Marrs 2003). Finally, management of the surrounding cropland may have affected buffer strip vegetation. Schippers and Joenje (2002) found that field boundary diversity could be enhanced by preventing nutrient input from crop fields. In the present study, prairie vegetation in strips may have been affected by inadvertent nutrient or other chemical inputs from the crop fields.

Weeds in crop

There were no differences in the number or percent cover of weed species between watersheds that included prairie buffer strips and 100% crop watersheds. Some farmers show concern that unsprayed crop margins will encourage weeds in adjacent crops (van der Meulen et al. 1996). However, according to results of the present study, prairie buffer strips within crops do not cause a weed problem. This finding agrees with previous studies that indicated non-cropped areas surrounding crops do not generally cause weed problems (Marshall 1989; Marshall & Arnold 1995; Musters et al. 2009). The overall increase in crop weed species richness from 2009 to 2010 and from 2009 to 2011 was unexpected, but was likely due to variables such as the degree of crop canopy cover at the time of sampling, the timing of herbicide applications, and the weather.

To avoid potential problems of weeds entering the crop, buffer strips can be monitored and controlled for invasive exotic species. However, not all exotic species compete and threaten native species, and some may even fulfill important ecological roles; therefore control and extirpation efforts in buffer areas should be prioritized to remove invasive species that are particularly mobile and those that commonly out-compete native species (SERI 2004).

CHAPTER 5. CONCLUSION

The prairie buffer strips greatly increased the biodiversity within these small agricultural watersheds. Diverse native prairie vegetation developed in the buffer strips within four years of their establishment and did not cause a weed problem in adjacent crops. The design of the prairie buffers (number and position of buffer strips within the watershed and proportion of the watershed converted to buffer) did not affect plant diversity or species composition.

Future research could study how the diversity and composition of prairie buffer strips develop in the next years in order to investigate if the prairie buffer strips continue to shift toward native and perennial species, remain in the current stage of succession, or become more degraded, possibly due to accruing agricultural inputs. In addition, future research could study how environmental variables such as soil moisture affect buffer strip species composition. Examining how prairie buffer strips develop when situated in other geographic locations (with various land-use histories and surrounding landscapes) could answer questions regarding how the soil seed bank and seed movement influence the prairie buffer strips and could try to ascertain the relative importance of these two phenomena. In addition, the vegetation of seeded versus non-seeded buffer strips could be studied.

Incorporating prairie buffer strips allows landowners to reduce sediment and nutrient loss from the land and to increase biodiversity and encourage native prairie plant species. Buffer strips composed of prairie may be more desirable than buffer strips composed of cool-season grasses, which are commonly used in conservation practices in the central US. The diverse prairie vegetation has many advantages, such as including more sturdy grasses (e.g., the warm-season grasses *Sorghastrum nutans* and *Andropogon gerardii*), which stand erect against water flow and increase the sediment that settles (Liu et al. 2008), and including both cool-season and warm-season plants, which provide more vegetative cover on the land throughout the growing season. Monoculture crop production and prevailing farming practices have nearly eliminated native Iowa prairie and greatly reduced perennial plants on the landscape. These widespread vegetation changes that resulted in uniform, simple landscapes have multifaceted negative effects on the functioning of the ecosystem (e.g., ecohydrologic imbalances such as flooding and pest outbreaks). This study concludes, however, that strategically incorporating prairie back into the row crop landscape in the form of buffer strips that occupy only 10 to 20% of the cropland will conserve soil and nutrients in watersheds and at the same time successfully reintroduce perennial species and help conserve native prairie species.

APPENDIX A. MANAGEMENT ACTIVITIES

Table 8. Management activities for the cropland and buffer strips 2007-2011

Date	Management
2007	
17 May	Glyphosate herbicide sprayed on crop portions of watersheds (application rate 2.24 kg total product/ha)
19 May	Soybean planted (planting rate 407,724 seeds/ha)
20 Jun	Glyphosate herbicide sprayed on crop portions of watersheds (application rate 2.24 kg total product/ha)
6 Jul	Buffer strips planted with tallgrass prairie seed mix containing 32 species (Table 1)
9-10 Oct	Soybean harvested
2008	
24 Apr	Applied anhydrous ammonia (135 kg N/ha)
6 May	Corn planted (planting rate 72,649 seeds/ha)
6 May	Glyphosate herbicide sprayed on crop portions of watersheds (application rate 2.24 kg total product /ha)
13 May	Applied 0-0-60 granular potassium chloride (101 kg K_2O/ha)
13 May	Applied 11-52-0 monoammonium phosphate (112 kg P_2O_5/ha)
19-21 Jun	Buffer strips mowed without removal of cuttings
24 Jun	Glyphosate herbicide sprayed on crop portions of watersheds (application rate 2.24 kg total product/ha)
Late Aug	Buffer strips mowed without removal of cuttings
22, 44 Nov	Corn harvested
2009	
12 May	Soybean planted (planting rate 407,724 seeds/ha)
13 May	Glyphosate herbicide sprayed on crop portions of watersheds (application rate 2.24 kg total product/ha)
25 Jun	Buffer strips mowed without removal of cuttings
30 Jun	Glyphosate herbicide sprayed on crop portions of watersheds (application rate 2.24 kg total product/ha)
20 Oct	*Cirsium arvense* in buffer strips spot treated using all-terrain vehicle mounted sprayer and hand wand with aminopyralid herbicide (21.1% concentration; 0.49 kg/ha; carrier application rate of 187 l/ha)
20-21 Oct, 2 Nov	Soybean harvested
2010	
9 Apr	Applied 24-112-101 (N-P_2O_5-K_2O) fertilizer (numbers are kg/ha)
10 Apr	Applied anhydrous ammonia (184 kg N/ha)
15 Apr	Corn planted (planting rate 75,120 seeds/ha)
25 May	Glyphosate herbicide sprayed on crop portions of watersheds (application rate 2.24 kg total product/ha)
16 Jun	*Cirsium arvense* in buffer strips spot treated using backpack sprayer with glyphosate herbicide (41% concentration; 37.4 g/l)
13-14 Oct	Corn harvested
30-31 Oct	Buffer strips mowed and baled
2011	
2 May	*Cirsium arvense* in buffer strips spot treated using backpack sprayer with glyphosate herbicide (41% concentration; 37.4 g/l)
19 May	Glyphosate herbicide sprayed on crop portions of watersheds (application rate 2.24 kg total product/ha)
19 May, 7 Jun	Soybean planted (planting rate 407,724 seeds/ha)
11 Jun	*Cirsium arvense* in buffer strips spot treated using backpack sprayer with glyphosate herbicide (41% concentration; 37.4 g/l)
1 July	Glyphosate herbicide sprayed on crop portions of watersheds (application rate 2.24 kg total product/ha)
7-8 Oct	Soybean harvested
18-19 Nov	Buffer strips mowed and baled

APPENDIX B. IOWA COEFFICIENTS OF CONSERVATISM

How conservative are the native species present in the prairie buffer strips? Coefficients of conservatism are values from 0-10 assigned to plant species according to whether the species is a generalist species, which may come from a range of sites including degraded sites (0) versus a conservative species, which come from an intact natural community (10) (Swink & Wilhelm 1994). Coefficients of conservatism for Iowa were found at http://www.public.iastate.edu/~herbarium/coeffici.html (Anon 2004).

The native species found in the buffer strips four years after establishment (in 2011) were evaluated in terms of their Iowa coefficient of conservatism (Table 7). Out of the 74 native species found in the quadrats surveyed in the buffer strips, six were conservative (values of 6-10), whereas 43 were generalist (values of 0-2) (Fig. 12). There were too few conservative species to detect a correlation between the percent cover of species and their coefficient of conservatism. Since a very small percent of the total buffer strip area was surveyed (0.1-1.2%), conservative species could be present in the buffer strips that were not present within the quadrats sampled.

Furthermore, it does not seem as though sampling 24-quadrats versus 12-quadrats served to include a larger number of conservative species. In 2011, a total of 10 additional species were found in the 24-quadrat sampling of watersheds A1, B1, and C1 that were not found in the 12-quadrat sampling of these three watersheds. Five of these species were unambiguous and native, and these five had coefficients of conservatism between one and four, indicating they were not conservative species.

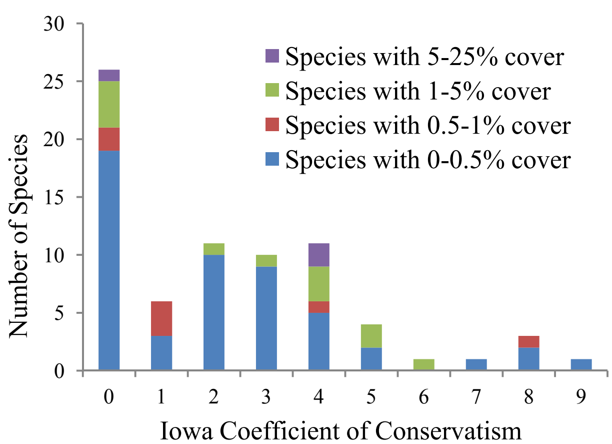

Fig. 12. 2011 species richness, separated by percent cover classes, for each Iowa coefficient of conservatism.

APPENDIX C. BETA DIVERSITY

A landscape that includes buffer strips can be thought of as hierarchically structured on four levels: quadrats within buffer strips, within fields, within locations. The diversity within each level is α-diversity, and the diversity within each level can be referred to as $\alpha_{Quadrat}$, α_{Strip}, α_{Field}, and $\alpha_{Location}$ diversity. The total diversity of the landscape is γ-diversity. The difference or turnover of species between quadrats, between buffer strips, between fields, and between locations is β-diversity, and the diversity between each level can be referred to as $\beta_{Quadrat}$, β_{Strip}, β_{Field}, and $\beta_{Location}$ diversity. β-diversity is important because it indicates an increase in diversity, the addition of different species on the landscape. If one of the goals of incorporating buffer strips on a crop landscape is increasing diversity on the landscape, determining the β-diversity between each level to understand how the hierarchical levels account for the increase/addition of diversity will be fundamental in designing the optimal buffer strip system. It is hypothesized that there will be β-diversity or species turnover at each level of the landscape, from quadrats to strips to fields to locations. However, it is important to ascertain the relative importance of each of these levels of β-diversity and to know which level of species turnover (β-diversity) is most important to reaching the overall γ-diversity. Are some levels of β-diversity larger than would be expected by chance? What is the relative importance of each level of diversity within the buffer strip landscape? In other words, would γ-diversity have been greatly reduced had the project covered one location, rather than four? Would γ-diversity have been greatly reduced had each location contained only one field? Would γ-diversity have been greatly reduced had each field contained only one buffer strip, rather than some fields containing two to three buffer strips spread up the watershed slope? Answering these questions can help to guide landowners implementing buffer strips to know how they can best position buffer strips on their land to include the most diversity.

The Partition program (Veech & Crist 2009b) was used to evaluate additive species diversity. Additive partitions of species richness divides the γ-diversity into the species richness found within a sample (α) and the species richness absent from the sample (β), in the same units (Crist et al. 2003). In a hierarchical sampling design, γ diversity equals α diversity plus β diversity of each level ($\gamma = \alpha_1 + \sum_{i=1}^{m} \beta i$, where α diversity at the lowest hierarchical level is represented by α_1, and each level of β diversity in the hierarchical design is represented by $i = 1,2,3 \ldots m$. The individual-based randomization technique was used, which randomly reassigns each percent cover of a species to any quadrat level sample (Veech & Crist 2009a). Individual-based randomization is appropriate to determine how observed diversity patterns may differ from expected diversity patterns because of intraspecific aggregation (Crist et al. 2003). For the Partition analysis, there were four locations, each location contained 1-5 fields, each field contained 1-3 strips, and each strip contained 4-12 quadrats. The *P* value is the proportion of randomized datasets that provided a diversity value higher than the observed value (Veech & Crist 2009a). In other words, a low *P* value indicates that the observed diversity is greater than would be expected by chance.

Additive and multiplicative γ species richness diversity in the buffer strip landscape was partitioned between the α and β components (Table 9). Analysis of additive species richness indicated that the between quadrat level and between strip level did not have more diversity than expected by chance, with $P > 0.9999$ and $P = 0.8157$, respectively. However, the between field and between location levels had significantly more diversity than expected by chance, with $P = 0.0124$ and $P < 0.0001$, respectively (Fig. 13). The low diversity values compared to what is expected by chance (i.e., high *P* values) at lower sampling levels and high diversity compared to what is expected by change (i.e., low *P* values) at higher sampling levels likely indicates that plants of a particular species were aggregated (Crist et al. 2003). The lower levels of quadrats and strips are closer together and likely will have resources suitable for particular species, whereas the higher levels of field and location are farther apart and likely will have resources suitable for a wider variety of species (Crist et al. 2003).

Table 9. Additive and multiplicative species richness α diversity for quadrats, strips, fields, and locations; β diversity for between quadrats, between strips, between fields, and between locations; and γ diversity.

	Additive Richness	Multiplicative Richness
α_{Quadrats}	17.39	17.39
β_{Quadrats}	23.49	2.35
α_{Strips}	40.88	40.88
β_{Strips}	13.79	1.34
α_{Fields}	54.67	54.67
β_{Fields}	13.08	1.24
$\alpha_{\text{Locations}}$	67.75	67.75
$\beta_{\text{Locations}}$	50.25	1.74
γ	118	118

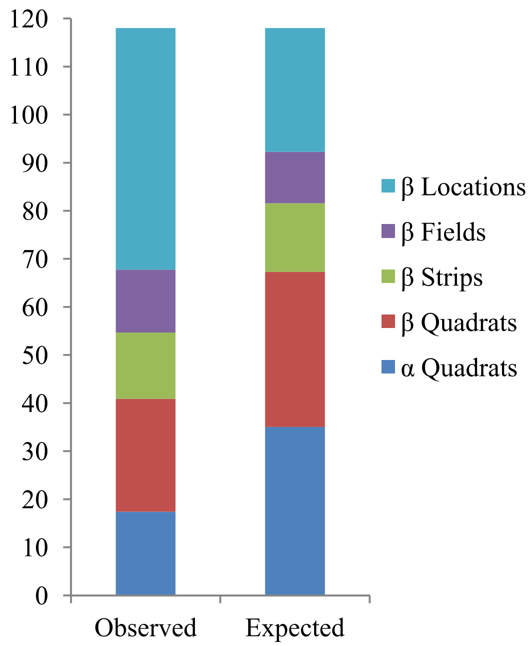

Fig. 13. Additive species richness γ diversity partitioned between α diversity for quadrats and β diversity between quadrats, between strips, between fields, and between locations, indicating the observed diversity values and the expected diversity values.

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