FINAL PERFORMANCE REPORT

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EVALUATING CONVERSION OF OLD WORLD BLUESTEM MONOCULTURES TO NATIVE PLANT COMMUNITIES

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Objective:

To evaluate techniques for converting OWB fields to native mixed-grass prairie plant communities and to compare bird and arthropod community assemblages in OWB fields compared with those in native mixed-grass prairie.

Summary of Progress:

The attached 2 Master's Theses serve as our final report.

Significant Deviations: None

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HERBICIDE CONTROL AND SEED BANK DYNAMICS OF OLD WORLD BLUESTEM

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HERBICIDE CONTROL AND SEED BANK DYNAMICS OF OLD WORLD BLUESTEM

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Combining glyphosate with burning or mowing improves control of the invasive grass Old World bluestem (*Bothriochloa ischaemum*)

ABSTRACT The invasive grass Old World bluestem (OWB; *Bothriochloa ischaemum*) threatens native plant and animal diversity, but traditional control methods of using only herbicides have had limited success. I used single, double, and triple applications of glyphosate in various combinations with and without a mowing or burning (prior to the herbicide applications) to determine the most effective treatment for controlling OWB for future restoration. Overall control of OWB was assessed by responses of OWB cover, frequency of live crowns, visual obstruction, and density of basal and reproductive tillers. One year after treatment, burning and mowing prior to a single herbicide application improved the amount of OWB control compared to a single herbicide treatment. Burning or mowing with two herbicide applications provided more OWB control relative to plots that received a double herbicide application without burning or mowing. The burn and mow double herbicide treatments did not exhibit an increase in reproductive tiller density or visual obstruction a year after treatment, whereas plots that received only two herbicide applications did. Burning or mowing with two herbicide treatments provided similar amounts of OWB control compared with the triple herbicide treatment. Combining burning or mowing with herbicide applications provided more effective OWB control than any herbicide applications that were not preceded by burning or mowing. Burning and mowing likely improves glyphosate effectiveness by altering OWB structure

so that plants are shorter with active regrowth, and clear of standing dead material, enhancing herbicide deposition and translocation, improving overall control.

Introduction

Non-native species have been transported by humans into new habitats for a variety of reasons such as landscaping ornamentals, erosion control, and livestock forage (Sax et al., 2005). Following introduction, many of these non-native species escape their original planting, invading and establishing in native ecosystems resulting in altered community structure and ecosystem function (Mooney & Hobbs, 2000; Gurevitch & Padilla, 2004), as well as increasing the risk to threatened and endangered species (Wilcove et al., 1998). Therefore, attention should be focused on invasive species eradication and restoration of invaded systems to restore ecosystem function, native biodiversity, and protect threatened and endangered species (Packard & Mutel, 2005).

In the central and southern Great Plains, Old World bluestems (OWB) [*Bothriochloa bladhii* (Retz.) S.T. Blake and *Bothriochloa ischaemum* (L.) Keng] are a group of non-native, perennial, warm-season grasses that were introduced from Europe and Asia (Harlan, 1952). Old World bluestems are usually planted in monocultures for cattle forage or hay production because they establish easily and tolerate both drought and heavy grazing (Harlan, 1952; Coyne & Bradford, 1986). Currently, OWBs have been introduced into 16 states, mostly in the southern United States (USDA, 2007), and have been widely utilized as perennial vegetation for soil stabilization in Conservation Reserve Program (CRP) plantings, roadside rights-of-way, and pasture grass for hay production. The actual amount of land area planted to OWB, not only in CRP seed mixes but also voluntary plantings by land managers remains unknown, but White and Dewald (1996) estimated that over one million ha were planted to OWBs from 1985 to 1995 in Texas and Oklahoma.

Despite the popular use of OWB by land managers, recent research suggests that OWB monocultures do not provide suitable habitat for most native wildlife species. In Kansas, monocultures of OWB had a lower bird species richness and abundance and lower arthropod availability than native mixed grass prairie (Hickman et al., 2007). Another study concluded that OWB monocultures supported lower abundance and diversity of rodents than native vegetation (Sammon & Wilkins, 2005). In northern Texas, swift foxes (*Vulpes velox)* avoided CRP fields planted to OWB (Kamler et al., 2003). OWB also negatively affects native vegetation by reducing native plant diversity as much as 30% after invasion (Gabbard & Fowler, 2006).

The widespread use of OWB and increased awareness that OWB have undesirable and unknown effects on native grassland biodiversity have private land managers and government agencies expressing interest in controlling OWB and restoring those sites to native vegetation. However, controlling OWB for future restoration has proven to be exceedingly difficult. Four studies have evaluated OWB control methods with variable degrees of success (Medlin et al., 1998; Harmoney et al., 2004; Harmoney et al., 2007; Simmons et al., 2007). Adequate control requires more than one herbicide application per year or a combination of herbicide and tillage (Medlin et al., 1998; Harmoney et al., 2004; Harmoney et al., 2007). Medlin et al. (1996) used glyphosate plus two tillage treatments and was able to control OWB by 85–99% one year after treatment. Tillage, however, is not always an appropriate control method, especially for prairie remnants or areas that have rocky ground and have high erosion potential, or contain rare species (Packard & Mutel, 2005). Glyphosate has been found to be the most effective herbicide for controlling OWB (Harmoney et al., 2004; Harmoney et al., 2007). Glyphosate applied once during the spring provided 43% control of OWB by the end of the first year following application (Harmoney et al. 2004). Applying glyphosate twice during a single growing season increased control to 90% after the first frost (Harmoney 2007). Simmons et al. (2007) tested the independent effects of mowing, burning, and glyphosate and found that mowing did not reduce the cover of OWB relative to non-treated areas, a year after treatment was applied. Burning and glyphosate did reduce OWB cover, but neither reduced cover by more than 50%, which was necessary for successful restoration of invaded areas (Packard & Mutel, 2005).

Combining mowing and burning with herbicide could improve OWB control because studies with other invasive and weedy species noted greater success of control when mechanical and chemical treatments were combined rather than applied individually (Bradley & Hagood, 2002; Renz & DiTomaso, 2004). Mechanical treatments, such as mowing, followed by herbicide application increased control of several perennial invasive plants, such as Canada thistle (*Cirsium arvense*), cordgrasses (*Spartina spp.*), tropical soda apple (*Solanum viarum*), and perennial pepperweed (*Lepidium latifolium*) (Hunter, 1996; Mislevy et al., 1999; Bradley & Hagood, 2002; Hedge et al., 2003; Renz & DiTomaso, 2004). Burning, in combination with herbicide applications, increased control of many invasive species such as tall fescue (*Festuca arundinacea*), Bermuda grass (*Cynodon dactylon*), dalmatian toadflax (*Linaria *genistifolia*), and giant mimosa (*Mimosa pigra*) (Masters et al., 2001; Lesica & Martin, 2003).

Effectiveness of foliar applied herbicides, such as glyphosate, requires a lethal dose of herbicide to be translocated from the actively growing leaves to the root system (Hunter, 1996). Previous research has shown that glyphosate translocation increases when herbicide is deposited on the lower leaves in the canopy (McWhorter & Hanks, 1993; Renz & DiTomaso, 2004). Renz and DiTomaso (2004) concluded that mowing changes plant canopy structure such that a greater leaf area exists in the bottom third of the canopy thus increasing glyphosate translocation and enhanced control. I hypothesized that burning or mowing followed by herbicide applications will alter plant canopy structure to allow for more effective glyphosate translocation and provide equal or greater control of OWB relative to single and multiple applications of herbicides alone (i.e. without mowing or burning. Therefore, mu objective was to determine how herbicide timing, number of applications, and the combination of mechanical and herbicide treatments affect OWB monocultures, in order to determine the most effective treatment combinations for controlling OWB for subsequent restoration.

Methods

Research was conducted at the Marvin Klemme Range Research Station (35° 22' N, 99° 04' W), in western Oklahoma, USA. The station was primarily composed of upland prairie with rolling hills and native vegetation dominated by mixed- and shortgrass prairie species. The area receives approximately 76 cm of precipitation per year, with an average summer high temperature of 34.2° C (Brock et al., 1995). The OWB control study was conducted in a 6.5-ha field previously cultivated for wheat

(*Triticum aestivum*) and converted to a monotypic stand of OWB in 1989 (Gunter et al., 1995). Currently, vegetative cover of the field is almost exclusively OWB with small patches of buffalograss (*Buchloe dactyloides*) and scattered forbs (personal observation).

In 2007, single, multiple, and combined treatments of glyphosate, burning, and mowing were applied throughout the growing season. The experimental design was an incomplete factorial randomized block design. Due to constraints of space, not all possible combinations factors were tested, but treatments were selected based on previous research (McWhorter & Hanks, 1993; Renz & DiTomaso, 2004 Harmoney et al., 2004; Harmoney et al., 2007 Simmons et al., 2007). Each treatment was replicalcated four times. Treatments were stratified in that all burned and mowed plots were grouped together within each replication, but randomized within each grouping to effectively apply each treatment. A total of 11 combinations of glyphosate, burning, and mowing were applied to plots of 10 x 10–m (table 1). In 2007, treatments with single, double, and triple applications of glyphosate were applied at three different timings: early (18 May), middle (2 August), and late (1 September) growing season. The single herbicide treatment was applied during the middle (2 August) timing. The two double application treatments were applied at the early and middle timings(double-herbicide-early-middle) or at the early and late timings (double-herbicide-early-late). The triple treatment had an herbicide application at each timing: early, middle, and late growing season (triple-herbicde). The burning for the burn-single-herbicide application treatments occurred early (18 May) and was followed by an herbicide application 4–5 weeks later, when OWB had regrown to the 4 to 5 leaf stage (Harmoney and Hickman 2004). The burn double herbicide treatments occurred at two different timing combinations: 1) an early

(18 May) burn followed by an herbicide application (28 June) with an additional herbicide application late (1 September) (burn-early-double-herbicide) and 2) an early (18 May) application and middle burn (25 July) followed by an herbicide application (30 August) (burn-middle-double-herbicide). The treatment timing of the combined mowing and herbicide treatments were the same timing as the combined burn and herbicide treatments except mowing was substituted for burning and designated as mow-early-double-herbicide and mow-middle-double-herbicide.

Glyphosate (Roundup WeatherMAX, Monsanto, St. Louis, MO) was applied at a rate of 2.125-kg ai/ha, (mixed with 0.232-g of ammonia sulfate) using a R&D EXD-203s bicycle sprayer with 11002 AirMix 110° fan nozzles, approximately 20–25 cm above the vegetation. The early herbicide treatment was applied when OWB had 4–5 fully formed leaves (Harmoney & Hickman, 2004). I conducted all burning in favorable weather conditions with relative humidity above 40%, winds below 30-km/hr, and temperature between 20–30 °C. Burning was applied with a combination of ring and strip head fire technique. Each mow treatment was applied with a tractor mounted mower.

The vegetation sampling method was a modification of those used by Harmoney et al. (2004). A 1 x 1–m quadrat divided into 100 subquadrats (10 x 10–cm each) and frequency determined by counting the number of subquadrats that contained living OWB crowns. Three frequency readings were recorded per plot during each sampling period. To determine basal tiller density all tillers were counted in five randomly selected 10 x 10–cm subquadrats for each plot. Tiller density was recorded three times in every plot. A 0.5 x 0.5–m frame was used to quantify reproductive tiller density, percent OWB cover and percent herbicide control of OWB, with three readings of each per plot. Percent

OWB cover was visually estimated and classified into one of eight foliar cover classes (0; < 1%; 1–5%; 6–25%; 26v50%; 51–75%; 76–95%; >96%). Midpoint values for each cover class were used in analysis (Daubenmire, 1959). Vegetation structural measurements were recorded using a digital visual obstruction technique developed by Limb et al. (2007). During 2007, vegetation sampling occurred at end of season (November). In February 2008, all plots were burned to remove standing dead litter. The vegetation sampling in 2008 occurred at the end of the growing season (October).

Data for end of season 2007 and 2008 were analyzed using an ANOVA procedure with an LSD post hoc at the $p < 0.05$ significance level, to test for differences among treatments for: frequency of live crowns, OWB cover, basal tillers, reproductive tillers, and vegetative structure (SAS 9.1 2003). Data was analyzed separately for end of year 2007 and end of year 2008. Relative importance value (RIV) was used to determine the overall control for each treatment, by combining all response variables into an index. The index value represents control levels of OWB, with lower values indication a greater amount of control. The relative importance value index was calculated for each plot using the formula derived from Mozdzer et al. (2008).

$$\mathrm{RIV} = \left[\left(\frac{f}{F}\times 100\right)+\left(\frac{c}{C}\times 100\right)+\left(\frac{b}{B}\times 100\right)+\left(\frac{r}{R}\times 100\right)\right]$$

Where f = mean frequency of live OWB crowns within each plot, F = maximum frequency of live OWB crowns per plot, c = mean percent cover of OWB within each plot, C = maximum percent cover of OWB within each plot, b = mean number of basal tillers within each plot, B = maximum number of basal tiller within each plot, r = mean number of reproductive tillers within each plot, and R = maximum number of reproductive tillers within each plot. A regression analysis was performed to test for relationships between end of second year RIV and OWB structure at the last herbicide application.

Results

End of first year (2007)

At the end of the first year (2007), all treatments significantly reduced OWB cover compared with the untreated control ($p \leq 0.05$) (Fig. 1). The triple-herbicide-application treatment, both double herbicide application treatments (double-herbicide-early-middle and double-herbicide-early-late), and all double herbicide applications with a mow or burn (mow-early-double-herbicide, mow-middle-double-herbicide burn-early-double-herbicide, and burn-middle-double-herbicide) had the lowest OWB cover. The mow-single-herbicide and burn-single-herbicide treatments significantly reduced OWB frequency and basal tiller density compared with the single-herbicide treatment (Fig. 2 and 3). All treatments with two herbicide applications regardless of mowing and burning, and the triple-herbicide treatment had similar low values for cover, frequency of crowns, and basal tillers, except for the double-early-middle-herbicide treatment which had slightly higher values for percent cover, frequency of crowns, and basal tillers. All treatments except the single-herbicide treatment significantly reduced the number of basal tillers relative to the control ($p \leq 0.05$) (Fig. 3). Three treatments had no reproductive tillers at the end of the first year: triple-herbicide, double-early-late-herbicide and burn-early-double-herbicide treatment (Fig. 4).

Visual obstruction was reduced relative to the control in all treatments except in the single-herbicide treatment and the double-early-late-herbicide treatment. The double-early-late-herbicide treatment had 57% greater visual obstruction relative to the other double and triple herbicide treatments ($p \leq 0.05$) (Fig. 5). Overall there were 6 treatments with less than 5% cover and 10 crowns/m^2 at the end of the first year (triple-herbicide, both mow double herbicide, both burn double herbicide, and the double-early-late-herbicide treatment).

End of second year (2008)

At the end of the second year (2008), only two treatments, the triple-herbicide and the burn-middle-double-herbicide treatments, maintained a similar amount OWB cover and frequency as the end of 2007 (Fig. 6 and 7). Both double herbicide application treatments had less OWB cover compared with the single-herbicide treatment. The triple-herbicide treatment resulted in an even greater reduction of OWB cover, by at least 40%, relative to both double herbicide application treatments. Both mow double herbicide and both burn double herbicide application treatments reduced OWB cover by 77–88% and 90–98%, respectively, which was a greater reduction compared to the 32–51% reduction for both double herbicide application treatments. Both mow double herbicide application and both burn double herbicide application treatments had similar OWB cover as the triple herbicide application treatment ($p \leq 0.05$). Compared to treatments with a single herbicide application, the burn-single-herbicide treatment had the lowest number of basal tillers and had similar basal tiller density as most of the other double herbicide application treatments (Fig. 8). Two treatments had less than 75 basal tillers/m^2: triple-herbicide-treatment, and burn-middle-double-herbicide treatment (Fig. 8).

The mow-single-herbicide, burn-single-herbicide and both double herbicide application treatments had significantly more reproductive tillers and greater visual obstruction relative to the control ($p \leq 0.05$) (Fig. 9 and 10). Those four treatments had 4–7 times more reproductive tillers and 2–3 times greater visual obstruction compared to the control. In contrast, both mow double herbicide application and both burn double herbicide application treatments had visual obstruction and reproductive tiller density that were not higher than the control.

The RIV showed positive relationship with visual obstruction after the last herbicide application, but only 15% of the RIV variation was explained by the visual obstruction ($p = 0.013$, $r^2 = 0.15$) (Fig. 11). Overall, both mow and both burn double herbicide application treatments consistently had lower OWB cover, reproductive tillers, and visual obstruction compared with both double herbicide application treatments.

Discussion

These results suggest that mowing or burning prior to an herbicide application increases the control of OWB. In both Harmoney et al. (2004) and my study, a single application of glyphosate did not reduce OWB frequency or basal tiller density. However, if a mechanical pretreatment (mowing or burning) was applied prior to glyphosate application, OWB frequency and tiller density were significantly lower after the first season. Simmons et al. (2007) tested the independent effects of mowing, burning, and glyphosate (one and two applications) on OWB cover and concluded that two mowing events had no effect on OWB cover, but a growing season burn reduced OWB cover by 30% one year after treatment. Simmons et al. (2007) also reported that two applications of glyphosate reduced OWB cover by 50%, which is similar to the 32% and 51% cover reductions for the double herbicide treatments in my study. Combining mechanical and chemical treatments resulted in a greater reduction in OWB cover: 77–88% and 90–98%

for the treatments that combined two herbicide applications plus a mow or burn prior one of herbicide application, respectively. Independently, mowing, burning, and two glyphosate applications were not effective at controlling OWB; however, all treatments that combined mowing or burning with double herbicide applications resulted in a greater level of control of OWB. Our results support the conclusion of other studies that suggest combining mechanical treatments with chemical treatments can improve control of perennial invasive and weedy species (Mislevy et al., 1999; Adams & Galatowitsch, 2006; Renz & DiTomaso, 2006).

One reason for the increased control could be that the combined treatments increased herbicide effectiveness and reduced OWB vigor. After the first season, all treatments with two or three herbicide applications reduced OWB cover, frequency, and basal tiller density, with similar effectiveness. By the end of the second season, all mow and burn double herbicide application and the triple-herbicide treatments maintained relatively low OWB cover, frequency, and basal tiller number compared to the other treatments. Both double herbicide application treatments had relatively low OWB frequency and basal tillers, but had relatively high cover. In addition to high OWB cover, the both double herbicide application treatments also had reproductive tiller density and visual obstruction greater than the untreated control. I propose that this phenomenon is most likely caused by intraspecific competitive release. OWB has high intraspecific competition and aggressively resprouts (Schmidt et al. 2008). The surviving OWB plants in the double herbicide application treatments were vigorous enough to take advantage of the low density of OWB plants and reduced intraspecific competition and thus were able to grow taller and produce more reproductive tillers compared with untreated control

(Aguiar et al., 2001) (fig 12). Even though the all mow and burn double herbicide application treatments applied the same quantity of herbicide as the double herbicide application treatments, the mow and burn double herbicide application treatments reduced OWB vigor and did not exhibit the competitive release exhibited as in the double herbicide application treatments.

The reduced vigor and greater overall reduction of OWB for the combined treatments might be attributable to an increase in herbicide effectiveness due to the prior mowing and burning, which lowered plant structure, removed standing dead, and produced young regrowth. There was a positive relationship between OWB structure at last herbicide application and OWB control at the end of second year (Fig.. 11). This suggests plots that were mowed or burned, had shorter OWB structure when sprayed leading to a greater amount of OWB control compared with plots that were not mowed or burned, which had taller OWB structure when sprayed. Renz and DiTomaso (2004) suggested that mechanically reducing plant structure prior to an herbicide application, increased the amount of herbicide deposited on the basal third of the plant, which improves control because basal leaves are more efficient at translocating herbicide to the roots than upper leaves (McWhorter & Hanks, 1993). Only 15% of the OWB control variation was explained by structure in my study, so other factors may also explain the increased OWB control for the combined mechanical and chemical treatments.

The combined treatments were sprayed 4 or 5 weeks after mowing or burning and the OWB regrowth was at an earlier growth stage than the OWB regrowth from the first application of the double herbicide treatments that were sprayed 11 and 19 weeks after first treatments. Glyphosate is more readily absorbed in plants at a younger phenological stage than plants at an older phenological stage (Camacho & Moshier, 1991). Mowing and burning also decreased the amount of standing dead (i.e. last years growth and previously controlled plants still standing), which can intercept the herbicide and reduce herbicide effectiveness by decreasing the contact with living leaves (Wolf et al., 2000; DiTomaso et al., 2006). Burning removed a greater amount of standing dead than mowing (personal observation). The burn herbicide treatments consistently provided slightly greater OWB control, possibly due to less herbicide interception by standing dead compared with the mow herbicide treatments that had greater amounts of standing dead. The greater overall control of OWB by the combined mechanical and chemical treatments is possibly due to the effects of prior mowing or burning that decreases the amount of standing dead, reduces plant structure, and promotes regrowth.

Management implications

A single herbicide application does not adequately control OWB, even with prior mowing or burning. Two herbicide applications do effectively control OWB for the first year, but the control does not persist in the following year because OWB cover, reproductive tillers, and vertical structure increase in the second year. The burn and mow double herbicide applications treatments improved overall OWB control after the second year with no significant increase of cover, frequency, basal tillers, reproductive tillers, and structure relative to the end of the first year. Triple-herbicide treatment also provided similar OWB control after the second year as the burn and mow double herbicide applications but used less herbicide, suggesting that a mow or burn combined with herbicide applications can reduce the amount of herbicide required without sacrificing the level of OWB control. The burn plus herbicide application treatments consistently provided more OWB control compared with the mow plus herbicide application treatments. The difference in the effectiveness of the treatments might be attributed to greater biomass and standing dead removed by burning. The most effective combined treatment was the burning in combination with two herbicide applications one early in the season, followed by a middle season burn and the second herbicide application 4 weeks later applied to young regrowth.

Conclusion

Combining mowing or burning with two applications of glyphosate, with one application 4 or 5 weeks after mowing or burning, is more effective at controlling OWB compared with only using glyphosate applications. Effects of two herbicide applications combined with a mow or burn does not exhibit increased cover, reproductive tiller density, or vertical structure in the following year as some of the herbicide only treatments exhibited. A prior mowing and burning treatment might have increased herbicide effectiveness by lowering plant structure, removing standing dead and producing regrowth, which allowed for more efficient herbicide absorption and translocation. This study supports the conclusion of other studies in that combining mechanical and chemical treatments improves the control of perennial invasive and weedy plant species (Bradley & Hagood, 2002; Lesica & Martin, 2003; Renz & DiTomaso, 2004).

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Table 1. Treatment table, list each treatment, timing of herbicide, mowing, and burning applications for each treatment, treatment abbreviations, and the description of each treatment.

treatment	herbicide timing	mechanical and herbicide timing	treatment abbreviations	description
single herbicide	Middle 2 Aug.		M	one herbicide application at the mid timing
burn single herbicide		Early 18 May	Burn+E	spring burn followed by herbicide application 4 weeks later
mow single herbicide		Early 18 May	Mow+E	spring mow followed by herbicide application 4 weeks later
double herbicide	Early, Late 18 May, 1 Sept.		E,L	two herbicide application at the early and late timing
	Early, Middle 18 May, 2 Aug.		E,M	two herbicide application at the early and mid timing
burn double herbicide	Late 1 Sept.	Early 18 May	Burn+E, L	spring burn followed by herbicide application 4 weeks later, with an additional herbicide application at the late timing
	Early 18 May	Middle 25 July	E,Burn+M	herbicide application early, and a mid burn with a herbicide application 4 weeks later
mow double herbicide	Late 1 Sept.	Early 18 May	Mow+E, L	spring mow followed by herbicide application 4 weeks later, with an additional herbicide application at the late timing
	Early 18 May	Middle 25 July	E,Mow+M	herbicide application early, and a mid mow with a herbicide application 4 weeks later
Triple herbicide	Early, Middle, Late 18 May, 2 Aug. 1 Sept		E,M,L	Herbicide application early, mid, and late
control			control	No herbicide applications

Fig. 1

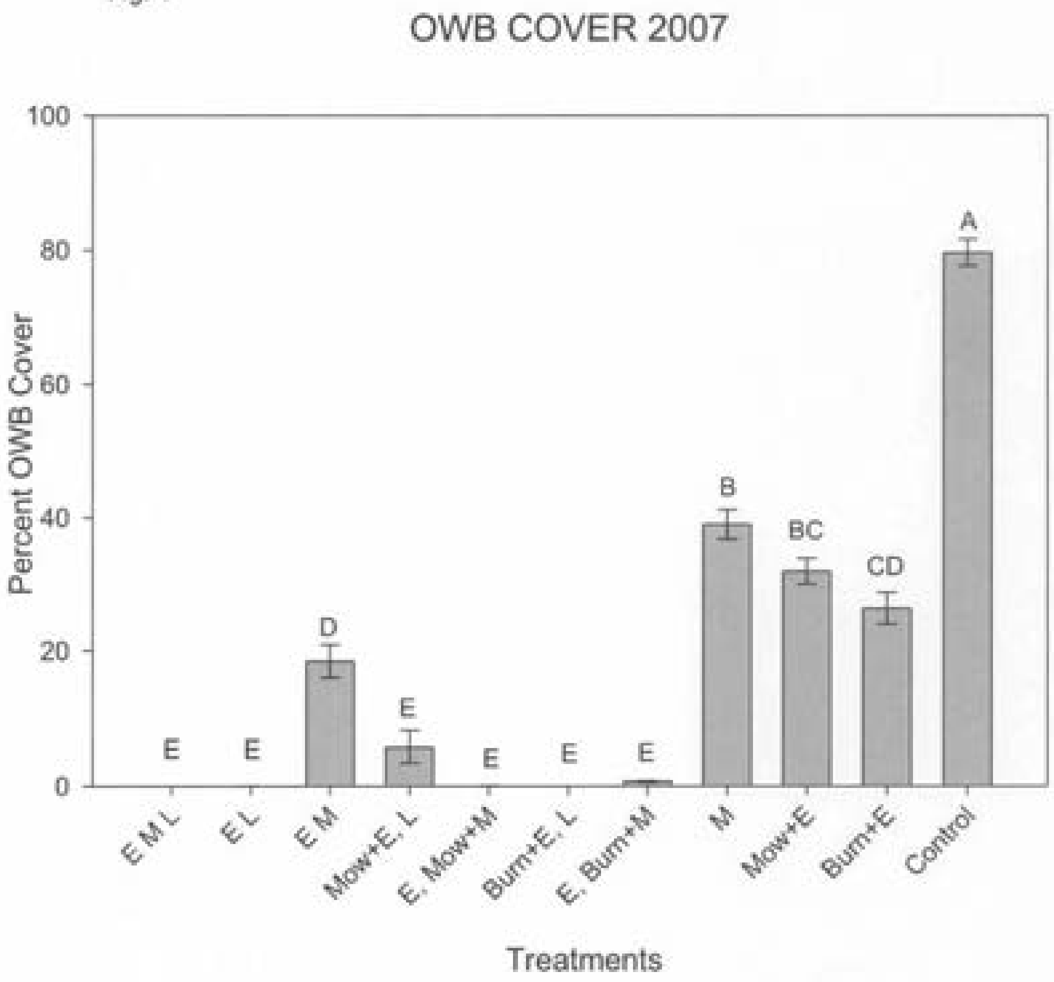


Fig. 1 Percent cover of OWB at end of season 2007. Different letters indicate significant difference ($p < 0.05$), E = early season herbicide application, M =middle season herbicide application, L = late season herbicide application, Mow+E = early season mow followed by a herbicide application, Mow+M = middle season mow followed by a herbicide application, Burn+E = early season burn followed by a herbicide application, Burn+M = middle season burn followed by a herbicide application

Fig. 2

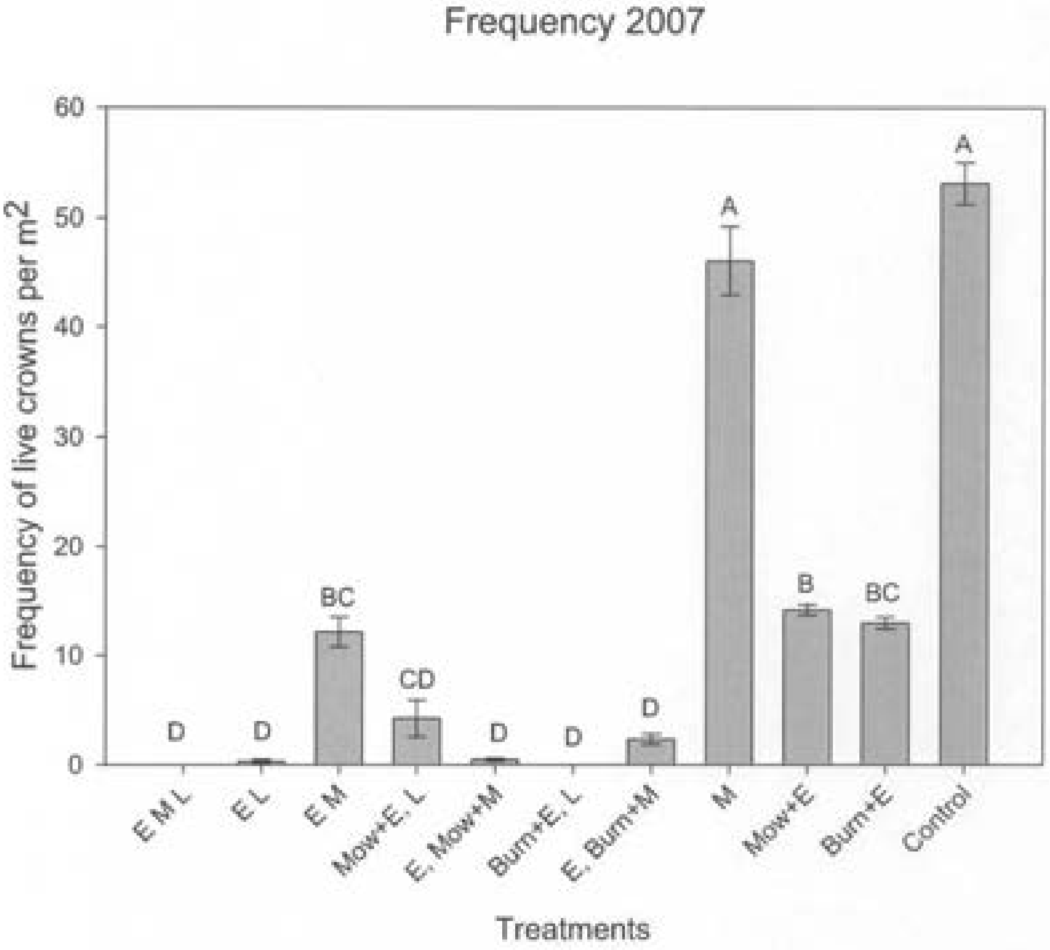


Fig 2. Frequency of live OWB crowns (per m^2) at end of season 2007. Different letters indicate significant difference ($p < 0.05$), E = early season herbicide application, M =middle season herbicide application, L = late season herbicide application, Mow+E = early season mow followed by a herbicide application, Mow+M = middle season mow followed by a herbicide application, Burn+E = early season burn followed by a herbicide application, Burn+M = middle season burn followed by a herbicide application

Fig. 3

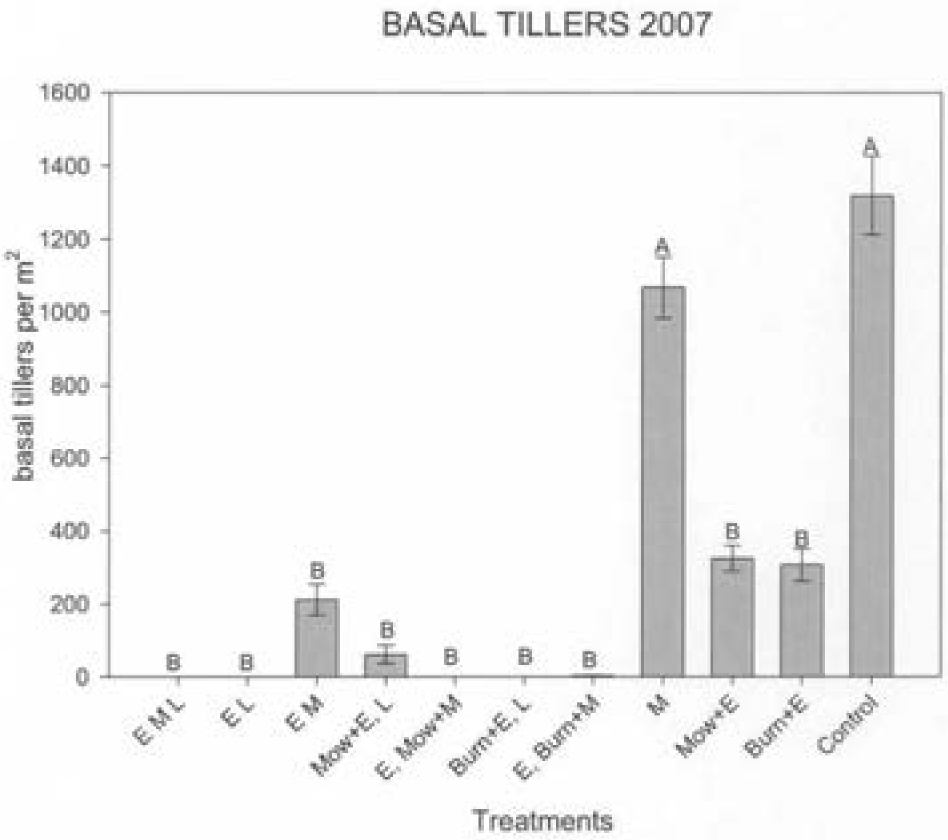


Fig 3. Basal tiller density (per m^2) of OWB at end of season 2007. Different letters indicate significant difference ($p < 0.05$), E = early season herbicide application, M =middle season herbicide application, L = late season herbicide application, Mow+E = early season mow followed by a herbicide application, Mow+M = middle season mow followed by a herbicide application, Burn+E = early season burn followed by a herbicide application, Burn+M = middle season burn followed by a herbicide application

Fig. 4

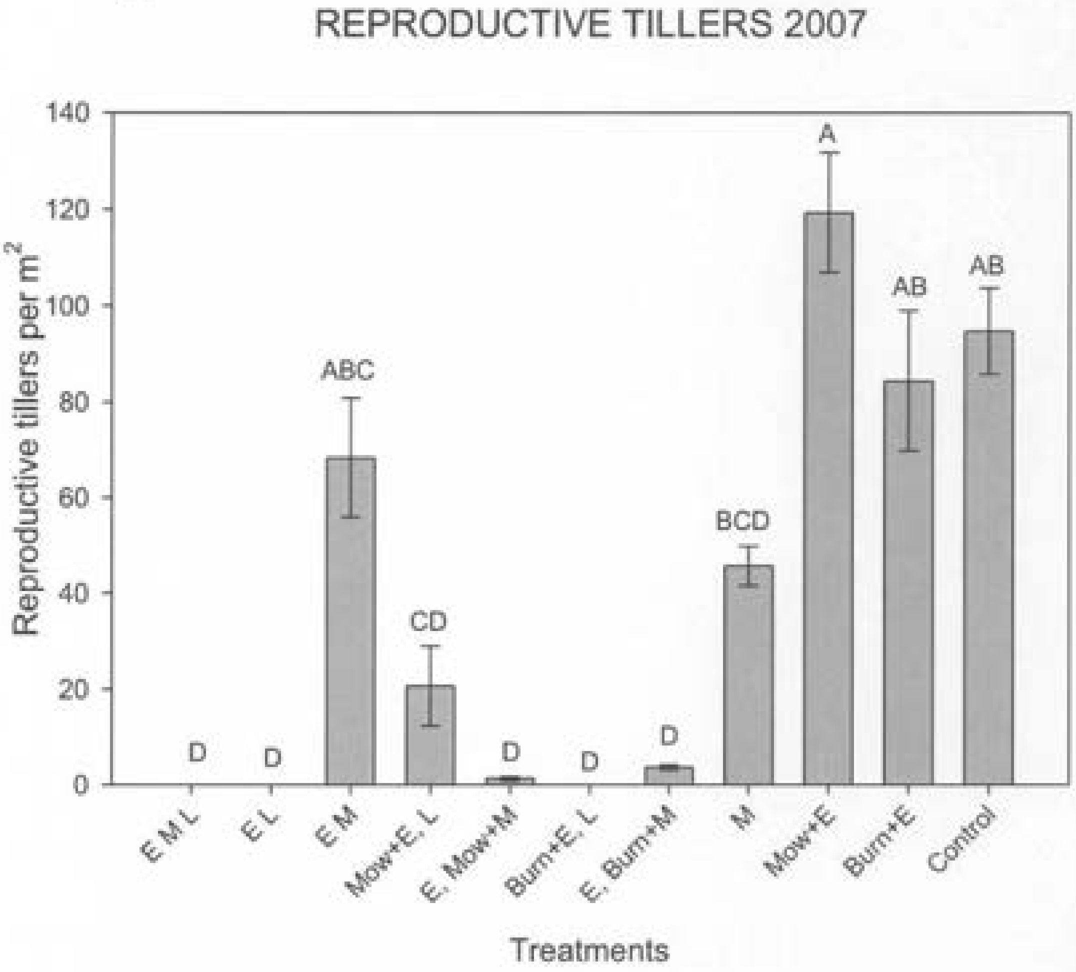


Fig 4. Reproductive tiller density (per m^2) of OWB at end of season 2007. Different letters indicate significant difference ($p < 0.05$), E = early season herbicide application, M =middle season herbicide application, L = late season herbicide application, Mow+E = early season mow followed by a herbicide application, Mow+M = middle season mow followed by a herbicide application, Burn+E = early season burn followed by a herbicide application, Burn+M = middle season burn followed by a herbicide application

Fig. 5

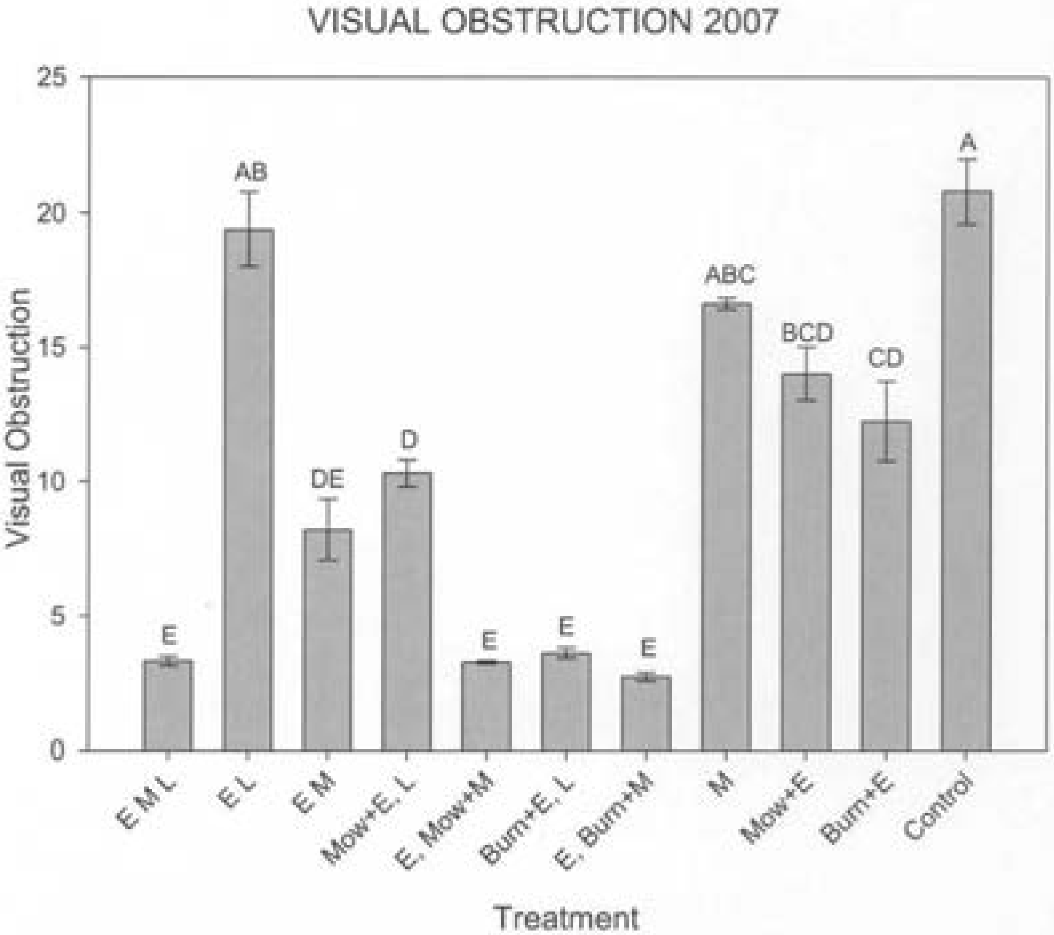


Fig 5. Visual obstruction at end of season 2007. Different letters indicate significant difference ($p < 0.05$), E = early season herbicide application, M =middle season herbicide application, L = late season herbicide application, Mow+E = early season mow followed by a herbicide application, Mow+M = middle season mow followed by a herbicide application, Burn+E = early season burn followed by a herbicide application, Burn+M = middle season burn followed by a herbicide application

Fig. 6

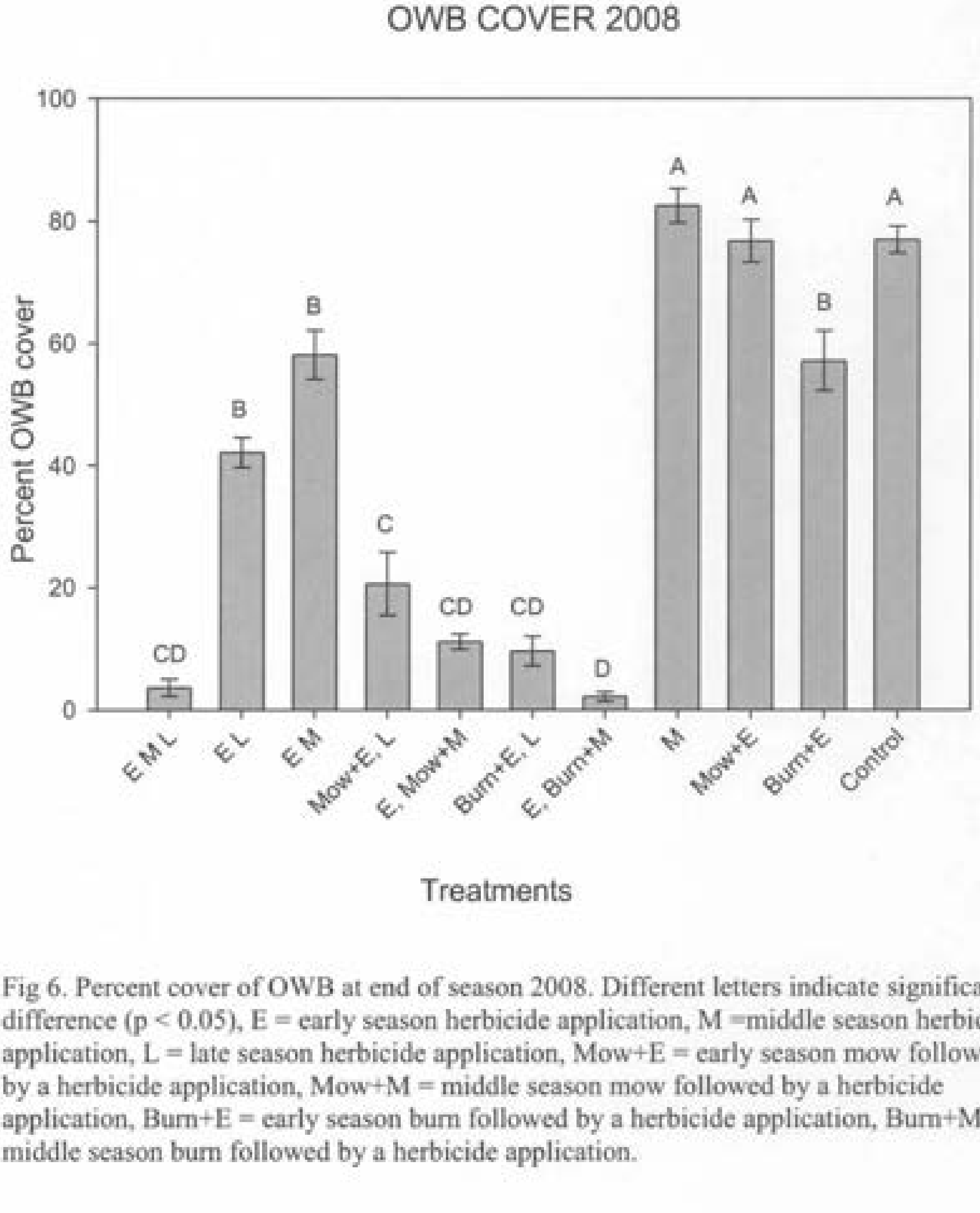


Fig 6. Percent cover of OWB at end of season 2008. Different letters indicate significant difference ($p < 0.05$), E = early season herbicide application, M =middle season herbicide application, L = late season herbicide application, Mow+E = early season mow followed by a herbicide application, Mow+M = middle season mow followed by a herbicide application, Burn+E = early season burn followed by a herbicide application, Burn+M = middle season burn followed by a herbicide application.

Fig. 7

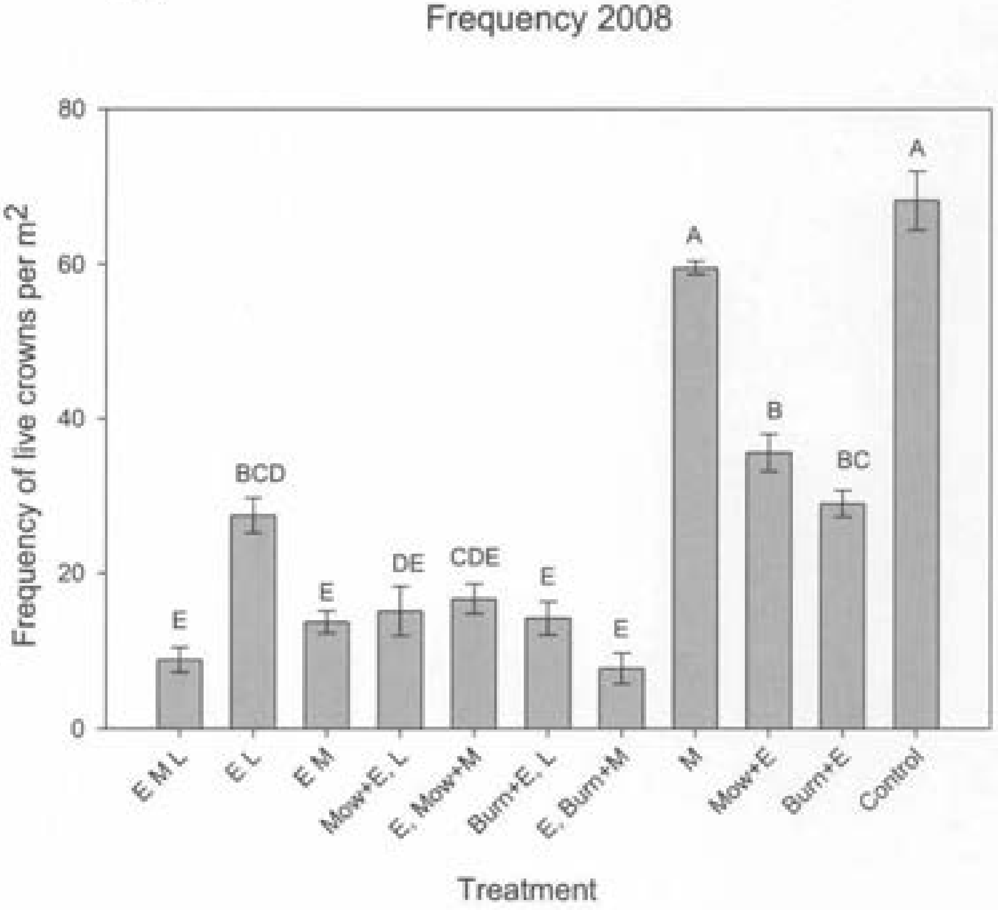


Fig 7. Frequency of live OWB crowns (per m^2) at end of season 2008. Different letters indicate significant difference ($p < 0.05$), E = early season herbicide application, M =middle season herbicide application, L = late season herbicide application, Mow+E = early season mow followed by a herbicide application, Mow+M = middle season mow followed by a herbicide application, Burn+E = early season burn followed by a herbicide application, Burn+M = middle season burn followed by a herbicide application

Fig. 8

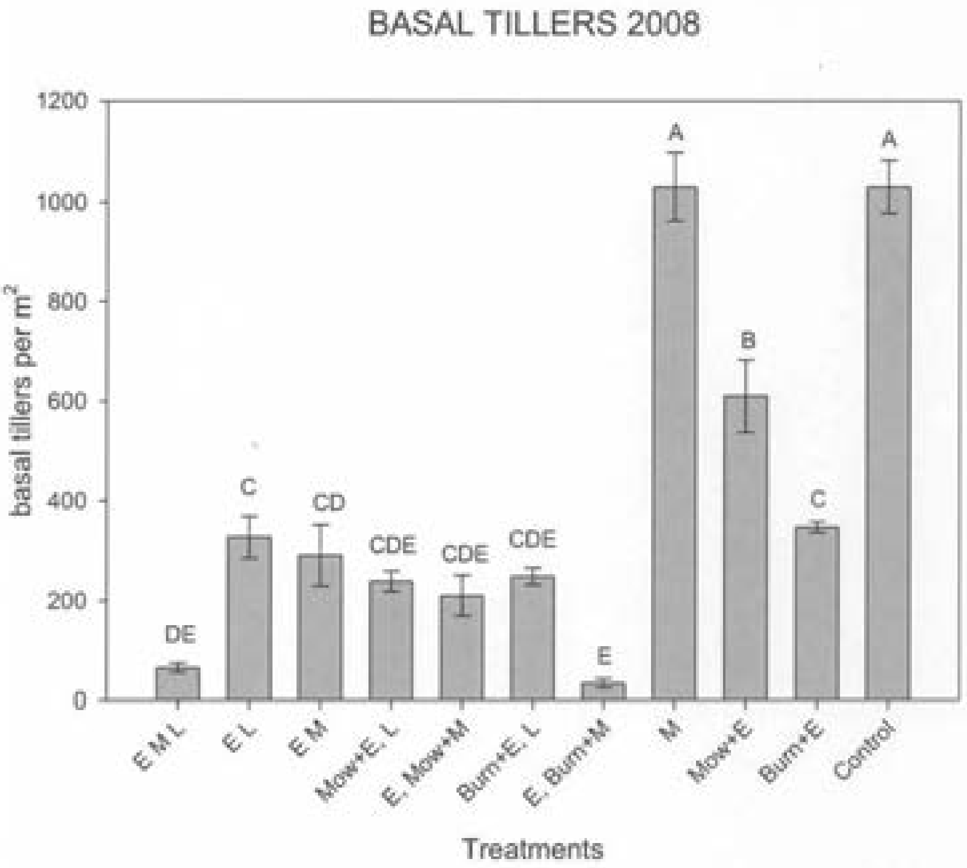


Fig 8. Basal tiller density (per m^2) of OWB at end of season 2008. Different letters indicate significant difference ($p < 0.05$), E = early season herbicide application, M =middle season herbicide application, L = late season herbicide application, Mow+E = early season mow followed by a herbicide application, Mow+M = middle season mow followed by a herbicide application, Burn+E = early season burn followed by a herbicide application, Burn+M = middle season burn followed by a herbicide application

Fig. 9

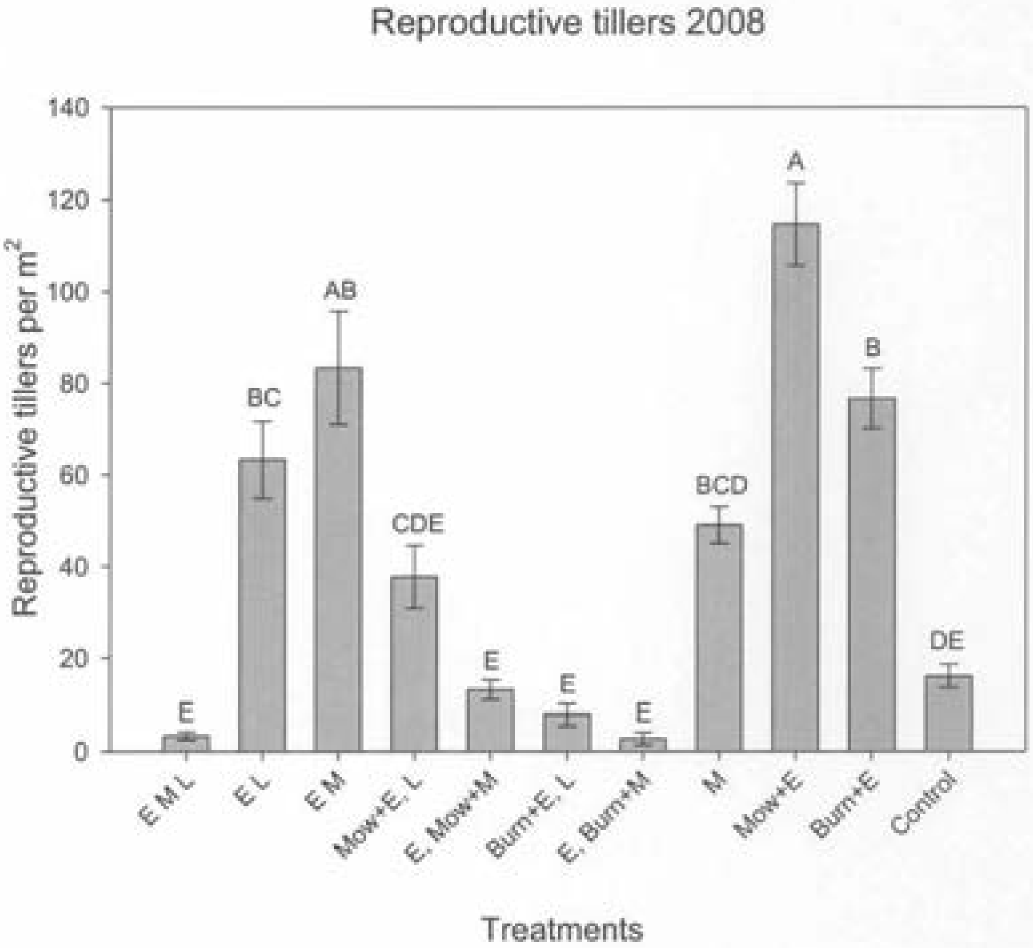


Fig 9. Reproductive tiller density (per m^2) of OWB at end of season 2008. Different letters indicate significant difference ($p < 0.05$), E = early season herbicide application, M =middle season herbicide application, L = late season herbicide application, Mow+E = early season mow followed by a herbicide application, Mow+M = middle season mow followed by a herbicide application, Burn+E = early season burn followed by a herbicide application, Burn+M = middle season burn followed by a herbicide application.

Fig. 10

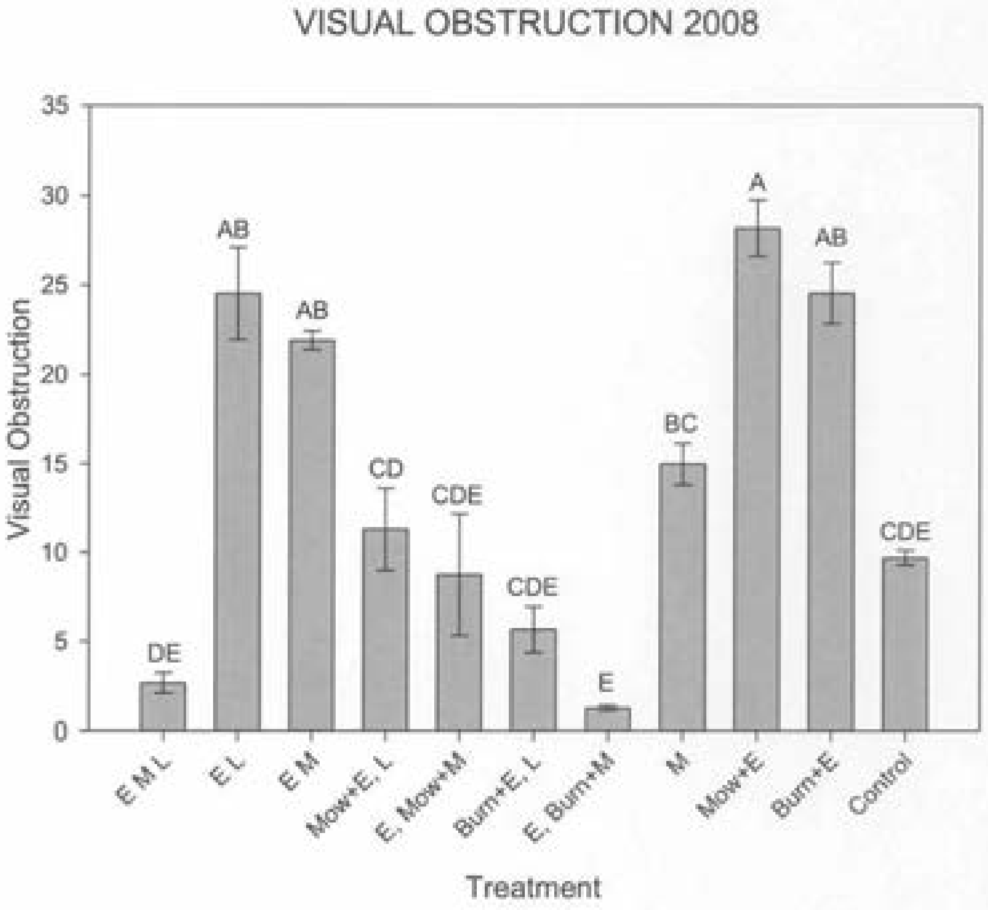


Fig 10. Visual obstruction at end of season 2008. Different letters indicate significant difference ($p < 0.05$), E = early season herbicide application, M =middle season herbicide application, L = late season herbicide application, Mow+E = early season mow followed by a herbicide application, Mow+M = middle season mow followed by a herbicide application, Burn+E = early season burn followed by a herbicide application, Burn+M = middle season burn followed by a herbicide application.

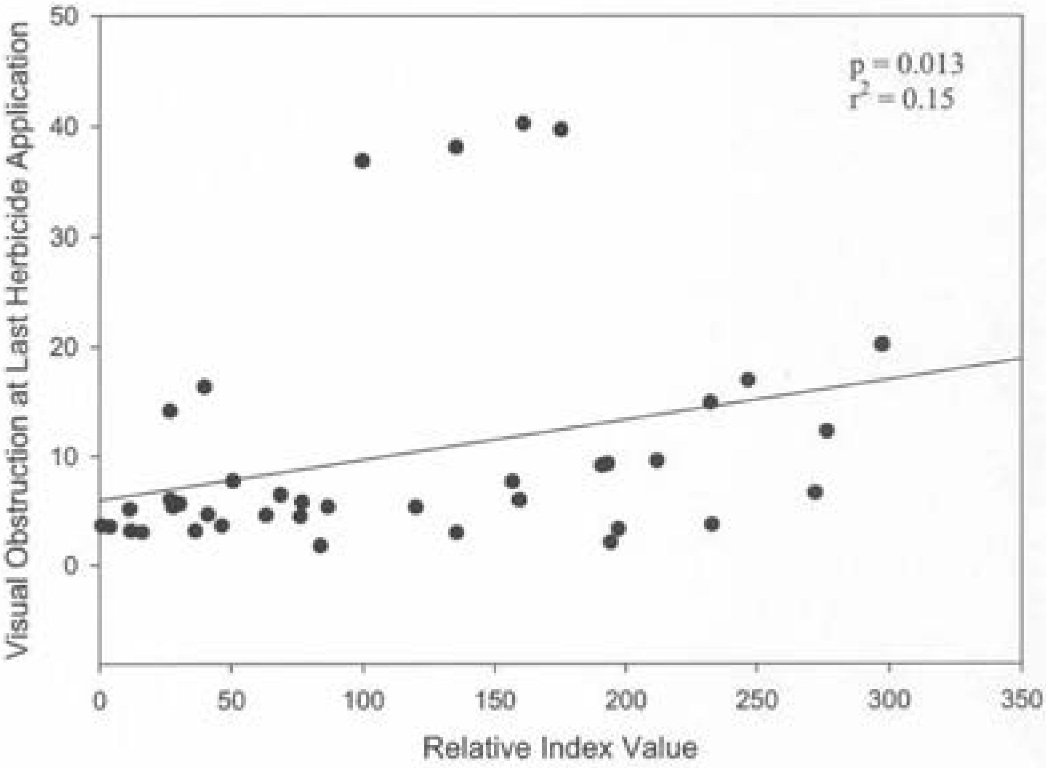
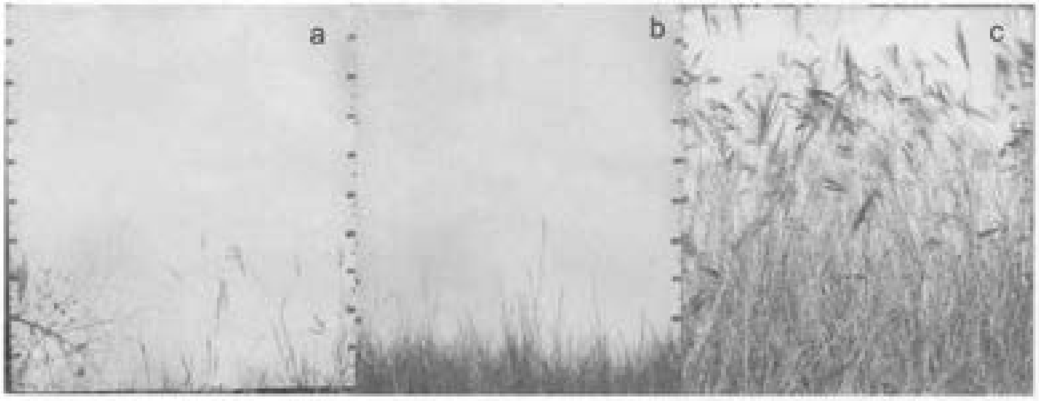


Fig 11. Relationship between visual obstruction at last herbicide application and relative important value (RIV) of OWB.

Fig. 12

Visual Obstruction



Visual obstruction photos from sample of treatments a) Burn double herbicide, timing early burn with an herbicide application 4 weeks after, with in additional application late b) control treatment c) Double herbicide, Early, middle timing.

Chapter II

Aboveground plant community and seed bank composition along an invasion gradient

ABSRACT Invasive species are known to reduce diversity and abundance in a native plant community, but, it is unclear how aboveground invasion effects the native seed bank. My objective was to assess effects of invasion by the exotic grass old world bluestem (OWB; *Bothriochloa spp.*) on native aboveground plant species composition and seed bank diversity and abundance. The aboveground plant and seed bank communities were sampled along a invasion gradient of OWB. Old world bluestem invasion had differential effects on native diversity and abundance in the aboveground plant community and seed bank. Native aboveground species diversity and cover showed a steep declined as OWB cover increased. There was a slight decline in native seed diversity, and no change in native seed density as invasion increased. OWB seed density increased with increasing invasion. I hypothesize that as OWB invasion increases native aboveground plants decrease in diversity and abundance, but native seed bank diversity and density does not decline, but over time as native seeds are lost, and the a lack of native seed replenishment from the aboveground community, native seed bank diversity and density will decline.

Introduction

The soil seed bank is a reservoir of viable seeds under the soil surface that remains dormant until conditions are favorable for germination (Fenner & Thompson, 2005). Soil seed banks are a dynamic system, with seeds constantly lost through germination, death, or predation, while other seeds are added via seed dispersal and seed rain (Nathan & Casagrandi, 2004; Arrieta & Suarez, 2005; Fenner & Thompson, 2005). The seed bank represents the potential future vegetation of an area following a disturbance, or death of an existing plant (Leck et al., 1989).

Seed bank dynamics are effected by a variety of interacting factors, such as seed dispersal, seed rain, germination, disturbance and microsite characteristics (Eriksson & Ehrlen, 1992; Kinucan & Smeins, 1992; Bertiller & Aloia, 1997; Coulson et al., 2001). Land use and disturbance regimes also can have a profound effect on the composition and diversity of the seed bank (Kinucan & Smeins, 1992). Microsite attributes such as slope, aspect, and amount of bareground or litter influence seed bank composition through differential seed input and germination (Bertiller, 1992; Dalling & Hubbell, 2002; Kalamees & Zobel, 2002). The quantity of seeds in the seed rain, distance and direction of seed movement are also important factors in seed bank formation (Kalamees & Zobel, 2002).

Generally, there is low similarity between plant species represented in the aboveground vegetation relative to the species in the seed bank, and similarity can vary depending on the plant community (Hopfensperger, 2007). The density of seeds in seed banks, especially in grasslands, tends to have a high degree of heterogeneity, with wide fluctuations in seed densities over short distances (Fenner & Thompson, 2005). For instance, the seed banks of some plant species have a clumped distribution near parent plants due to limited seed dispersal mechanisms (Jensen, 1998). Annual grasslands in semi-arid regions, tend to have higher similarity between the seed bank and aboveground vegetation compared with other ecosystems (Olano et al., 2005). However, in grasslands of the Great Plains, the dominant perennial grasses are often poorly represented in the seed bank (Kinucan & Smeins, 1992; Hild et al., 2001). In contrast, some species, mostly annuals and small seeded species, make up a small percentage of the aboveground vegetation but tend to be more abundant in the seed bank (Leck et al., 1989; Bertiller & Aloia, 1997). The similarity between the aboveground plant composition and the seed bank composition can also depend upon other factors such as disturbance, management, and presence of invasive species (Hopfensperger, 2007).

Invasion by non-native plant species is typically observed first in the aboveground plant community and found to alter community composition and ecosystem structure and function (Mooney & Hobbs, 2000). However, this apparent aboveground invasion also can result in unobserved alterations in the composition and abundance of the seed bank community (Witkowski & Wilson, 2001; Holmes, 2002; Krinke et al., 2005; Giantomasi et al., 2008). Invasive plant species tend to produce large and persistent seed banks, with the density of the invasive seeds generally increasing as aboveground abundance and seed production of the invasive increases (Mason et al., 2007; Cline et al., 2008), resulting in the invasive species becoming the dominant species in both the aboveground and seed bank communities (Cox & Allen, 2008).

Currently the understanding of the relationship between aboveground invasion by exotic plant species and native seed bank diversity is unclear (Vila & Gimeno, 2007).

Some authors reported lower diversity and abundance of native seeds in an invaded area compared with uninvaded areas (Holmes, 2002; Cline et al., 2008). Other researchers have concluded that large viable native seed banks can exist under invaded areas (Ghorbani et al., 2007; Fourie, 2008). However, native seed banks under invaded areas are typically missing many dominant species, although ruderal and pioneer species are abundant (Bossuyt et al., 2007; Vosse et al., 2008).

Old World bluestems (OWB, *Bothriochloa spp.*) are a group of non-native, perennial, warm-season grasses that reproduce mainly by seeds but also vegetatively by stolons and rhizomes (Harlan, 1952; Schmidt & Hickman, 2006). These grasses were introduced to the United States from Eurasia for use as forage for cattle (Harlan, 1952). Currently, OWBs have been introduced into 16 states, mostly in the southern United States (USDA, 2008) and have been widely promoted and utilized as perennial cover crop for soil stabilization in Conservation Reserve Program (CRP), roadside rights-of-way, and pasture grass for hay production for grazing animals. Old World bluestems have escaped their original plantings, have invaded native prairies, and have been shown to reduce diversity of native plants, grassland birds, and small mammals (Sammon & Wilkins, 2005; Adams & Galatowitsch, 2006; Gabbard & Fowler, 2006; Hickman et al., 2007).

My objective was to assess the effect of OWB invasion on native mixed-grass prairie by quantifying diversity and abundance of the aboveground plant species community and the seed bank community over a range of increasing aboveground invasion by the exotic OWB. Another objective was to assess composition and species similarity between the seed bank and aboveground plant community. By quantifying the seed bank and aboveground plant community in areas of differing levels of OWB invasion, I addressed the following questions: does OWB aboveground cover correlate with the density of OWB seeds in the seed bank and, is native seed bank and aboveground plant community diversity and abundance affected by increasing OWB aboveground cover? The results of this study could provide insight on which stage of invasion, if any, the native seed bank is capable of natural recovery of a native aboveground plant community after successful eradication of OWB.

Methods

Study site

The research was conducted on 129.5 ha of the Marvin Klemme Range Research Station. (35° 22' N, 99° 04' W) in western Oklahoma. The study site is primarily an upland mixed-grass prairie with rolling hills and the native vegetation is dominated by perennial grasses such as side-oats grama [*Bouteloua curtipendula* (Michx.) Torr.], blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths], little bluestem [*Schizachyrium scoparium* (Michx.) Nash], buffalograss [*Bouteloua dactyloides* (Nutt.) J.T. Columbus], and common forbs are western ragweed (*Ambrosia psilostachya* DC.), annual broomweed [*Amphiachyris dracunculoides* (DC.) Nutt.], and Texas croton [*Croton texensis* (Klotzsch) Müll. Arg.]. During the study period (March-August 2008) the site received 43 cm of precipitation with an average high temperature of 28.2° C and average low temperature of 13.3°C. Longterm averages of the area are 76 cm of precipitation annually, with an average summer high temperature of 34.2° C and an average winter low of 4.4° C (Brock et al., 1995). The soils are silty clay loams of the Cordell series. The site is composed of five pastures under differing management regimes. One pasture (46 ha) has been managed for the past eight years with patch burning using a four year fire return interval with cattle grazing season-long (May to October) at a moderate stocking rate. The second pasture (56 ha) was aerially sprayed with picloram and 2,4-D (Grazon P+D^{tm}) in 2001 and 2004 for musk thistle (*Carduus nutans*) control and has been grazed season long by cattle at a moderate stocking rate (May to Oct). A remnant pasture of 6.2 ha has not been grazed or burned for at least 50 years. Old world bluestem was first introduced to this site in 1989 in two monoculture plantings (6.5 ha and 1 ha), that have been managed for hay production (Gunter et al., 1995).

Sampling

In November 2007, the entire 129.5 ha area was scouted for populations of OWB with line transects of variable lengths. All populations of OWB were marked with a handheld GPS unit and classified as either having high ($>$ 5 populations for a 20 m section of the transect) or low ($<$ 5 populations for a 20 m section of the transect) levels of OWB invasion, in order to ensure a gradient of OWB invasion. Fifteen sites with high levels of invasion and 15 with low levels of invasion were randomly selected for seed bank sampling. An additional 15 sites, not invaded by OWB also were selected for a total of 45 sampling locations. Plots of 10 x 20 m were established for vegetation and seed bank sampling, and all plots were at least 75 m from other plots.

Aboveground vegetation sampling

Within each 10 x 20 m plot ($n = 45$), 15 subplots of 1 m^2 were used to visually estimate the percent cover of plant species. Aboveground foliar cover of each plot was sampled twice (early May and late August) in 2008. Because some plant species are only present in the aboveground vegetation during early season (cool season grasses and early spring forbs), while other plants (warm season grasses and forbs) are just emerging and reach peak biomass later in the year, the two data sets (May and August) were pooled into one data set, to attain an accurate measurement of aboveground vegetation and seed bank species similarity. The highest cover value of each species during the two sampling periods was used in the analysis (Hickman et al., 2004). Scientific nomenclature of all plant species follows the USDA PLANTS database (USDA, 2008).

Seed bank sampling

The seed bank was sampled during March 2008 with a 9 cm diameter soil core to a depth of 5 cm, 4 soil cores were taken in each of the 15 subplots (1 m^2) and were pooled, for a total of 60 soil cores from each 10 x 20 m plot. Each sample was sieved through a 4 mm sieve to remove coarse material and 0.5 mm sieve to remove fine material. Sieved samples were spread on top of 26 x 54 cm trays filled with 10 cm of sterile potting soil and 5 cm of vermiculite and covered with an additional thin layer of vermiculite (approximately 1 cm deep). The trays were placed in a greenhouse at temperature of 20–25°C. An additional four trays filled with potting soil and vermiculite were randomly placed around the greenhouse as controls to account for seed contamination in the greenhouse. The seed bank composition of each sample was assessed by direct germination method (Gross, 1990; TerHeerdt et al., 1996). All emerged seedlings were identified to species, if possible, counted, and removed after positive identification. Those seedlings that could not be identified were transplanted to a new pot and grown until identification was possible. Germination began 15 April 2008 and after 60 days the soil within the trays was stirred to stimulate more germination.

Seedlings were recorded until no new seedlings had emerged for a period of one week (19 August 2008).

Data analysis

Regression analysis was used to determine the relationship between aboveground OWB cover and the density of OWB seeds in the seed bank, as well as native species diversity, evenness, and richness, for both the seed bank and the aboveground vegetation (SPSS 16). The mean percent cover, species richness, and seed density (seeds/m^2) for each plot was used in the analysis. Native diversity and evenness were calculated using the Shannon diversity (H') and Pielou's index of evenness. Only native species were included in the calculations (Magurran, 1988). Sorenson similarity index was used to determine the similarity of between species in the seed bank and aboveground community (Magurran, 1988). All species detected in the seed bank and aboveground vegetation were classified into one of eight functional groups, using the USDA Plants database (appendix 1). The "dominant native perennial grasses" functional group contained all perennial grass species which averaged greater than 5% cover in the uninvaded plots. The other native perennial grasses were classified as "non-dominant grasses."

Regression analysis was performed to test for relationships between OWB aboveground cover and seed density, as well as the cover and seed density of each functional group. The species similarity between the species in the aboveground vegetation and the species in the seed bank was determined using the Sorenson similarity index (Magurran, 1988). A regression analysis was used to assess the relationship between aboveground species composition and seed bank species similarity, and aboveground OWB cover.

Results

A total of 134 species were detected in the aboveground plant community. Germinated seeds totaled 30 462 with 112 species recorded in the seed bank. Sixty-eight species were found in both the aboveground and seed bank communities with 44 and 90 species unique to the aboveground plant community and the seed bank, respectively. The average seed bank density was 6 020 seeds/m^2 for all plots.

Aboveground species composition

Native perennial grasses and perennial forbs comprised 76% of total vegetation cover. The dominant perennial grasses *Bouteloua curtipendula, B. gracilis, Buchloe dactyloides*, *Schizachyrium scoparium, Aristida purpurea,* and *Andropogon gerardii* comprised 44% of the aboveground composition (appendix 2). In addition to OWB, 12 invasive species were recorded representing 4% of the total vegetation cover. Excluding OWB, *Bromus* sp. was the most abundant invasive species. In the invaded plots, aboveground OWB cover ranged from 1–61% cover. Native species diversity and evenness decreased as OWB increased ($p = 0.0001$, $r^2 = 0.31$ and $p = 0.0001$, $r^2 = 0.41$, respectively) (Fig. 1a, b). Native species richness averaged 32 species per plot and showed no relationship with OWB cover ($p = 0.502$, $r^2 = 0.011$) (Fig. 1d). Native species cover had a negative relationship with increasing OWB cover ($p = 0.0001$, $r^2 = 0.51$) (Fig. 1c).

The cover of native dominant perennial grasses and native annual forbs had a negative relationship with OWB cover ($p = 0.0001$, $r^2 = 0.43$ and $p = 0.01$, $r^2 = 0.14$, respectively) (Fig. 2a,c). Native perennial forb cover showed a weak negative correlation with OWB cover ($p = 0.08$, $r^2 = 0.07$) (Fig. 2b). The cover of non-dominant perennial grasses was not reduced as OWB cover increased ($p = 0.91$, $r^2 = 0.0001$) (Fig. 2d).

Seed bank

Seeds of native, non-dominant perennial grasses and annual forbs represented 66% of the total seed bank density. Unlike the aboveground plant community, native dominant perennial grasses were not abundant in the seed bank, and each species had a low average seed density, ranging from 6–57 seeds/m^2. Four species, *Sporobolus asper, Bothriochloa ischaemum, Bromus* sp. and *Chloris verticillata*, comprised 48% of the total seed bank, with the native grass *S. asper* making up the largest proportion of the total seed bank (appendix 1). A total of 17 non-native species were detected, with OWB and *Bromus* sp. being the most abundant in the seed bank, and together accounted for 91% of the invasive seed bank and 20% of the total seed bank. In the invaded areas OWB formed a large seed bank (averaging 1 076 seeds/m^2 but ranged from 10–4481 seeds/m^2) and OWB seed density was related positively to OWB cover ($p = 0.001$, $r^2 = 0.58$) (Fig. 3). Native seed diversity and evenness showed a negative relationship with OWB cover ($p = 0.042$ $r^2 = 0.093$, and $p = 0.004$, $r^2 = 0.18$, respectively) (Fig. 4, a, b).

Total native seed density showed no relationship with aboveground OWB invasion ($p = 0.17$, $r^2 = 0.042$) (Fig. 4c). There was high variation in native seed densities with the invaded plots at 797–24 869 seeds/m^2 and uninvaded plots at 1 059–10 011 seeds/m^2. The invaded plots had on average almost twice the density of native seeds compared with the uninvaded plots. The increased seed densities can be contributed to the non-dominant perennial grasses such as *S. asper, Chloris verticillata, Bothriochloa* *laguroides*, and *Sporobolus cryptandrus*, which collectively represented 60% of the native seed density in the invaded plots. For example, *S. asper* average seed density increased by 1 420 seeds/m^2 in the invaded plots compared with the uninvaded plots. The other non-dominant perennial grasses, *C. verticillata, B. laguroides,* and *S. cryptandrus,* had twice the density of seeds in the invaded plots compared with the uninvaded plots. Despite the increased densities of those species, native seed density was not related to aboveground OWB cover ($p = 0.17$, $r^2 = 0.042$) (Fig. 4c). The seed density for all functional groups was not related to aboveground OWB cover (data not shown), neither was native species richness ($p = 0.19$, $r^2 = 0.039$) (Fig. 4d). The average Sorenson similarity index between the species in the aboveground vegetation and the seed bank was low, averaging 0.38 (range 0.59–0.16) and was not related to aboveground OWB cover ($p = 0.38$, $r^2 = 0.017$) (Fig. 5).

Discussion

Generally, the native diversity of the aboveground plant community and seed bank declined as aboveground OWB cover increased; however, the magnitude of the reduction in native diversity was less for the seed bank than the aboveground plant community. Results indicate that there was a dense seed bank in this mixed-grass prairie study, with an average density of 6 020 seeds/m^2, and a large range in seed density (797–24 869 seeds/m^2). These values were similar to the values found in other studies in mixed-grass prairies (Leck et al., 1989; Romo & Bai, 2004; Cline et al., 2008). Old World bluestem was one of the dominant species found in the seed bank, along with three other grasses, two native (*S. asper* and *C. verticillata*) and one other non-native invasive grass, *Bromus* sp., supporting other studies that have found only a few species dominating the seed bank of the invaded sites (Wearne & Morgan, 2006). Although *Bromus* sp., an invasive annual grass, formed a dense seed bank, it did not contribute much to the aboveground cover.

The dominant perennial grasses in the aboveground vegetation, *Bouteloua curtipendula, B. gracilis, Buchloe dactyloides*, and *Schizachyrium scoparium* averaged 44% cover per plot in the aboveground species composition whereas they only represented 5.5% of the seeds in the seed bank. Perennial, high seral grass species such as these have often been shown to be absent or at low densities in seed banks (Kinucan & Smeins, 1992; Romo & Bai, 2004). In contrast, four other native perennial grasses all lower seral species, *S. asper, C. verticillata, Bothriochloa laguroides, S. cryptandrus*, were not well represented in the aboveground plant community but had seed densities 18 times greater than the dominant grasses. Native annual forbs also were disproportionately represented in the seed bank relative to their low cover in the aboveground vegetation. Native perennial forbs showed the opposite trend, in that they were abundant in the aboveground vegetation and at low density in the seed bank. These results were not surprising because annual species rely on yearly seed germination to be represented in the aboveground plant community, and tend to accumulate in the seed bank because of high levels of seed production (Bertiller & Aloia, 1997). Thus, there was a low similarity between species in the aboveground vegetation and species in the seed bank, which is typical for most seed banks (Hopfensperger, 2007). The low similarity is most likely related to the differential abundance of some species in the aboveground plant community (e.g. dominant perennial grasses and perennial forbs), relative to the seed bank composition.

The dominant perennial grasses had the highest percent cover of any functional group in the uninvaded plots, but as OWB cover increased, the cover of the dominant grasses decreased, and OWB became the most abundant species. The dominant grasses had the greatest decline in cover than any other native functional group. OWB has been shown to be highly competitive and is capable of reducing the height and biomass of *Bouteloua curtipendula, Schizachyrium scoparium,* and *Andropogon gerardii* (all dominant perennial grasses in the present study) in a greenhouse study (Schmidt & Hickman, 2006). All major native functional groups (dominant grasses, annual, and perennial forbs) exhibited decline in canopy cover as OWB invasion increased, with the exception of the non-dominant perennial grasses. Overall native cover showed steep declines as OWB invasion increased.

These results indicate that as the level OWB invasion increased, there was a loss of native plant diversity. Native species richness did not show a correlation with OWB invasion; however, reduced native species diversity, evenness, and cover were closely related to increasing OWB cover suggesting that although the number of native species present in the aboveground plant community does not decline, their abundances are reduced with increasing cover of OWB. Field studies have shown that OWB invasion reduces diversity and abundance of native plants regardless of environmental conditions and management practices such as burning and grazing, except under dense tree cover (Reed et al., 2005; Gabbard & Fowler, 2006). Reed et al. (2005) suggests that OWB is capable of changing the condition of the surrounding soil, which enhances its ability to compete with other native plants. I hypothesize that OWB's aggressiveness, competitiveness, and wide environmental tolerance allows OWB to decrease native plant species diversity and abundance, as invasion levels increases.

Old World bluestem is capable of forming a large seed bank (up to 4 481 seeds/m^2). Recent studies have shown that other invasive species tend to have large seed banks, their seed densities generally increase as aboveground abundance increases, due to greater seed production, which can result in the invasive species dominating the seed bank (Krinke et al., 2005; Fourie, 2008; Vosse et al., 2008). Similarly, in this study, I found OWB capable of becoming the most abundant species in the seed bank. For example, in plots with greater than 15% OWB cover, OWB seeds were the most abundant species in 9 of the 11 seed bank plots. Other invasive species have been observed to be the most dominant seed in the seed bank. The results suggest that as OWB cover increases, OWB seed density also increases, resulting in OWB becoming the dominant species in both the aboveground plant community and the seed bank.

Although native seed bank diversity and evenness statistically declines as aboveground invasion increased, the regression was relatively weak, with aboveground OWB invasion explaining only 9 and 18%, respectively, of the variation in native seed diversity and evenness. Regression analyses also indicated that native seed bank density and seed density of all native species functional groups were not related to aboveground OWB invasion. This suggests that increasing cover of OWB has a minimal effect on the native seed bank, inconsistent with results from several studies that found decreases in native seed diversity, native seed density, or both in invaded areas (Holmes, 2002; Bossuyt et al., 2007; Cline et al., 2008). However, other studies have found that diversity and/or density of native species were not different or were only slightly reduced from invaded and uninvaded areas (King & Buckney, 2001; Mason et al., 2007). For example, Holmes and Cowling (1997) showed that in areas that were recently, heavily invaded (>80% cover, <25 years), native seed diversity was similar to the uninvaded areas, but in areas with a long history of invasion (>25 years), there was a significant reduction in native seed diversity. Because some species produce a persistent seed bank and can remain viable for over ten years, native seed diversity can persist in soil after heavy invasion (Fourie, 2008). OWB was first introduced at Klemme Research Range 19 years before this study was conducted, and it is unknown how long OWB has existed in the sampled plots (Gunter et al., 1995). One limiting factor in OWB invasion might be a lack of efficient long distance dispersal (Gabbard & Fowler, 2006). It is unlikely that OWB invasion has existed long enough to observe a drastic reduction of native seed density and diversity decreased, suggesting that as OWB invasion increases, OWB seed density increases, but native seed bank diversity and density are maintained until native seeds lose their viability in the soil over time.

Given that a large native seed bank exists under the invaded area (average 5 315 seeds/m^2), I propose there is potential for natural restoration from the native seed bank after successful OWB eradication in invaded prairies. Although natural recovery to a high serial plant community might be difficult (Bossuyt et al., 2007), because 86% of the native seed bank in the invaded plots was composed of non-dominant grasses and annual forbs, and the dominant aboveground species were at low densities in most plots. Reinvasion also might be possible with the large seed bank of OWB in the invaded areas. Therefore, a short period of opportunity might exist for natural restoration since a large native seed bank can exist during the early stages of invasion when OWB invasion does not affect native seed density, and low OWB seed densities exist. Importantly, the possibility for natural recovery decreases as invasion increases due to increased OWB seed densities. Unfortunately, the high degree of variability in native seed bank density limits the ability of restoration attempts to depend solely on a large native seed bank for natural recovery (Vosse et al., 2008).

The findings suggest that OWB invasion had differential effects on native diversity and abundance in the aboveground vegetation compared with the seed bank. Increasing OWB invasion showed a greater reduction of native diversity and abundance in the aboveground plant community compared with native seed bank, which supports the findings of Holmes and Cowling (1997) that aboveground invasion reduced the native aboveground plant diversity more quickly than the native seed bank diversity. A similar lag between the seed bank and aboveground vegetation has been described in successional change from one plant community to a different plant community, in which seeds of the previous plant community persist in the soil even though that plant community no longer exists (Davies & Waite, 1998). Aboveground invasion may have similar effects on native seed bank diversity and density as aboveground successional change.

Based on the results of the present study and conclusions of other studies, I hypothesize that invasion by an invasive species affects the native aboveground plant community, the native seed bank, and the invasive seed bank differentially. As an invasive species increases in abundance in the aboveground vegetation, native species in the aboveground plant community decrease in diversity and abundance, through a variety of interactions, including competitive interactions (Mooney & Hobbs, 2000). Increasing invasion has a direct effect on invasive seed density with the increased seed input from a greater production of seed by the invasive species (Witkowski & Wilson, 2001). Unlike the native aboveground vegetation, invasive plants and their seeds do not directly interact with the existing native seeds, as they do with the native aboveground plants. Therefore, increasing aboveground invasion has minimal direct effect on native seed density and diversity, but as aboveground native diversity and abundance decrease with invasion, so do native seed production and input into the seed bank (Wearne & Morgan, 2006). Initially, after an area has been heavily invaded, the aboveground vegetation might have low density and diversity of native plants, but because some native species persist in the soil for many years, the native seed bank is capable of maintaining a high diversity and density of native seeds. Over time as native seeds are lost through death, predation, or possibly germination, the reduction and lack of native seed replenishment from the native aboveground plants, result in a loss of native seed bank diversity and density as time since invasion increases.

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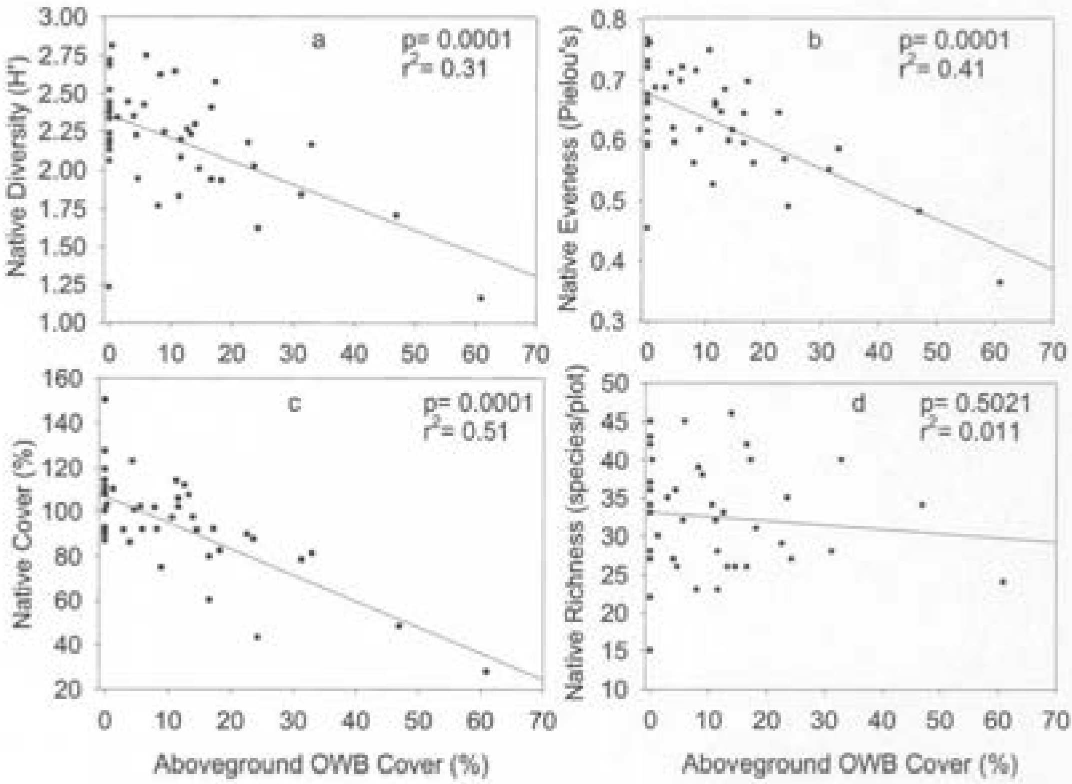

Fig.1. Regression analysis of the relationship between mean aboveground percent cover of OWB and a) mean Shannon diversity index of native aboveground plant species composition b) mean Pielou's evenness index of aboveground native plant species composition c) mean percent cover of aboveground native plant species composition and d) mean richness of aboveground native species.

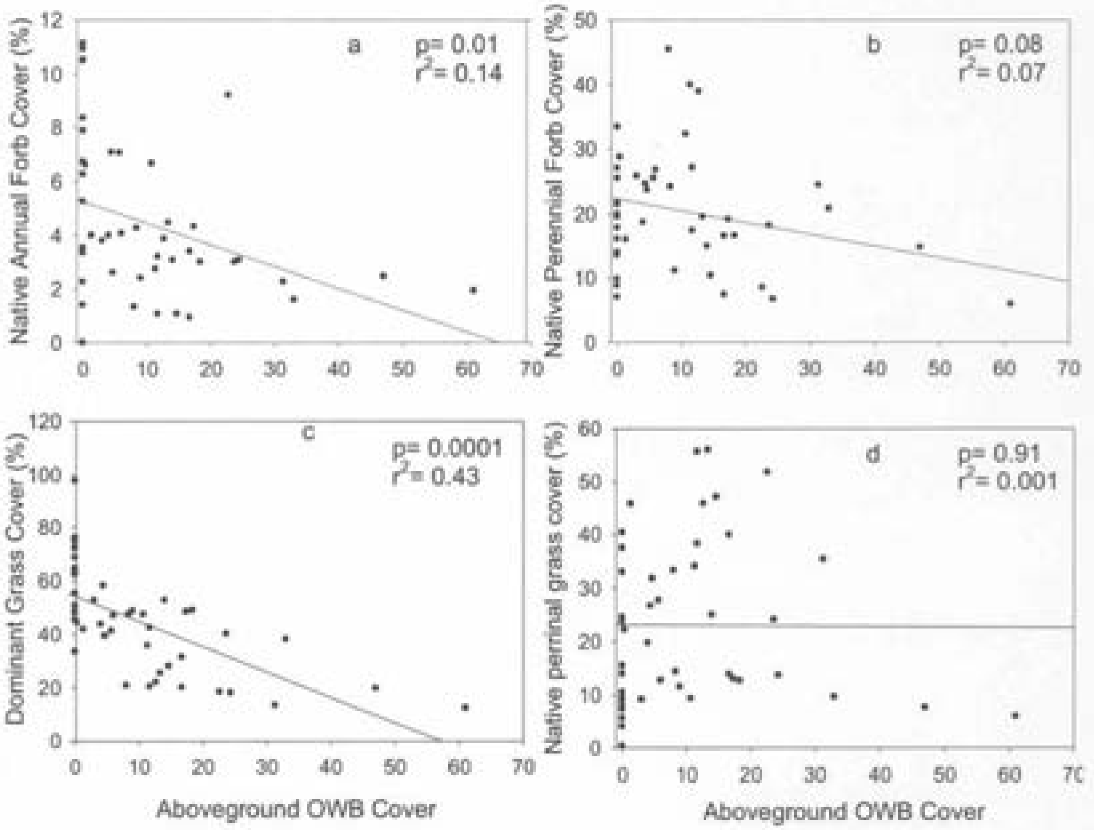

Fig. 2. Regression analysis of the relationship between mean aboveground percent cover of OWB and percent cover of native functional groups a) mean native annual forbs b) mean native perennial forbs c) mean native dominant grass and d) mean native non-dominant grasses.

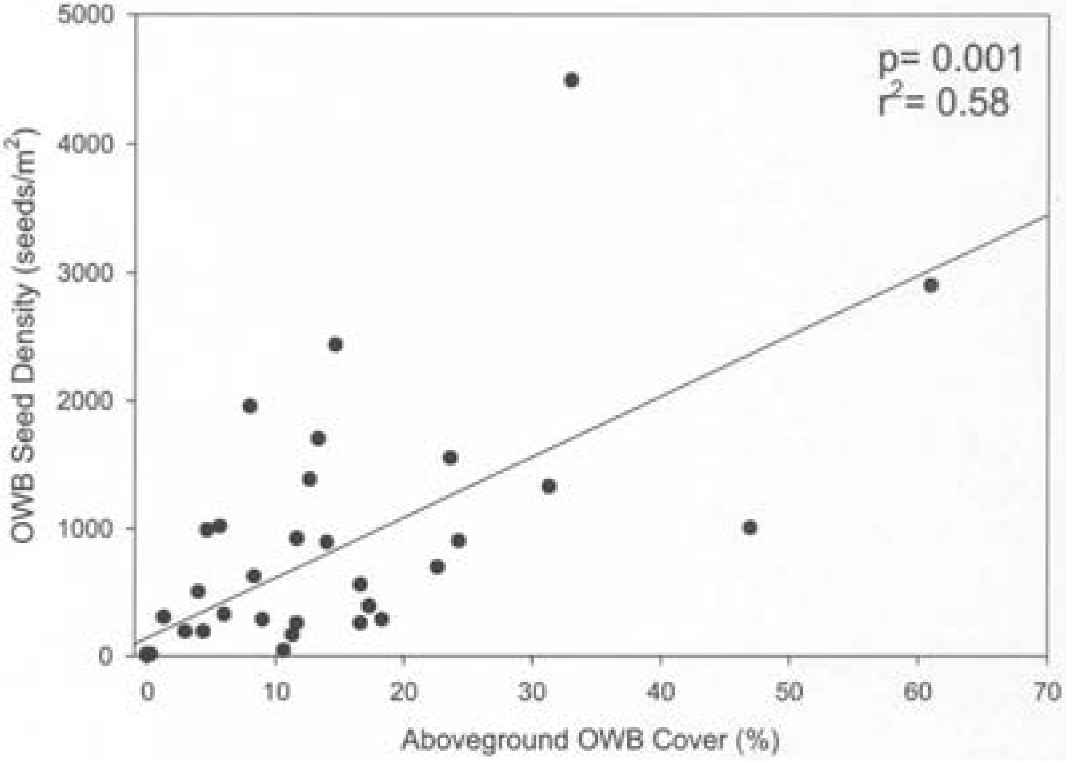

Fig. 3. Regression analysis of the relationship between mean aboveground percent cover of OWB and mean density of OWB seeds in the seed bank.

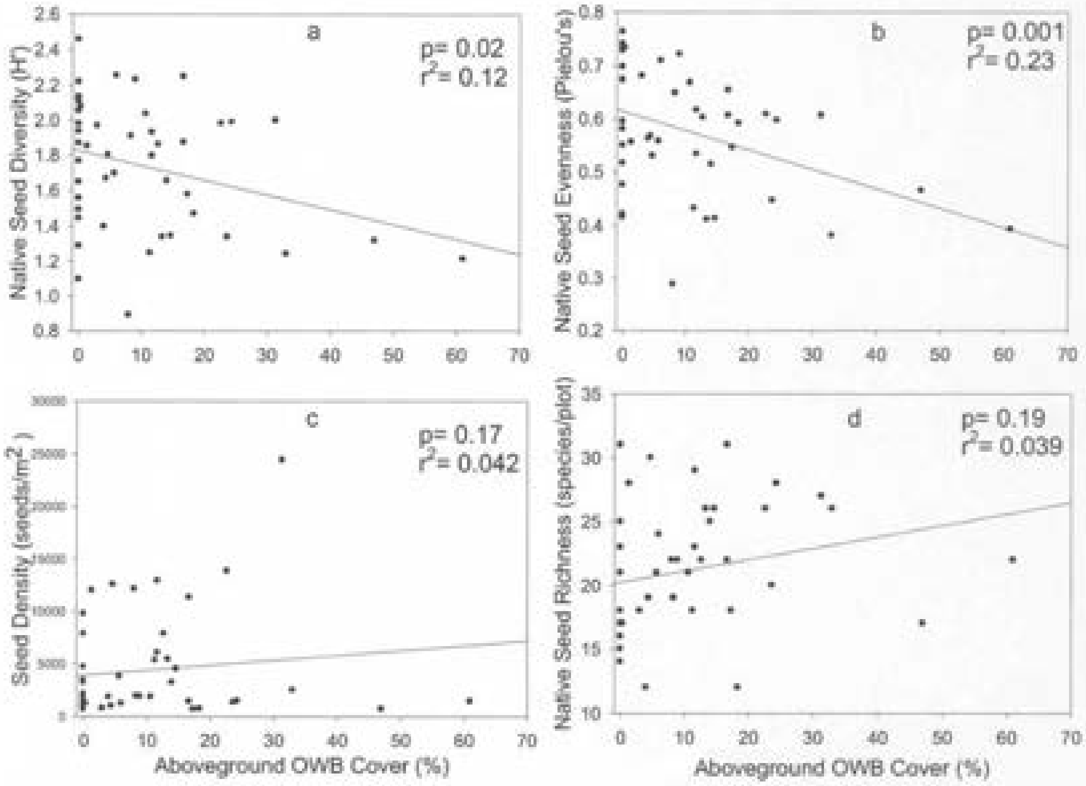

Fig. 4. Regression analysis of the relationship between mean aboveground percent cover of OWB and a) mean Shannon diversity index of native seeds b) mean Pielou's evenness index of native seeds c) mean density of native seeds (seeds/m^2) and d) mean richness of native seeds.

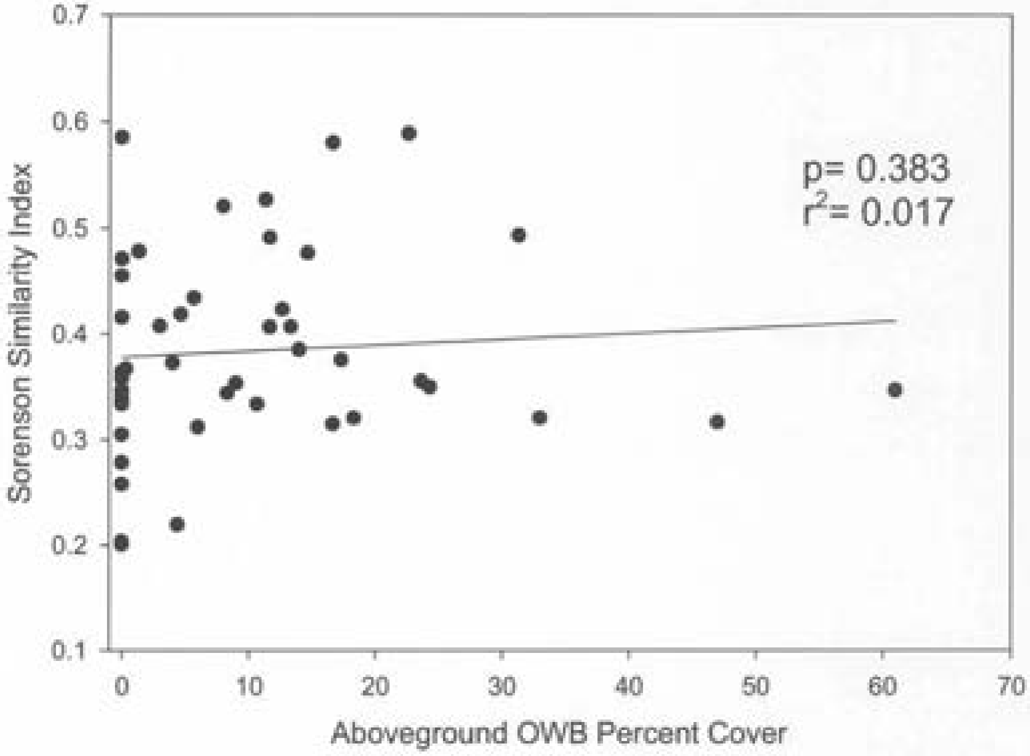

Fig. 5. Regression analysis of the relationship between mean aboveground percent cover of OWB and the Sorenson similarity index between the aboveground species and the seed bank species

Appendix 1. Mean seed density (seeds/m^2) of species recorded in the seed bank community at different levels of aboveground OWB invasion

	Percent invasion by OWB				
Scientific Name	**Uninvaded**	**1–10**	**11–20**	**21–30**	**>30**
	----------Mean seed density (Standard error)----------				
Native dominant grasses					
Schizachyrium scoparium	89.7 *(56.4)*	35.2 *(17.3)*	25.8 *(21.6)*	15.6 *(15.6)*	112.5 *(129.9)*
Buchloe dactyloides	63.6 *(18.5)*	46.1 *(33.5)*	71.9 *(22.1)*	53.1 *(30.8)*	25.8 *(26.3)*
Bouteloua curtipendula	8.0 *(3.1)*	9.4 *(5.3)*	62.5 *(28.6)*	18.7 *(9.4)*	9.4 *(7.7)*
Bouteloua gracilis	18.7 *(10.9)*	10.9 *(6.4)*	0.0 *(0)*	0.0 *(0)*	68.0 *(78.5)*
Andropogon gerardii	16.1 *(12)*	0.0 *(0)*	0.0 *(0)*	0.0 *(0)*	0.0 *(0)*
Aristida purpurea	2.0 *(1.9)*	0.8 *(0.8)*	4.7 *(3.9)*	0.0 *(0)*	7.0 *(8.1)*
Native non-dominant grasses					
Sporobolus asper	235.0 *(78.1)*	1262.0 *(809)*	1974.8 *(561.4)*	1096.7 *(1073)*	2160.0 *(2302)*
Chloris verticillata	155.0 *(52.5)*	780.0 *(454.6)*	521.0 *(176.6)*	1527.9 *(1471)*	449.9 *(383.1)*
Sporobolus cryptandrus	198.0 *(53.2)*	472.0 *(302)*	274.2 *(105.2)*	434.3 *(424.9)*	157.0 *(51.2)*
Bothriochloa laguroides	147.0 *(44.2)*	361.0 *(72)*	467.1 *(123.1)*	275.0 *(70.6)*	236.7 *(112.3)*
Bouteloua hirsuta	695.0 *(359.5)*	275.0 *(137.8)*	110.1 *(36.6)*	56.2 *(28.1)*	79.7 *(52.7)*
Carex sp.	167.4 *(142.3)*	60.1 *(31.9)*	85.9 *(32.7)*	187.5 *(164.2)*	656.2 *(696.4)*
Tridens albescens	0.7 *(0.6)*	18.0 *(10.2)*	96.1 *(59)*	415.6 *(392.1)*	447.6 *(456.7)*
Tridens muticus	0.7 *(0.6)*	144.0 *(130.7)*	25.8 *(13.4)*	0.0 *(0)*	0.0 *(0)*
Tridens flavus	2.0 *(1.9)*	0.0 *(0)*	55.5 *(41.3)*	18.7 *(18.7)*	0.0 *(0)*

Eleocharis sp.	0.7	*(0.6)*	11.7	*(8.1)*	16.4	*(5.4)*	9.4	*(0)*	16.4	*(18.9)*
Poa arachnifera	1.3	*(0.9)*	10.9	*(10.9)*	1.6	*(1.1)*	28.1	*(28.1)*	0.0	*(0)*
Sorghastrum nutans	0.0	*(0)*	11.7	*(11.7)*	0.0	*(0)*	15.6	*(15.6)*	11.7	*(13.5)*
Setaria sp.	1.3	*(1.3)*	10.2	*(6.9)*	8.6	*(8.6)*	9.4	*(9.4)*	0.0	*(0)*
Typha sp.	8.7	*(3.9)*	2.3	*(1.2)*	4.7	*(3.2)*	0.0	*(0)*	4.7	*(3.1)*
Elymus smithii	0.0	*(0)*	12.5	*(12.5)*	0.0	*(0)*	0.0	*(0)*	2.3	*(2.7)*
Dichanthelium oligosanthes	3.3	*(2)*	0.0	*(0)*	8.6	*(8.6)*	0.0	*(0)*	0.0	*(0)*
Juncus. sp	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	9.4	*(10.8)*
Schedonnardus paniculatus	2.7	*(2)*	0.0	*(0)*	1.6	*(1.6)*	0.0	*(0)*	0.0	*(0)*
Panicum obtusum	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	2.3	*(2.7)*
Native perennial forbs										
Oxalis stricta	26.1	*(16.6)*	220.3	*(121.6)*	257.0	*(110.7)*	524.9	*(303.2)*	105.5	*(111.2)*
Nothoscordum bivalve	169.4	*(86.4)*	32.8	*(10.3)*	47.7	*(30.8)*	3.1	*(3.1)*	0.0	*(0)*
Ambrosia psilostachya	15.4	*(7.7)*	18.0	*(7.8)*	54.7	*(25.4)*	34.4	*(13.6)*	37.5	*(15.3)*
Phyla lanceolata	1.3	*(0.9)*	3.1	*(1.8)*	3.1	*(1.8)*	3.1	*(3.1)*	35.2	*(22.3)*
Artemisia ludoviciana	0.7	*(0.6)*	0.8	*(0.8)*	7.8	*(7)*	18.7	*(18.7)*	0.0	*(0)*
Physalis heterophylla	10.7	*(7.6)*	0.0	*(0)*	7.8	*(5.5)*	3.1	*(3.1)*	2.3	*(2.7)*
Cuscuta sp.	4.7	*(2.8)*	10.9	*(3)*	3.1	*(1.8)*	0.0	*(0)*	0.0	*(0)*
Oxalis violacea	0.0	*(0)*	9.4	*(7)*	1.6	*(1.6)*	0.0	*(0)*	0.0	*(0)*
Symphyotrichum ericoides	1.3	*(0.9)*	0.8	*(0.8)*	3.1	*(2.4)*	0.0	*(0)*	2.3	*(2.7)*
Physalis pumila	7.4	*(7.1)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Vernonia baldwinii	2.0	*(1.9)*	1.6	*(1.1)*	2.3	*(2.3)*	0.0	*(0)*	0.0	*(0)*
Scutellaria resinosa	5.4	*(3.1)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Erysimum asperum	0.0	*(0)*	3.9	*(3.9)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Lithospermum arvense	2.0	*(1.9)*	0.8	*(0.8)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*

Oputia sp.	0.0	*(0)*	0.0	*(0)*	1.6	*(1.1)*	0.0	*(0)*	0.0	*(0)*
	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Native annual grasses	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Panicum capillare	24.1	*(12.5)*	49.2	*(22.1)*	17.2	*(8.1)*	109.4	*(104.7)*	63.3	*(65.9)*
Vulpia octoflora	6.0	*(3.5)*	3.9	*(2.4)*	0.0	*(0)*	18.7	*(18.7)*	2.3	*(2.7)*
Eriochloa contracta	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	3.1	*(3.1)*	0.0	*(0)*
Native annual forbs										
Helenium microcephalum	0.7	*(0.6)*	0.8	*(0.8)*	2.3	*(1.7)*	0.0	*(0)*	1305.0	*(1507)*
Conyza canadensis	392.4	*(295.8)*	70.3	*(20.7)*	207.8	*(127.4)*	253.1	*(143.5)*	23.4	*(15.6)*
Croton sp.	115.8	*(24.2)*	165.6	*(54.2)*	252.3	*(90.6)*	109.4	*(50)*	210.9	*(141.2)*
Euphorbia prostrata	1.3	*(1.3)*	7.0	*(4.3)*	31.2	*(23)*	3.1	*(3.1)*	482.8	*(514.8)*
Plantago sp.	58.9	*(19)*	59.4	*(23.4)*	85.9	*(30.7)*	78.1	*(27.2)*	49.2	*(25.1)*
Ammannia coccinea	2.0	*(1.4)*	3.9	*(3.2)*	3.9	*(3.2)*	6.2	*(6.2)*	302.3	*(341.9)*
Solanum rostratum	8.0	*(6.4)*	50.8	*(27)*	111.7	*(43.6)*	78.1	*(41.3)*	65.6	*(31.2)*
Amphiachyris dracunculoides	22.1	*(9.5)*	36.7	*(22.2)*	71.9	*(21.2)*	12.5	*(12.5)*	42.2	*(28.5)*
Acalypha ostryifolia	32.1	*(29.7)*	0.0	*(0)*	41.4	*(23.1)*	0.0	*(0)*	0.0	*(0)*
Euphorbia marginata	1.3	*(0.9)*	2.3	*(1.7)*	10.9	*(6.3)*	28.1	*(16.2)*	11.7	*(13.5)*
Verbena bracteata	1.3	*(0.9)*	3.1	*(1.8)*	13.3	*(10.9)*	9.4	*(5.4)*	11.7	*(10.2)*
Euphorbia dentata	20.8	*(18.7)*	0.8	*(0.8)*	11.7	*(9.5)*	0.0	*(0)*	4.7	*(5.4)*
Centaurea americana	8.0	*(4.5)*	9.4	*(4.9)*	6.2	*(3.3)*	3.1	*(3.1)*	2.3	*(2.7)*
Helianthus annuus	22.8	*(22)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Polygonum pensylvanicum	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	14.1	*(12.9)*
Geranium carolinianum	1.3	*(1.3)*	4.7	*(4.7)*	1.6	*(1.6)*	6.2	*(6.2)*	0.0	*(0)*
Tetraneuris linearifolia	6.0	*(2.8)*	2.3	*(1.7)*	5.5	*(3.2)*	0.0	*(0)*	0.0	*(0)*
Gaura mollis	6.7	*(4.4)*	6.2	*(5.5)*	0.8	*(0.8)*	0.0	*(0)*	0.0	*(0)*
Verbena dakotaka	3.3	*(1.8)*	1.6	*(1.6)*	3.1	*(2.4)*	0.0	*(0)*	2.3	*(2.7)*

Linum rigidum	3.3	*(1.8)*	1.6	*(1.1)*	0.8	*(0.8)*	3.1	*(3.1)*	0.0	*(0)*
Leucospora multifida	0.0	*(0)*	0.8	*(0.8)*	1.6	*(1.6)*	3.1	*(3.1)*	2.3	*(2.7)*
Coreopsis tinctoria	1.3	*(0.9)*	1.6	*(1.1)*	0.8	*(0.8)*	0.0	*(0)*	0.0	*(0)*
Solanum ptycanthum	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	3.1	*(3.1)*	0.0	*(0)*
Polanisia dodecandra	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	3.1	*(3.1)*	0.0	*(0)*
Lepidium sp.	0.0	*(0)*	1.6	*(1.6)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Aster subulatus	0.0	*(0)*	0.8	*(0.8)*	0.8	*(0.8)*	0.0	*(0)*	0.0	*(0)*
Palafoxia rosa	0.0	*(0)*	1.6	*(1.1)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Ambrosia trifida	0.0	*(0)*	0.0	*(0)*	0.8	*(0.8)*	0.0	*(0)*	0.0	*(0)*
Pluchea odorata	0.0	*(0)*	0.8	*(0.8)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Monolepis nuttalliana	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Native legumes										
Schrankia nuttallii	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	2.3	*(2.7)*
Dalea purpurea	0.0	*(0)*	1.6	*(1.1)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Strophostyles helvula	0.0	*(0)*	0.8	*(0.8)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Psoralea tenuiflora	0.7	*(0.6)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Astragulus sp.	0.7	*(0.6)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Native woody	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*	0.0	*(0)*
Salix sp.	5.4	*(1.8)*	3.9	*(1.8)*	1.6	*(1.1)*	3.1	*(3.1)*	11.7	*(0)*
Populus deltoides	6.0	*(4.5)*	1.6	*(1.1)*	4.7	*(2.4)*	3.1	*(3.1)*	0.0	*(0)*
Ulmus americana	0.0	*(0)*	0.8	*(0.8)*	0.8	*(0.8)*	0.0	*(0)*	0.0	*(0)*
Celtis sp.	0.0	*(0)*	0.0	*(0)*	0.8	*(0.8)*	0.0	*(0)*	0.0	*(0)*
Invasive perennial grasses										

Bothriochloa ischaemum	0.0 *(0)*	529.6 *(160.5)*	769.4 *(211.3)*	1046.7 *(257)*	2425.0 *(924)*
Sorghum halepense	0.0 *(0)*	0.0 *(0)*	7.0 *(7)*	0.0 *(0)*	72.6 *(83.9)*
Cynodon dactylon	12.1 *(4.2)*	11.7 *(6.1)*	38.3 *(15.2)*	0.0 *(0)*	4.7 *(5.4)*
Invasive annual grasses					
Bromus sp.	533.6 *(319.1)*	396.8 *(199)*	985.0 *(488.6)*	106.2 *(92.2)*	178.1 *(139)*
Panicum miliaceum	2.0 *(1.9)*	0.8 *(0.8)*	0.0 *(0)*	0.0 *(0)*	2.3 *(2.7)*
Invasive forbs					
Mollugo verticillata	16.1 *(10.7)*	4.7 *(3.2)*	36.7 *(21.6)*	106.2 *(106.2)*	11.7 *(10.2)*
Amaranthus blitoides	18.1 *(12.8)*	19.5 *(12.2)*	8.6 *(2.9)*	6.2 *(3.1)*	28.1 *(17.1)*
Melilotus officinalis	0.0 *(0)*	0.0 *(0)*	16.4 *(16.4)*	0.0 *(0)*	60.9 *(66.8)*
Stellaria media	0.0 *(0)*	56.2 *(56.2)*	0.8 *(0.8)*	0.0 *(0)*	0.0 *(0)*
Capsella bursa-pastoris	0.0 *(0)*	0.0 *(0)*	1.6 *(1.1)*	3.1 *(3.1)*	49.2 *(56.8)*
Carduus nutans	10.0 *(2.8)*	14.8 *(12.3)*	11.7 *(6.1)*	6.2 *(3.1)*	0.0 *(0)*
Chenopodium album	16.1 *(15.5)*	0.0 *(0)*	0.8 *(0.8)*	9.4 *(5.4)*	0.0 *(0)*
Taraxacum officinale	0.7 *(0.6)*	2.3 *(1.2)*	4.7 *(4.7)*	3.1 *(3.1)*	0.0 *(0)*
Daucus sp.	0.0 *(0)*	0.0 *(0)*	7.0 *(7)*	0.0 *(0)*	0.0 *(0)*
Convolvulus arvensis	1.3 *(1.3)*	0.0 *(0)*	0.0 *(0)*	0.0 *(0)*	0.0 *(0)*
Lactuca serriola	0.0 *(0)*	0.8 *(0.8)*	0.0 *(0)*	0.0 *(0)*	0.0 *(0)*
Rumex crispus	0.7 *(0.6)*	0.0 *(0)*	0.0 *(0)*	0.0 *(0)*	0.0 *(0)*
Lamium amplexicaule	0.0 *(0)*	0.0 *(0)*	0.0 *(0)*	0.0 *(0)*	0.0 *(0)*

Appendix 2. Mean percent cover of species recorded in the aboveground plant community at different levels of aboveground OWB invasion

	Percent invasion by OWB				
Scientific Name	**Uninvaded**	**1–10**	**11–20**	**21–30**	**>30**
	---------------------------------Mean percent cover (Standard error)---------------------------				
Native dominant grasses					
Bouteloua cutripendula	9.98 *(2.4)*	13.52 *(4.5)*	14.81 *(2.6)*	16.33 *(9.2)*	8.25 *(2.5)*
Bouteloua gracilis	17.71 *(3.6)*	10.78 *(2.7)*	5.31 *(1.7)*	5.00 *(2.6)*	0.42 *(0.2)*
Aristida purpurea	12.14 *(2.4)*	12.01 *(2.6)*	4.00 *(1.5)*	0.67 *(0.4)*	4.77 *(2.4)*
Buchloe dactyloides	8.52 *(3.1)*	5.77 *(2)*	4.70 *(1.5)*	3.33 *(2.3)*	1.33 *(0.7)*
Schizachyrium scoparium	6.62 *(4.2)*	1.70 *(1.2)*	5.97 *(3)*	0.00 *(0)*	5.02 *(5.8)*
Andropogon gerardii	8.19 *(4.8)*	0.67 *(0.5)*	0.42 *(0.3)*	0.11 *(0.1)*	1.08 *(1.3)*
Bothriochloa laguroides	4.46 *(1.1)*	8.37 *(1.6)*	10.67 *(1.5)*	10.22 *(2.6)*	5.50 *(1.4)*
Sporobolus asper	3.15 *(1.2)*	4.20 *(2)*	11.87 *(2.9)*	5.78 *(3.4)*	5.58 *(4.3)*
Bouteloua hirsuta	5.43 *(2.4)*	2.76 *(1.1)*	2.20 *(0.8)*	1.33 *(1)*	0.75 *(0.9)*
Chloris verticillata	0.77 *(0.3)*	1.15 *(0.7)*	2.89 *(1.1)*	6.89 *(6.7)*	0.25 *(0.2)*
Elymus smithii	0.05 *(0)*	0.59 *(0.6)*	0.82 *(0.6)*	2.80 *(1.4)*	1.08 *(1.3)*
Tridens muticus	0.39 *(0.3)*	1.31 *(0.9)*	1.76 *(1.2)*	0.00 *(0)*	0.00 *(0)*
Panicum obtusum	0.48 *(0.5)*	0.53 *(0.4)*	0.14 *(0.1)*	1.44 *(1.4)*	0.08 *(0.1)*
Setaria sp.	0.04 *(0)*	0.81 *(0.8)*	0.44 *(0.3)*	0.84 *(0.8)*	0.02 *(0)*
Sporobolus cryptandrus	0.50 *(0.2)*	0.95 *(0.4)*	0.20 *(0.1)*	0.22 *(0.2)*	0.00 *(0)*
Erioneuron pilosum	0.99 *(0.3)*	0.67 *(0.3)*	0.06 *(0.1)*	0.00 *(0)*	0.00 *(0)*
Tridens albescens	0.02 *(0)*	0.06 *(0.1)*	0.04 *(0)*	0.07 *(0.1)*	0.92 *(1.1)*
Elymus virginicus	0.26 *(0.3)*	0.00 *(0)*	0.56 *(0.5)*	0.00 *(0)*	0.08 *(0.1)*
Tridens flavus	0.00 *(0)*	0.00 *(0)*	0.47 *(0.3)*	0.00 *(0)*	0.42 *(0.5)*

Sorghastrum nutans	0.33 *(0.2)*	0.00 *(0)*	0.17 *(0.2)*	0.00 *(0)*	0.00 *(0)*
Schedonnardus paniculatus	0.13 *(0.1)*	0.14 *(0.1)*	0.03 *(0)*	0.00 *(0)*	0.00 *(0)*
Dichanthelium oligosanthes	0.05 *(0)*	0.03 *(0)*	0.19 *(0.2)*	0.00 *(0)*	0.00 *(0)*
Paspalum setaceum	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*	0.22 *(0.2)*	0.00 *(0)*
Spartina pectinata	0.00 *(0)*	0.00 *(0)*	0.03 *(0)*	0.00 *(0)*	0.00 *(0)*
Carex sp.	0.00 *(0)*	0.06 *(0.1)*	0.08 *(0.1)*	0.44 *(0.4)*	0.68 *(0.8)*
Native perennial forb					
Ambrosia psilostachya	4.31 *(1)*	7.91 *(2.9)*	9.89 *(2.9)*	3.40 *(1.8)*	4.68 *(2.7)*
Gutierrezia sarothrae	2.62 *(0.8)*	2.42 *(0.8)*	1.38 *(0.7)*	1.00 *(0.7)*	1.83 *(0.9)*
Artemisia ludoviciana	0.63 *(0.3)*	1.78 *(0.8)*	0.68 *(0.3)*	1.11 *(1.1)*	2.08 *(1.8)*
Calylophus lavandulifolia	1.09 *(0.5)*	2.29 *(0.7)*	0.96 *(0.4)*	0.13 *(0.1)*	1.08 *(1.1)*
Cirsium undulatum	0.40 *(0.2)*	0.66 *(0.4)*	1.43 *(0.4)*	0.91 *(0.9)*	0.27 *(0.2)*
Symphyotrichum ericoides	0.72 *(0.3)*	0.32 *(0.2)*	0.71 *(0.4)*	0.11 *(0.1)*	1.50 *(1.2)*
Oxalis stricta	0.07 *(0)*	0.59 *(0.3)*	1.22 *(0.4)*	1.22 *(1.1)*	0.22 *(0.1)*
Opuntia macrorhiza	0.47 *(0.2)*	1.23 *(0.7)*	0.56 *(0.5)*	0.00 *(0)*	0.00 *(0)*
Physalis heterophylla	0.35 *(0.2)*	0.06 *(0)*	0.79 *(0.3)*	0.49 *(0.3)*	0.57 *(0.4)*
Calylophus serrulatus	0.34 *(0.2)*	0.22 *(0.2)*	0.26 *(0.1)*	0.11 *(0.1)*	1.28 *(1.4)*
Sisyrinchium campestre	0.62 *(0.2)*	0.74 *(0.3)*	0.36 *(0.3)*	0.07 *(0)*	0.13 *(0.1)*
Gaura longiflora	0.16 *(0.1)*	0.28 *(0.1)*	0.23 *(0.1)*	0.78 *(0.7)*	0.42 *(0.4)*
Evolvulus nuttallianus	0.89 *(0.3)*	0.68 *(0.3)*	0.21 *(0.1)*	0.00 *(0)*	0.03 *(0)*
Liatris punctata	0.41 *(0.1)*	0.51 *(0.3)*	0.18 *(0.1)*	0.00 *(0)*	0.45 *(0.4)*
Paronychia jamesii	0.66 *(0.2)*	0.59 *(0.2)*	0.19 *(0.1)*	0.00 *(0)*	0.10 *(0.1)*
Krameria lanceolata	0.71 *(0.4)*	0.56 *(0.3)*	0.11 *(0.1)*	0.00 *(0)*	0.00 *(0)*
Hymenoxys scoposa	0.54 *(0.2)*	0.64 *(0.2)*	0.09 *(0)*	0.04 *(0)*	0.02 *(0)*
Asclepias viridis	0.23 *(0.1)*	0.42 *(0.2)*	0.24 *(0.1)*	0.11 *(0.1)*	0.33 *(0.2)*
Tragia ramosa	0.32 *(0.1)*	0.48 *(0.3)*	0.19 *(0.2)*	0.11 *(0.1)*	0.17 *(0.2)*
Castilleja sessiliflora	0.29 *(0.2)*	0.74 *(0.3)*	0.16 *(0.1)*	0.00 *(0)*	0.00 *(0)*

Ratibida columnifera	0.24	*(0.2)*	0.12	*(0.1)*	0.09	*(0.1)*	0.56	*(0.3)*	0.00	*(0)*
Hedyotis nigricans	0.39	*(0.3)*	0.25	*(0.2)*	0.15	*(0.1)*	0.02	*(0)*	0.10	*(0.1)*
Gaillardia suavis	0.03	*(0)*	0.10	*(0.1)*	0.23	*(0.1)*	0.04	*(0)*	0.43	*(0.5)*
Chrysopsis villosa	0.33	*(0.2)*	0.07	*(0.1)*	0.03	*(0)*	0.02	*(0)*	0.25	*(0.3)*
Machaeranthera pinnatifida	0.31	*(0.1)*	0.20	*(0.1)*	0.03	*(0)*	0.00	*(0)*	0.10	*(0.1)*
Calylophus hartwegii	0.24	*(0.2)*	0.26	*(0.2)*	0.08	*(0.1)*	0.00	*(0)*	0.00	*(0)*
Vernonia baldwinii	0.00	*(0)*	0.03	*(0)*	0.49	*(0.4)*	0.00	*(0)*	0.00	*(0)*
Solanum carolinense	0.00	*(0)*	0.00	*(0)*	0.03	*(0)*	0.44	*(0.4)*	0.00	*(0)*
Polygala alba	0.00	*(0)*	0.11	*(0.1)*	0.05	*(0)*	0.22	*(0.2)*	0.00	*(0)*
Hymenopappus scabiosaeus	0.05	*(0)*	0.12	*(0.1)*	0.06	*(0)*	0.13	*(0.1)*	0.02	*(0)*
Yucca glauca	0.15	*(0.1)*	0.01	*(0)*	0.01	*(0)*	0.11	*(0.1)*	0.03	*(0)*
Solanum elaeagnifolium	0.05	*(0)*	0.00	*(0)*	0.23	*(0.1)*	0.00	*(0)*	0.00	*(0)*
Dyssodia pentachaeta	0.21	*(0.2)*	0.01	*(0)*	0.03	*(0)*	0.00	*(0)*	0.00	*(0)*
Leucelene erciodies	0.05	*(0.1)*	0.17	*(0.1)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*
Penstemon albidus	0.15	*(0.1)*	0.00	*(0)*	0.06	*(0.1)*	0.00	*(0)*	0.00	*(0)*
Lithospermum caroliniense	0.00	*(0)*	0.03	*(0)*	0.00	*(0)*	0.00	*(0)*	0.17	*(0.2)*
Solidago canadensis	0.17	*(0.2)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*
Engelmannia peristenia	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*	0.17	*(0.2)*
Solidago missouriensis	0.12	*(0.1)*	0.00	*(0)*	0.01	*(0)*	0.00	*(0)*	0.00	*(0)*
Scutellaria resinosa	0.07	*(0)*	0.00	*(0)*	0.03	*(0)*	0.00	*(0)*	0.00	*(0)*
Cuscuta sp.	0.02	*(0)*	0.04	*(0)*	0.03	*(0)*	0.00	*(0)*	0.00	*(0)*
Oxalis violacea	0.04	*(0)*	0.04	*(0)*	0.01	*(0)*	0.00	*(0)*	0.00	*(0)*
Salvia azurea	0.00	*(0)*	0.03	*(0)*	0.06	*(0.1)*	0.00	*(0)*	0.00	*(0)*
Gaura villosa	0.10	*(0.1)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*
Mirabilis linearis	0.10	*(0.1)*	0.10	*(0.1)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*
Zinnia grandiflora	0.00	*(0)*	0.00	*(0)*	0.10	*(0.1)*	0.00	*(0)*	0.00	*(0)*
Cucurbita foetidissima	0.10	*(0.1)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*
Ferocactus sp.	0.10	*(0.1)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*	0.10	*(0.1)*
Nothoscordum bivalve	0.10	*(0.1)*	0.10	*(0.1)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*

Cirsium ochrocentrum	0.00 *(0)*	0.00 *(0)*	0.10 *(0.1)*	0.00 *(0)*	0.00 *(0)*
Achillea millefolium	0.00 *(0)*	0.10 *(0.1)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*
Kuhnia eupatorioides	0.00 *(0)*	0.10 *(0.1)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*
Galium virgatum	0.10 *(0.1)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*
Phyla lanceolata	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*	0.10 *(0.1)*
Allium sp.	0.00 *(0)*	0.00 *(0)*	0.01 *(0)*	0.00 *(0)*	0.00 *(0)*
Native annual grasses					
Panicum capillare	0.08 *(0.1)*	0.06 *(0)*	0.03 *(0)*	0.13 *(0.1)*	0.00 *(0)*
Native annual forbs					
Linum rigidum	1.06 *(0.3)*	1.23 *(0.3)*	0.30 *(0.1)*	0.40 *(0.4)*	0.27 *(0.1)*
Croton sp.	1.00 *(0.3)*	0.48 *(0.1)*	0.53 *(0.2)*	0.33 *(0.2)*	0.37 *(0.2)*
Grindelia squarrosa	0.16 *(0.1)*	0.52 *(0.3)*	0.79 *(0.3)*	0.80 *(0.3)*	0.22 *(0.2)*
Euphorbia marginata	0.01 *(0)*	0.29 *(0.2)*	0.22 *(0.1)*	1.33 *(1.3)*	0.33 *(0.3)*
Eriogonum annuum	0.56 *(0.2)*	0.54 *(0.2)*	0.09 *(0.1)*	0.02 *(0)*	0.00 *(0)*
Amphiachyris dracunculoides	0.49 *(0.2)*	0.11 *(0.1)*	0.25 *(0.1)*	0.11 *(0.1)*	0.17 *(0.2)*
Hedeoma drummondii	0.67 *(0.3)*	0.18 *(0.1)*	0.25 *(0.2)*	0.00 *(0)*	0.00 *(0)*
Coreopsis tinctoria	0.34 *(0.1)*	0.42 *(0.3)*	0.16 *(0.1)*	0.02 *(0)*	0.02 *(0)*
Conyza canadensis	0.20 *(0.2)*	0.03 *(0)*	0.03 *(0)*	0.67 *(0.7)*	0.00 *(0)*
Plantago patagonica	0.19 *(0.1)*	0.25 *(0.1)*	0.07 *(0)*	0.20 *(0.2)*	0.05 *(0.1)*
Erigeron strigosus	0.12 *(0.1)*	0.04 *(0)*	0.11 *(0)*	0.33 *(0.2)*	0.10 *(0.1)*
Plantago sp.	0.30 *(0.2)*	0.02 *(0)*	0.08 *(0)*	0.00 *(0)*	0.05 *(0)*
Centaurea americana	0.11 *(0.1)*	0.09 *(0)*	0.09 *(0)*	0.04 *(0)*	0.10 *(0.1)*
Helianthus annuus	0.43 *(0.4)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*
Thelesperma filifolium	0.12 *(0.1)*	0.03 *(0)*	0.03 *(0)*	0.00 *(0)*	0.17 *(0.2)*
Solanum rostratum	0.00 *(0)*	0.01 *(0)*	0.01 *(0)*	0.22 *(0.2)*	0.10 *(0.1)*

Aster subulatus	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*	0.33 *(0.3)*	0.00 *(0)*
Geranium carolinianum	0.02 *(0)*	0.04 *(0)*	0.00 *(0)*	0.13 *(0.1)*	0.08 *(0.1)*
Euphorbia missurica	0.13 *(0.1)*	0.06 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*
Palafoxia rosa	0.00 *(0)*	0.08 *(0.1)*	0.09 *(0.1)*	0.00 *(0)*	0.00 *(0)*
Monarda citriodora	0.07 *(0.1)*	0.04 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*
Triodanis perfoliata	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*	0.11 *(0.1)*	0.00 *(0)*
Euphorbia prostrata	0.00 *(0)*	0.01 *(0)*	0.03 *(0)*	0.02 *(0)*	0.05 *(0.1)*
Acalypha ostryifolia	0.00 *(0)*	0.00 *(0)*	0.03 *(0)*	0.00 *(0)*	0.00 *(0)*
Euphorbia dentata	0.02 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*
Lepidium sp.	0.00 *(0)*	0.01 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*
Verbena sp.	0.00 *(0)*	0.00 *(0)*	0.01 *(0)*	0.00 *(0)*	0.00 *(0)*
Native legumes					
Psoralea tenuiflora	1.34 *(0.4)*	0.90 *(0.4)*	1.72 *(0.6)*	0.44 *(0.4)*	2.28 *(2.1)*
Astragalus sp.	0.43 *(0.2)*	0.22 *(0.1)*	0.22 *(0.2)*	0.67 *(0.5)*	0.70 *(0.5)*
Schrankia nuttallii	0.00 *(0)*	0.14 *(0.1)*	0.11 *(0.1)*	0.13 *(0.1)*	0.33 *(0.3)*
Dalea purpurea	0.06 *(0)*	0.11 *(0)*	0.22 *(0.1)*	0.00 *(0)*	0.13 *(0.1)*
Strophostyles helvula	0.10 *(0.1)*	0.00 *(0)*	0.03 *(0)*	0.00 *(0)*	0.00 *(0)*
Dalea aurea	0.02 *(0)*	0.07 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*
Chamaecrista fasciculata	0.00 *(0)*	0.06 *(0.1)*	0.01 *(0)*	0.00 *(0)*	0.00 *(0)*
Lupinus texensis	0.02 *(0)*	0.00 *(0)*	0.03 *(0)*	0.00 *(0)*	0.00 *(0)*
Acacia angustissima	0.02 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*
Native woody					
Rhus glabra	0.02 *(0)*	0.00 *(0)*	0.00 *(0)*	0.00 *(0)*	0.60 *(0.7)*
Ulmus sp.	0.00 *(0)*	0.03 *(0)*	0.00 *(0)*	0.00 *(0)*	0.02 *(0)*
Celtis sp.	0.00 *(0)*	0.02 *(0)*	0.01 *(0)*	0.00 *(0)*	0.02 *(0)*

Invasive perennial grasses										
Bothriochloa ischaemum	0.00	*(0)*	4.56	*(0.9)*	14.08	*(0.8)*	23.56	*(0.5)*	43.08	*(8)*
Cynodon dactylon	0.00	*(0)*	0.17	*(0.1)*	0.08	*(0.1)*	0.33	*(0.2)*	2.75	*(3)*
Sorghum halepense	0.00	*(0)*	0.00	*(0)*	0.06	*(0.1)*	0.00	*(0)*	0.00	*(0)*
Invasive annual grasseses										
Bromus sp.	3.10	*(1.7)*	2.48	*(1.2)*	4.51	*(1.1)*	1.24	*(1.1)*	0.65	*(0.5)*
Invasive forbs										
Carduus nutans	0.14	*(0.1)*	1.56	*(1.5)*	1.28	*(1.1)*	2.22	*(2.2)*	0.00	*(0)*
Medicago lupulina	0.00	*(0)*	0.00	*(0)*	0.06	*(0.1)*	0.00	*(0)*	0.25	*(0.3)*
Convolvulus arvensis	0.00	*(0)*	0.00	*(0)*	0.03	*(0)*	0.11	*(0.1)*	0.10	*(0.1)*
Capsella bursa-pastoris	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*	0.11	*(0.1)*	0.00	*(0)*
Taraxicum officinale	0.00	*(0)*	0.00	*(0)*	0.11	*(0.1)*	0.00	*(0)*	0.00	*(0)*
Melilotus officinalis	0.00	*(0)*	0.00	*(0)*	0.08	*(0.1)*	0.00	*(0)*	0.00	*(0)*
Tragopogon dubius	0.00	*(0)*	0.01	*(0)*	0.06	*(0)*	0.00	*(0)*	0.00	*(0)*
Chenopodium album	0.05	*(0)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*	0.02	*(0)*
Lactuca serriola	0.00	*(0)*	0.00	*(0)*	0.03	*(0)*	0.00	*(0)*	0.00	*(0)*
Amaranthus blitoides	0.00	*(0)*	0.01	*(0)*	0.00	*(0)*	0.00	*(0)*	0.00	*(0)*

VITA

Scott Gallup Robertson

Candidate for the Degree of

Master of Science

Thesis: HERBICIDE CONTROL AND SEED BANK DYNAMICS OF OLD WORLD BLUESTEM

Major Field: Natural Resource Ecology and Management

Biographical:

Personal Data:

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Name: Scott Gallup Robertson Date of Degree: May, 2009

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: HERBICIDE CONTROL AND SEED BANK DYNAMICS OF OLD WORLD BLUESTEM

Pages in Study: 72 Candidate for the Degree of Master of Science

Major Field: Natural Resource Ecology and Management

Scope and Method of Study:
The invasive grass Old World bluestem (OWB; *Bothriochloa ischaemum*) threatens native plant and animal diversity. I used single, double, and triple applications of glyphosate in various combinations with and without a mowing or burning to determine the most effective treatment for controlling OWB for future restoration. Also I assessed the affects of OWB invasion on native species diversity and abundance of the aboveground plant community and seed bank community.

Findings and Conclusions:
One year after treatment, burning and mowing prior to a single herbicide application improved the amount of OWB control compared to a single herbicide treatment. Burning or mowing with two herbicide applications provided more OWB control relative to plots that received only two herbicide application. The burn and mow double herbicide treatments did not exhibit an increase in reproductive tiller density or visual obstruction a year after treatment, whereas plots that received only two herbicide applications did. Burning or mowing with two herbicide treatments provided similar amounts of OWB control compared with the triple herbicide treatment. Combining burning or mowing with herbicide applications provided more effective OWB control than the herbicide only treatments. Regarding the seed bank, native aboveground species diversity and cover showed a steep declined as OWB cover increased. There was a slight decline in native seed diversity, and no change in native seed density as invasion increased. OWB seed density increased with increasing invasion. I hypothesize that as OWB invasion increases native aboveground plants decrease in diversity and abundance, but native seed bank diversity and density does not decline, but over time as native seeds are lost, and the lack of native seed replenishment from the aboveground community, native seed bank diversity and density will decline.

ADVISER'S APPROVAL: Karen Hickman

AVIAN RESPONSE TO OLD WORLD BLUESTEM (*BOTHRIOCHLOA ISCHAEMUM*) MONOCULTURES IN MIXED-GRASS PRAIRIE

By

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Bachelor of Science in Fisheries and Wildlife Biology

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Russellville, Arkansas

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AVIAN RESPONSE TO OLD WORLD BLUESTEM (*BOTHRIOCHLOA ISCHAEMUM*) MONOCULTURES IN MIXED-GRASS PRAIRIE

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CHAPTER I

INFLUENCE OF SEEDED EXOTIC GRASSLANDS ON DENSITY AND COMMUNITY COMPOSITION OF BREEDING SONGBIRDS IN MIXED-GRASS PRAIRIE

Introduction

Grassland bird populations have exhibited more rapid and widespread declines than any other group of birds in North America (Peterjohn and Sauer 1999, Askins et al. 2007, Sauer et al. 2007), with habitat loss, degradation, and fragmentation often cited as the primary causes (Vickery and Herkert 2001). While the majority of habitat loss has involved conversion of native prairie to grain cultivation, seeded grasslands, managed to support a single or small number of exotic grass species, have become extensive throughout the Great Plains, and may be an important factor contributing to grassland bird declines (Delisle and Savidge 1997, Sutter and Brigham 1998, Hickman et al. 2006). In the mid 1980s, it was estimated that seeded monocultures accounted for > 30% of the total grassland cover in Montana, North Dakota, Wyoming, South Dakota, Colorado, Nebraska, Kansas, Oklahoma, New Mexico, and Texas (USDA 1986). With the passage of the 1985 Food Security Act's Conservation Reserve Program (CRP), millions of additional hectares were converted from cropland to exotic monocultures (Schenk and Williamson 1991, Baker 2000).

The CRP provides landowners financial incentives to remove cropland from production and place it in permanent cover under 10- or 15-year contracts (USDA 2008b, Anstey et al. 1995). The original CRP sign-up allowed, and in some cases encouraged (Baker 2000), landowners to plant exotic species such as weeping lovegrass (*Eragrostis curvula*), crested wheatgrass (*Agropyron cristatum*), and Old World bluestem (OWB; *Bothriochloa ischaemum*). These grasses have a wide tolerance of environmental conditions and are easy to establish, but they also may displace native species, thereby reducing diversity and disrupting native grassland ecosystems (D'Antonio and Vitousek 1992). Despite more stringent requirements to plant native grasses in both new CRP sign-ups and renewals after 1996, fields planted to a single, exotic species are still abundant. It has been estimated that >1 million ha were planted in Oklahoma and Texas alone over 10 years (White and Dewald 1996). Over 50% of the CRP land has been planted to OWB in some western Oklahoma counties (Ripper and VerCauteren 2007).

Studies examining effects of exotic grass species on birds have found mixed results. For example, Scott and Lima (2004) and Jones and Bock (2005) showed that some grassland birds, including species of conservation priority, can benefit from exotic grass fields if they meet specific area and structural requirements for breeding. Others suggest that exotic grasslands provide less suitable habitat for breeding birds because these fields support simplified plant communities and fewer arthropods than native fields (Flanders et al. 2006, Hickman et al. 2006). Despite widespread use and invasive potential of OWB, few studies have examined effects of seeded OWB monocultures on grassland songbirds (McIntyre and Thompson 2003, Chapman et al. 2004, Hickman et al. 2006), and these have not included a sampling method that allows for robust comparisons of abundance and density among different species. Moreover, the overall avian conservation value of OWB fields has not been compared to that of native mixed-grass prairie.

My objectives were to compare 1) abundance and community composition of breeding birds, 2) vegetation structure and composition, and 3) arthropod biomass between OWB monocultures and native mixed-grass prairie.

Methods

I conducted this study in May–July, 2007 and 2008 in Alfalfa, Grant, and Garfield counties in north-central Oklahoma, which is part of the Prairie Tableland ecoregion of the Central Great Plains (Woods et al. 2005). This ecoregion is characterized by level to slightly rolling plains (local relief, 3–42 m) with deep, fertile soils. The mean daily high temperature ranges from 13°C to 35°C from May through July. Mean precipitation is 68–94 cm, >30% of which falls from May through July (Oklahoma Climatological Survey 2008). The dominant land use in the study area is small grain agriculture (primarily winter wheat and grain sorghum) and alfalfa production. Seeded grassland is abundant, mainly as OWB monocultures (Ripper and VerCauteren 2007). The natural vegetation is mixed-grass prairie, dominated by little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), side-oats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), indiangrass (*Sorghastrum nutans*), switchgrass *(Panicum virgatum*), and buffalograss (*Buchloe dactyloides*). Rangeland is more common than cropland on steeper slopes (Woods et al. 2005). I selected all study sites within a broad agricultural matrix interspersed with grassland cover. Dominant land cover consisted of about 68% cropland and 26% native rangeland or exotic pastures in Alfalfa, Grant, and Garfield counties (USDA 2008a).

I selected 12 privately owned study sites to provide 6 replicates of OWB monoculture and 6 replicates of native mixed-grass prairie (Fig. 1). I attempted to select study fields representative of the region, with consideration given to area (60–100 ha), topography (flat to gently rolling), and management. Fields were classified according to a visual estimation of grazing intensity (Smith 1998). Fields with a higher proportion of vegetation visible than bare ground were classified as lightly grazed. Fields with a higher proportion of bare ground were classified as heavily grazed. Eleven of 12 sites were lightly grazed by cattle during the study; one field of native grasses was heavily grazed. Four of the OWB sites also were managed for hay production. Because OWB is a warm-season grass, haying in the study area occurred once or twice annually in mid-July to mid-August, after the completion of field sampling. Two of the OWB fields were fertilized during the study to promote hay production; no other specific disturbances related to hayfield management occurred at any of the sites during the study.

I estimated bird density at all fields using distance sampling (Buckland et al. 2001). I used National Agricultural Imagery Program (http://www.fsa.usda.gov/FSA) aerial photos to establish 750-m transects in each field; no transect was placed within 50 m of a field's edge. I avoided placing transects parallel and close to field edges and riparian zones to avoid biasing detection distances in response to linear features parallel to the transect line. Transects were marked with a hand-held GPS unit and the same transects were resampled throughout the study.

Each field was sampled between three and five times in 2007 and five times in 2008 from mid-May through mid-July on days with no rain and light winds (<10 km/hr). I sampled between 0530 and 1000 h CDT by slowly walking each transect and recording all individuals seen or heard. Flyovers and birds using field edges were not counted. I used a compass and laser rangefinder to determine the distance (m) and angle (azimuth degrees) to each bird from the point of detection and later calculated the perpendicular distance from each bird to the transect.

I restricted statistical analyses to those species detected on $\geq$ 25% of the surveys within a field type, in at least 1 year. I estimated density (number of individuals/ha) for Grasshopper Sparrow (*Ammodramus savannarum*), Eastern Meadowlark (*Sturnella magna*), and Dickcissel (*Spiza americana*) in each year and in each of the two field types using the program DISTANCE (Thomas et al. 1998, Buckland et al. 2001). DISTANCE used the perpendicular distance from the transect line to each individual bird detected to generate a detection model used to provide a density estimate. Distance Sampling is described in detail by Buckland et al. (2001). I interpreted differences in breeding density as statistically significant based on non-overlapping 95% confidence intervals in density estimates provided by DISTANCE. Because differences were not detected between years, data for each species were pooled to test for field type effects.

No other bird species, aside from the three mentioned above, encountered during this study occurred frequently enough on study sites to obtain adequate sample sizes ($n >$ 60) for accurate density estimation with DISTANCE. Therefore, to minimize error resulting from differences in detectability, I compared detection-distance histograms among samples and truncated data to within 25 m of transects. That allowed analysis of 6 additional species with $\geq$ 25% detectability rates. Density (number of individuals/ha) was estimated for each visit to a site and averaged within years for statistical analyses. Data were pooled when no year effect was detected. I used a Wilcoxon signed-rank test for differences between years within field types and a Mann-Whitney *U*-test to detect differences between field types. SPSS 16.0 (SPSS Institute, Chicago IL) was used for statistical comparisons of all data not analyzed with DISTANCE.

To investigate differences in breeding bird community composition between OWB and native grasslands, I calculated and compared species richness, the Shannon index of diversity (*H '*; Magurran 2004), and two indices of conservation value (*CV*) among all fields. Conservation values were based on Partners in Flight priority scores (Carter et al. 2000, Nuttle et al. 2003), and calculated as:

$$CV_1 = \sum_{i=1}^{S} p_i w_i \text{ and } CV_2 = \sum_{i=1}^{S} r_i w_i,$$

where S was the number of species in the community, p was presence or absence of species i, r was relative abundance of the species, and w was a weighting factor derived from each species' PIF regional conservation score. The CV_2 score weighed each species' conservation value according to its relative abundance, while the CV_1 score weighed all species' conservation scores equally. Therefore, the CV_1 score was more sensitive to uncommon species. I used the Mann-Whitney *U*-test to compare community composition parameters between OWB and native sites.

I measured vegetation during the third week of July, 2007 and 2008. All vegetation sampling was conducted before the start of haying in each field. Points were established at 30 random distances along the same transects used to sample birds. At each point, I measured vertical obstruction from 4 directions using a Robel pole (Robel et al. 1970; n = 120 points/field). The lowest obstructed point visible from 4 m at a height of 1 m above the ground was recorded. Standard deviations of vertical obstruction at each point (within a 4 m radius) and across each sampling transect (750 m) were used as measurements structural heterogeneity at the point and field scales (e.g., Fuhlendorf and Engle 2004). Plant canopy cover was estimated 1 m in front of the Robel pole in the direction of the transect using a 1-m^2 frame (Towne et el. 2005). Only plants rooted completely inside the frame were recorded. I estimated percent cover of OWB, other grasses, forbs, litter, and bare ground in cover classes (0%, 1–5%, 6–25%, 26–50%, 51–75%, 76–95%, 96–100%). Litter was defined as any dead plant material on the soil surface in any state of decomposition. Midpoints of each cover class were used to calculate percent canopy cover of vegetation characteristics (Daubenmire 1959, Towne et al. 2005). I also recorded the maximum vegetation height inside the frame. Repeated-measures ANOVA was used to compare July vegetation structure and composition characteristics between the two field types with year as the repeated measure. I identified relationships among vegetation variables and densities of uncommon bird species using a Spearman rank correlation matrix.

To determine effects of OWB on food availability for breeding grassland birds, I collected and compared arthropod samples in each site during the third week of July 2007 and 2008. I sampled arthropods with a 32-cm diameter net in 2007 and a gasoline-powered, hand-held vacuum (D-vac; Dietrick et al. 1960) in 2008 along the same transects used to sample birds and vegetation. Following the method of Hull et al. (1996), I walked slowly along a randomly chosen 100-m section of each transect, sweeping the top of the vegetation with the D-vac or net (100 sweeps). Samples were frozen immediately following collection. I sorted all arthropods by order and obtained dry biomass (g/transect) for each order in each field. I tested for differences in biomass between OWB and native sites for the most abundant arthropod orders using ANOVA. Because of differences in sampling methods between 2007 and 2008, no comparisons of arthropod biomass were made between years.

Results

In the 2007 and 2008 breeding seasons, I observed 40 bird species using native fields and 28 using OWB monocultures (Tab. 1). Nine species had $\geq$ 25% detection rates in at least one field type and were compared between field types (Fig. 2). No year effects were detected between 2007 and 2008, so data were pooled for tests of differences between field types. Grasshopper Sparrow was the most abundant species, followed by Eastern Meadowlark and Dickcissel. Of those species analyzed with DISTANCE, density of Grasshopper Sparrow was significantly different and higher in OWB monocultures ($P = 0.01$). Densities of Dickcissel and Eastern Meadowlark did not differ between the two field types. Of the less abundant species, Killdeer ($U = 3.5$, $P = 0.01$) occurred at higher densities in fields planted to OWB, while Northern Bobwhite ($U = 3.0$, $P < 0.01$) and Lark Sparrow ($U = 9.0$, $P = 0.05$) occurred at higher densities in native mixed-grass prairie. I detected no differences among other species.

Mean Shannon diversity ($U = 6.00$, $P = 0.03$), species richness ($U = 4.50$, $P = 0.02$), and CV_1 ($U = 5.00$, $P = 0.02$) were higher in native fields. Mean CV_2 was higher in OWB fields than in native prairie (Tab. 2; $U = 0.00$, $P < 0.01$).

Differences in structure and composition of vegetation variables were detected between years and between field types (Tab. 3). Litter cover ($F = 10.1$, $P = 0.01$) was lower, and vegetation height ($F = 39.63$, $P < 0.001$), vertical obstruction ($F = 13.1$, $P = 0.01$), and point heterogeneity ($F = 8.56$, $P = 0.02$) were higher in July 2007 than in July

2008. Forb cover (*F* = 21.2, *P* = 0.002) and litter cover (*F* = 9.09, *P* = 0.017) were higher in native fields than OWB in both years.

Spearman-rank correlations revealed relationships between some bird species and vegetation characteristics (Tab. 4; Fig. 3). Dickcissel density was correlated positively to forb cover (*P* = 0.05), vertical obstruction (*P* < 0.01), and point structural heterogeneity (*P* = 0.03). Density of Brown-headed Cowbirds was correlated negatively to vegetation height (*P* = 0.04), and vertical obstruction (*P* = 0.01). Killdeer density was correlated negatively to forb cover (*P* = 0.02), vertical obstruction (*P* = 0.04), and point structural heterogeneity (*P* = 0.04). Mourning Dove density was correlated positively to bare ground (*P* = 0.01). Density of Northern Bobwhite was correlated positively to forb cover (*P* = 0.01), and litter cover (*P* < 0.01), and negatively correlated to bare ground (*P* = 0.01). Density of Lark Sparrow was correlated negatively to vegetation height (*P* = 0.01).

Total arthropod biomass was higher in native fields than OWB monocultures during both years (Fig. 4): 2007 (*F* = 4.59, *P* = 0.05) and 2008 (*F* = 11.83, *P* = 0.01). Orthoptera was the dominant arthropod order by biomass in both sampling periods, followed by Hemiptera, Coleoptera, and Aranaea (Fig. 5). Biomass of Orthoptera (*F* = 10.12, *P* = 0.01) and Coleoptera (*F* = 4.64, *P* = 0.05) in July 2007, and biomass of Orthoptera (*F* = 6.90, *P* = 0.03), Hemiptera (*F* = 21.17, *P* < 0.01), and Coleoptera (*F* = 5.14, *P* = 0.05) in July 2008 were higher in native-mixed grass prairie than seeded monocultures.

Discussion

Exotic species invasions can threaten native ecosystems, with potential negative consequences to community composition, competitive interactions, and disturbance regimes (Bock et al. 1986, D'Antonio and Vitousek 1992, Wilcove et al. 1998, Mack et al. 2000). Several studies have indicated that OWB may have substantial negative effects on native grasslands. Eck and Sims (1984) and Gabbard and Fowler (2007) showed that OWB can invade areas where it was not planted, reducing plant community diversity. Studies by McIntyre (2003) and McIntyre and Thompson (2003) suggest that OWB fields support lower arthropod diversity than do stands of native grasses. Hickman et al. (2006) found that bird species richness and abundance and arthropod biomass were lower in OWB monoculture fields relative to native mixed-grass prairie.

In this study, some bird community metrics were reduced on fields seeded to OWB and managed as monocultures, but these fields can provide usable and potentially superior breeding habitat for some grassland species such as Killdeer and Grasshopper Sparrow. For example, Grasshopper Sparrow occurred in OWB fields at more than twice the densities of native fields. Other studies have shown that Grasshopper Sparrows select larger tracts of uninterrupted habitat, with shorter vegetation, less vertical cover, and little shrub cover (e.g, Patterson and Best 1996, Vickery 1996, Delisle and Savidge 1997). Because OWB fields are often established on former cropland and are managed as monocultures, they generally meet the above characteristics. While vertical obstruction and vegetation height did not differ in this study, OWB fields did provide larger tracts of homogenous habitat, devoid of woody plants. It is unlikely, however, that the difference in Grasshopper Sparrow breeding density between OWB and native grass fields was due to landscape differences between the two types of fields. All fields occurred in similar agricultural/grassland matrices and all were large (60–100 ha) relative to the minimum area requirements reported for Grasshopper Sparrows in other parts of their range where they are abundant (e.g., 10–30 ha, Herkert 1994; 8–12 ha, Helzer and Jelinski 1999).

At a fine scale, Vickery et al. (1994) reported a positive association between Grasshopper Sparrow abundance and litter and forb cover. I found no correlation; rather, these two variables were higher in native fields than in OWB fields. In Wisconsin, Wiens (1969) found 30% forb cover in fields selected by Grasshopper Sparrows, in contrast to my findings of < 2% and < 15% in OWB and native fields, respectively, perhaps reflecting regional variation in habitats selected by this species. While Grasshopper Sparrow was abundant in both types of fields, the higher breeding density observed in OWB monocultures indicated that homogenous fields with fewer forbs and relatively less litter were perceived by the birds as appropriate breeding habitat.

These findings appear consistent with other studies (Jones and Bock 2005) that suggest that grass species composition is less important than vegetation structure in providing habitat for individual species of grassland birds. In eastern North America, for example, exotic grass fields support multiple species of grassland birds (Norment 2002, Scott et al. 2002). In some instances, however, high breeding densities may be correlated negatively with individual reproductive success (Dwernychuck and Boag 1972, Van Horne 1983). The fact that I observed a higher density of Grasshopper Sparrows in OWB fields despite decreased arthropod biomass suggested that individual reproductive success could have been lower in OWB fields than in native fields. Future research in this system should address the functional significance of OWB for Grasshopper Sparrow. Research that focuses on reproductive success and site fidelity of Grasshopper Sparrow in OWB fields elucidate the degree to which these fields generally provide favorable conditions for breeding or constitute ecological traps.

In contrast to Grasshopper Sparrows, the OWB fields in this study supported lower densities of species such as Northern Bobwhite and Lark Sparrow than native fields. These findings are supported by other studies (e.g., Bock et al. 1986, Flanders et al. 2006, Hickman et al. 2006) suggesting that exotic plant invasions alter vegetation structure and composition, reducing habitat suitability for various bird species. Differences in plant species composition between OWB and native fields may have contributed to differences in bird densities. Some researchers have shown that birds choose habitats on the basis of species composition of plant communities (Block and Brennan 1993, Rotenberry and Wiens 1998). While I did not compare specific plant composition, I did find a higher percentage of forbs in native fields. Because OWB fields are seeded and managed as monocultures, they contain lower plant species richness and structural diversity, resulting in reduced habitat for many grassland birds.

Vegetation structure, and by extension bird community composition, in managed grasslands can be influenced as much by the frequency of haying, intensity of grazing, and application of fertilizers as by the plant species composition. For example, densities of several bird species were related to vegetation characteristics that are influenced by management. Dickcissel density was correlated positively to forb cover, vertical obstruction, and field structural heterogeneity. Dickcissels nest in a variety of grassland habitats, including hayfields and native prairie. Dense cover, forbs or woody vegetation, moderate to tall vegetation, a layer of litter, and presence of elevated song perches are characteristics of fields selected by Dickcissels (Temple 2002. Dechant et al. 2003). In my study area, Dickcissel densities were highest where such structural characteristics were evident, regardless of field type.

Brown-headed Cowbird densities were correlated negatively to vegetation height and vertical obstruction. This reflects Brown-headed Cowbirds' affinity for livestock (Lowther 1993); vertical obstruction and vegetation height decrease with grazing intensity. Killdeer densities were correlated negatively to forb cover, vertical obstruction, and point heterogeneity. Killdeer require open habitats with short or no vegetation to employ the "running" foraging strategy characteristic of plovers (Jackson and Jackson 2000). Density of Mourning Doves, which often nest and exclusively forage on the ground (Otis et al. 2008), was correlated positively to bare ground. Northern Bobwhite densities were correlated positively to forb cover and litter cover, and negatively correlated to bare ground. Northern Bobwhites can inhabit a wide variety of early successional areas that provide woody cover and forbs, which make up an important component of adult diets (Brennan 1999). Density of Lark Sparrow, a ground foraging omnivore during the breeding season (Martin and Parrish 2000), was correlated negatively to vegetation height. With the exception litter and forb cover, the vegetation characteristics measured did not differ between the two field types; densities of the above bird species were correlated to vegetation characteristics regardless of whether fields were managed as OWB monocultures or native mixed grass prairie.

While individual species varied in response to numerous vegetative characteristics, bird community characteristics responded more clearly to field type. Mean species richness and diversity were higher in native fields than those planted to

OWB. This was expected because grasslands managed as monocultures typically provide less habitat heterogeneity, and fewer niches available for birds than native prairie (Sutter and Brigham 1998).

In addition to these traditional community metrics, I supplemented species richness and diversity calculations with indices of conservation value (*CV*) derived from Partners in Flight (PIF) categorical scores (Carter et al. 2000, Nuttle et al. 2003). Mean CV_1 scores, based on presence-absence, were higher in native fields than OWB. The CV_1 scores weigh all species equally, and that maximized the influence of rare species, such as Painted Bunting (*Passerina ciris*) and Bell's Vireo (*Vireo bellii*) on the assessment.

In contrast to CV_1 scores, CV_2 scores were determined using relative abundance (as a percentage of total abundance of all birds observed), so the influence of rare species remained limited in the equation. The CV_2 scores were higher in OWB fields, and this was due to the high relative abundance of grassland priority species, such as Grasshopper Sparrow. It is important to interpret *CV* indices in the context of other measurements of diversity and community composition (Nuttle et al. 2003). In this study, grasslands managed as OWB monocultures supported a lower richness, diversity, and one measure of *CV* of breeding bird communities. However, a *CV* based on relative abundance (i.e. CV_2) favored OWB fields, illustrating the importance of using multiple indicators a habitat's condition.

Exotic grasses may have detrimental effects on the functional relationships among birds and their prey. That arthropods are crucial to birds during the breeding season has been well established (Wiens 1969; 1973). Insects (Orthoptera, Lepidoptera, Coleoptera, Hemiptera, Hymenoptera) and spiders (Aranaea) are important to meet dietary requirements for molting, reproduction, and nestling development (Bent 1960, Baldwin 1970, Maher 1979). In this study, total arthropod biomass and biomass of taxa important for birds (e.g., Orthoptera, Hemiptera, and Coleoptera) were lower in OWB fields than in native fields. This is consistent with other studies (Jonas et al. 2002, McIntyre and Thompson 2003, Hickman et al. 2006) and may be an important mechanism limiting some bird species. For example, Martin (1987) showed that food limitation is an important ecological phenomenon and can influence life-history traits, population sizes, and community structure. As food availability decreases, territory size often increases, forcing breeding birds to spend more time and energy foraging for exogenous resources, resulting in lower nest success or adult survival. Effects of food limitation may be further compounded by interspecific competition, with community composition changing to favor those species with superior competitive abilities. Furthermore, species with high nest-site fidelity that undergo decreased reproductive success and adult survival due to food limitation may be more prone to site-specific population declines. Thus, compositional differences influencing food availability between OWB and native fields may have ramifications for breeding habitat quality.

The degree to which food availability influences habitat selection, however, is unclear (Cody 1981). For example, Shochat et al. (2005) suggested that arthropod abundance is important in determining where Grasshopper Sparrows, Eastern Meadowlarks, and Dickcissels establish territories. In their study, disturbed areas served as ecological traps because they produced more arthropods (thereby increasing breeding densities) but supported more nest predators. In my study, while reduced arthropod biomass may have caused some bird species to avoid OWB fields, this was not the case for Grasshopper Sparrows, which were present at higher densities in OWB than in native fields. Bock et al. (1986) likewise found higher densities of grassland birds in exotic grass fields than native prairie despite lower arthropod abundance, and Hull et al. (1996) found no relationship in Kansas CRP fields, further suggesting that food availability has a limited role in habitat selection for these species. Nevertheless, arthropods must be available as a food resource in grassland habitats during the breeding season for bird populations to persist. If bird species such as Grasshopper Sparrow select OWB fields based on structural or landscape factors, despite insufficient food resources, these fields may serve as ecological traps.

Recently, natural resource agencies have encouraged the planting of native grasses to benefit wildlife (USDA 2008c) but seeded OWB monocultures, established in the 1980's–1990's, are still abundant throughout the southern Great Plains. While the planting of OWB and other exotic grasses may provide superior wildlife habitat compared with areas of intensive agriculture (Johnson and Schwartz 1993, Best et al. 1997), and may be preferable for select bird species (Jones and Bock 2005), it is clear from this study and others (Flanders et al. 2006, Hickman et al. 2006) that native grasslands support more complex bird communities, including a number of species of conservation priority. In light of the negative impacts of exotic species on native biodiversity in general (Mack et al. 2000), I recommend that native grasses be used in future conservation programs.

Future research should be directed toward the potential influence of OWB on mechanisms of bird reproductive success and source/sink dynamics of common species and species of conservation priority. Additionally, studies should investigate landscape level effects of OWB monocultures on bird populations, incorporating the cropland-exotic monoculture-native grassland matrix at different scales. Understanding the mechanisms by which OWB and other exotic grasses influence native ecosystems will allow prioritization of conservation activities and the mitigation of negative impacts through more effective management practices.

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Table 1. Partners in Flight Regional Combined Scores (PIF RCS), total abundance (*n*), and frequency of sites in which detected (%) of all bird species observed using Old World Bluestem (OWB) monocultures and native grasslands during the 2007 and 2008 breeding seasons. Only species documented as breeding in the study area and defined as landbirds by PIF received RCS.

			OWB		Native	
Common Name	Scientific Name	PIF RCS	*n*	%	*n*	%
Grasshopper Sparrow	*Ammodramus savannarum*	15	610	100	312	100
Eastern Meadowlark	*Sturnella magna*	15	346	100	272	100
Dickcissel	*Spiza Americana*	15	232	100	447	100
Brown-headed Cowbird	*Molothrus ater*	12	66	83	43	100
Killdeer	*Charadrius vociferous*	–	43	83	4	33
Mourning Dove	*Zenaida macroura*	12	29	67	41	83
Common Nighthawk	*Chordeiles minor*	12	20	50	2	17
Western Meadowlark	*Sturnella neglecta*	15	16	83	2	17
Upland Sandpiper	*Bartramia longicauda*	–	13	83	2	33
Scissor-tailed Flycatcher	*Tyrannus forficatus*	16	11	67	22	50
Lark Sparrow	*Chondestes grammacus*	14	7	17	54	67
Baltimore Oriole	*Icterus galbula*	16	6	17	7	33
Ring-necked Pheasant	*Phasianus colchicus*	12	5	33	13	67
Horned Lark	*Eremophila alpestris*	11	5	33	0	0
Red-winged Blackbird	*Agelaius phoeniceus*	11	3	50	5	50
Eastern Kingbird	*Tyrannus tyrannus*	14	3	17	3	50
Common Grackle	*Quiscalus quiscula*	11	3	17	0	0
Cattle Egret	*Bubulcus ibis*	–	2	17	27	50
Western Kingbird	*Tyrannus verticalis*	14	2	17	4	50
American Goldfinch	*Carduelis tristis*	9	2	17	0	0
Mallard	*Anas platyrhynchos*	–	2	33	0	0
Northern Bobwhite	*Colinus virginianus*	14	1	17	90	100
Eastern Bluebird	*Sialia sialis*	9	1	17	1	17
Barn Swallow	*Hirundo rustica*	13	1	17	0	0
Great Egret	*Ardea alba*	–	1	17	0	0
Orchard Oriole	*Icterus spurious*	15	1	17	0	0
Swainson's Hawk	*Buteo swainsoni*	18	1	17	0	0
Turkey Vulture	*Cathartes aura*	11	1	17	0	0
Northern Mockingbird	*Mimus polyglottos*	11	0	0	12	50
Red-tailed Hawk	*Buteo jamaicensis*	11	0	0	12	83
Bell's Vireo	*Vireo bellii*	17	0	0	5	67
Clay-colored Sparrow	*Spizella pallid*	–	0	0	4	33
American Crow	*Corvus brachyrhynchos*	9	0	0	3	17
Bewick's Wren	*Thryomanes bewickii*	13	0	0	3	33
Yellow-billed Cuckoo	*Coccyzus americanus*	15	0	0	3	17
Blue Grosbeak	*Passerina caerulea*	12	0	0	2	33
Brown Thrasher	*Toxostoma rufum*	14	0	0	2	33
Great Crested Flycatcher	*Myiarchus crinitus*	11	0	0	2	17
Least Flycatcher	*Empidonax minimus*	9	0	0	2	17
Northern Cardinal	*Cardinalis cardinalis*	8	0	0	2	33
Painted Bunting	*Passerina ciris*	17	0	0	2	17
Wild Turkey	*Meleagris gallopavo*	12	0	0	2	33
Yellow Warbler	*Dendroica petechia*	10	0	0	2	33

Table 1. Continued.

			OWB		Native	
Common Name	Scientific Name	PIF RCS	*n*	%	*n*	%
Blue-gray Gnatcatcher	*Polioptila caerulea*	9	0	0	1	17
Eastern Phoebe	*Sayornis phoebe*	9	0	0	1	17
Field Sparrow	*Spizella pusilla*	14	0	0	1	17
Great Horned Owl	*Bubo virginianus*	12	0	0	1	17
Loggerhead Shrike	*Lanius ludovicianus*	16	0	0	1	17
Red-headed Woodpecker	*Melanerpes erythrocephalus*	16	0	0	1	17

Table 2. Bird community composition parameters (mean and SE): Shannon-Weiner diversity (H'), species richness, and conservation values (CV_1 and CV_2) of OWB monocultures and native mixed-grass prairie in north-central Oklahoma during the 2007 and 2008 breeding seasons.

	OWB			Native		
	$\bar{x}$	±	SE	$\bar{x}$	±	SE
H'*	1.44	±	0.14	1.86	±	0.11
Richness*	9.50	±	1.75	16.00	±	1.88
CV_1*	129.17	±	22.99	209.00	±	25.24
CV_2*	14.20	±	0.27	8.82	±	0.64

* $P < 0.05$

Table 3. Vegetation characteristics (mean and SE) of OWB monocultures and native mixed-grass prairie in north-central Oklahoma in July 2007 and 2008.

	July-07						July-08					
	OWB			Native			OWB			Native		
	$\bar{x}$	±	SE	$\bar{x}$	±	SE	$\bar{x}$	±	SE	$\bar{x}$	±	SE
Grass cover (%)	72.48	±	3.49	52.57	±	8.57	50.49	±	16.06	62.05	±	10.76
Forb cover (%) [a]	1.26	±	0.63	14.99	±	3.84	1.62	±	0.66	10.60	±	2.98
Litter cover (%) [a b]	3.01	±	0.73	5.76	±	0.91	7.66	±	2.53	19.75	±	3.63
Bare ground (%)	27.26	±	4.13	25.18	±	7.40	25.15	±	5.76	28.59	±	10.48
Vegetation height (cm) [b]	76.93	±	6.12	91.52	±	18.87	47.74	±	3.07	59.71	±	9.90
Vertical obstruction (dm) [b]	3.96	±	1.14	5.51	±	1.95	1.79	±	0.22	2.32	±	0.57
Point heterogeneity [b]	0.60	±	0.04	1.24	±	0.34	0.53	±	0.03	0.69	±	0.15
Field heterogeneity	1.22	±	0.16	2.36	±	0.73	1.10	±	0.22	1.08	±	0.19

[a] = $P < 0.05$ between field types [b] = $P < 0.05$ between years

Table 4. Spearman rank correlations between breeding bird densities (birds/ha) and July vegetation characteristics in OWB monocultures and native mixed-grass prairie in north-central Oklahoma during the 2007 and 2008 breeding seasons.

	Forb cover	Litter cover	Bare ground	Vegetation height	Vertical obstruction	Point heterogeneity
Brown-headed cowbird				-.434*	-.523*	
Killdeer	-.508*				-.441*	-.440*
Mourning Dove			.559**			
Northern Bobwhite	.540**	.580**	-.533*			
Lark Sparrow				-.522*		

* = P < 0.05 ** = P < 0.01

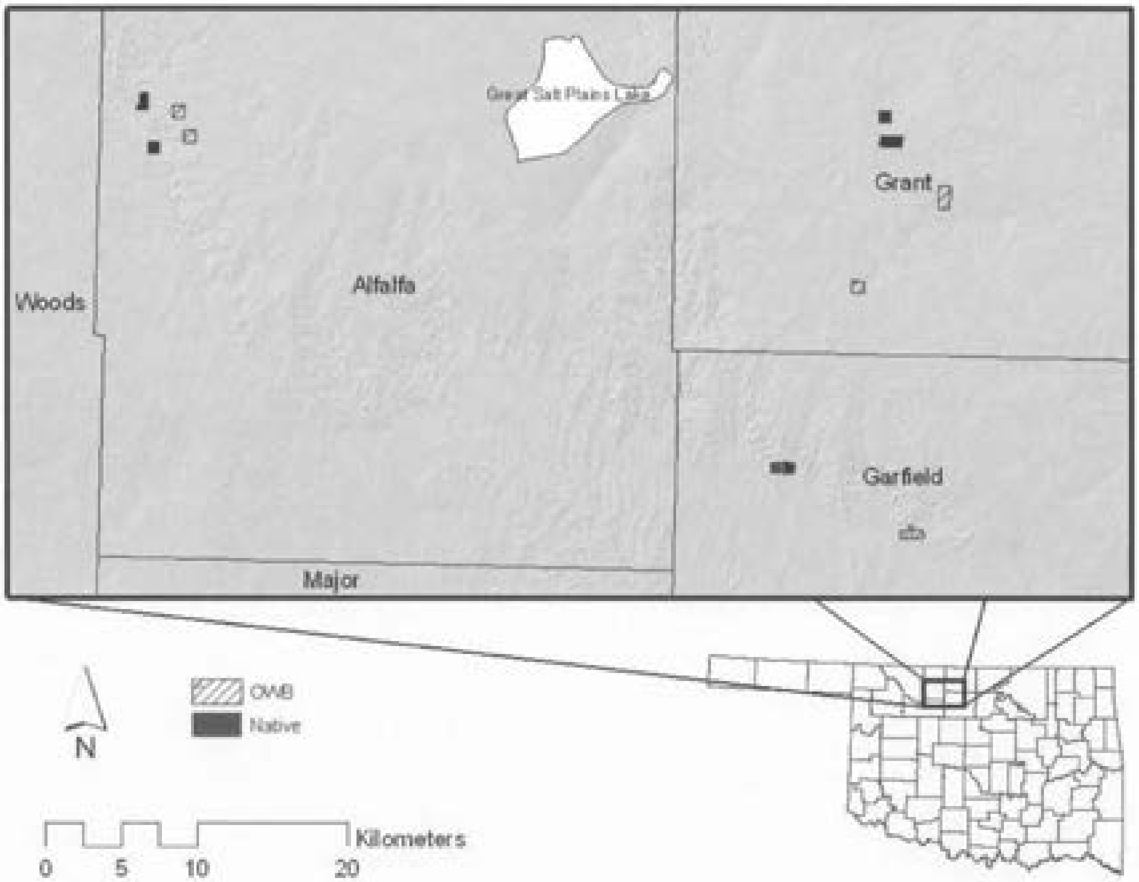


Figure 1. Map of study area showing all study sites: 6 OWB monocultures and 6 native fields in Alfalfa, Grant, and Garfield Counties in north-central Oklahoma.

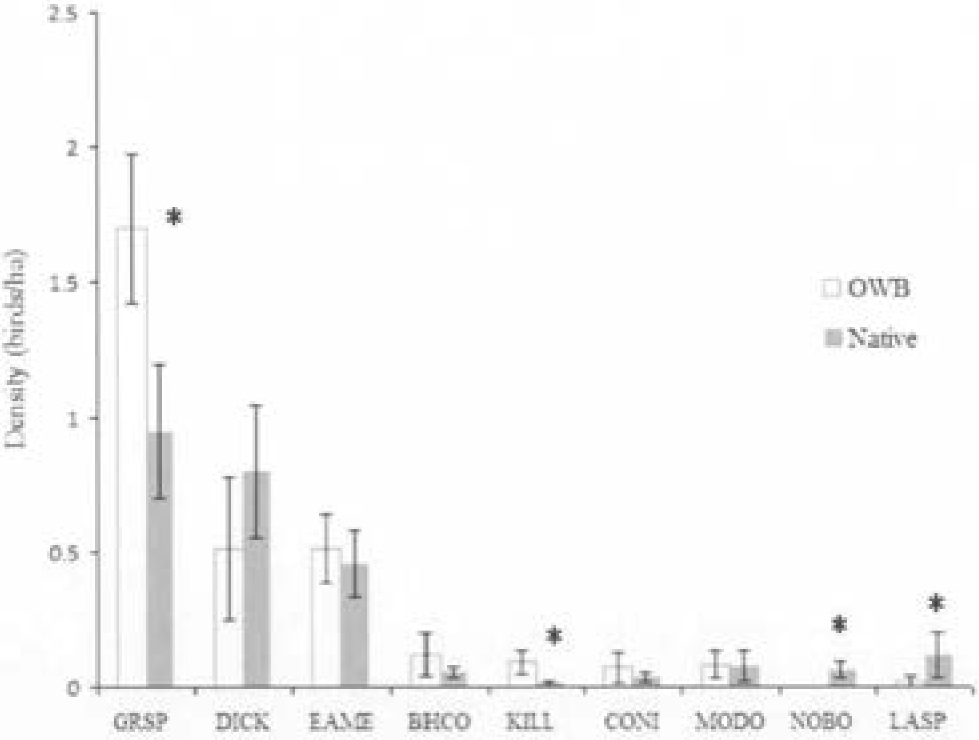


Figure 2. Mean density of bird species detected on at least 25% of surveys within a field type (OWB monocultures and native mixed-grass prairie) during the breeding season in north-central Oklahoma in 2007 and 2008. Error bars represent SE. Species included Grasshopper Sparrow (GRSP), Dickcissel (DICK), Eastern Meadowlark (EAME), Brown-headed Cowbird (BHCO), Killdeer (KILL), Common Nighthawk (CONI), Mourning Dove (MODO), Northern Bobwhite (NOBO), and Lark Sparrow (LASP). * designates those species with $P < 0.05$

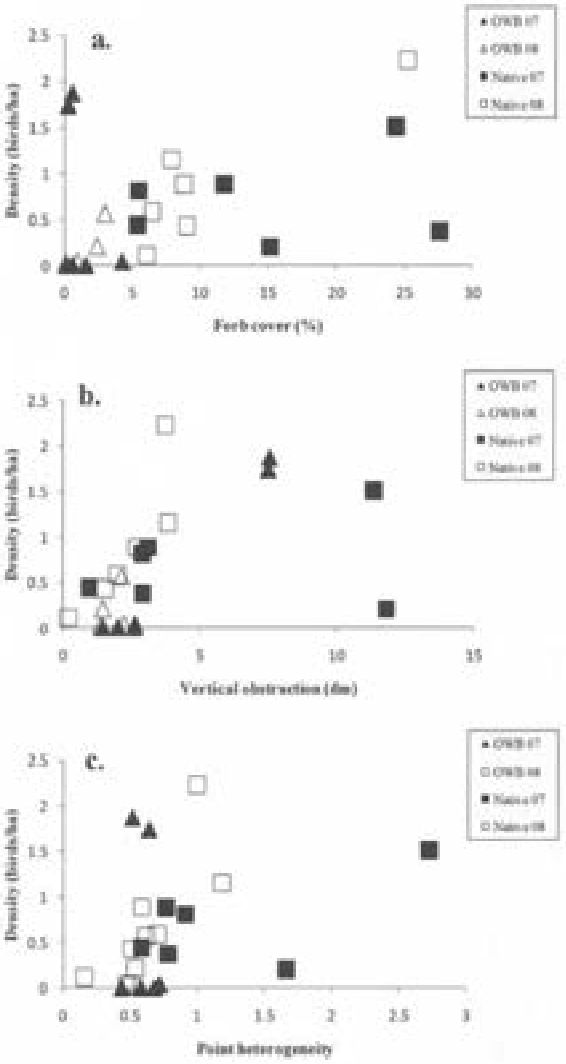
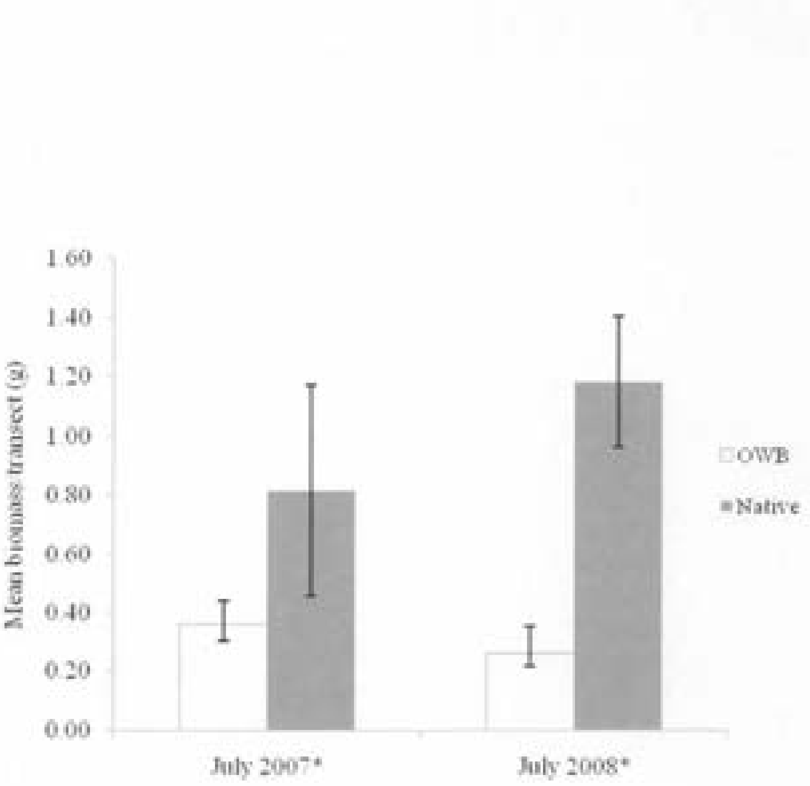
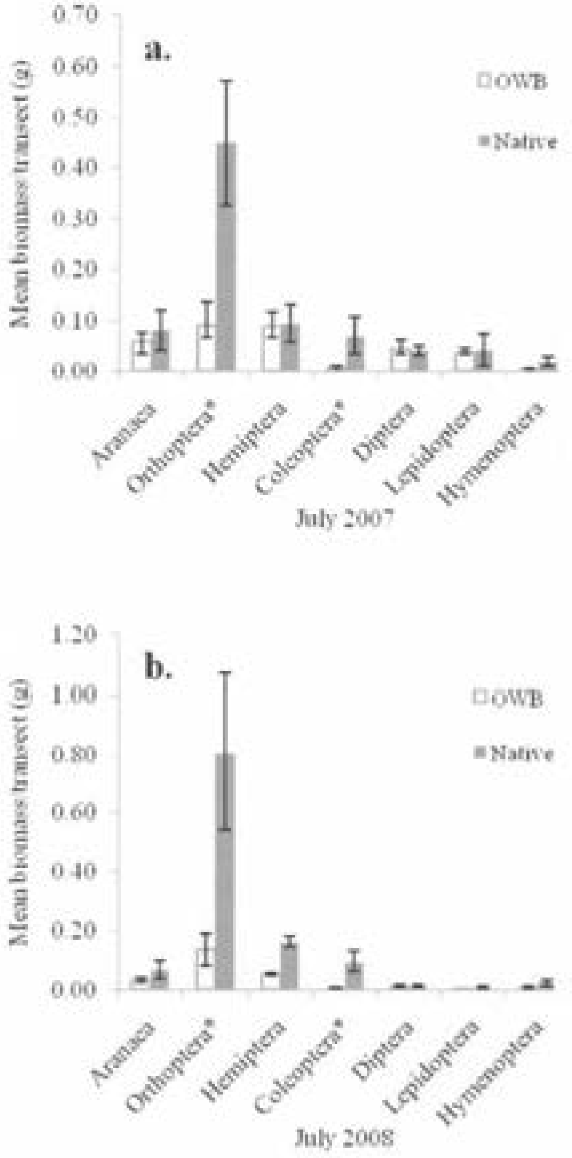


Figure 3. Relationship between Dickcissel density and a) forb cover, b) vertical obstruction, and c) point heterogeneity in OWB monocultures and native prairie during the 2007 and 2008 breeding seasons in north-central Oklahoma.



* = $P < 0.05$

Figure 4. Mean biomass (g) per transect of all arthropod orders in Old World Bluestem (OWB) monocultures and native mixed-grass prairie in July 2007 and 2008. Error bars represent SE.



* = $P < 0.05$

Figure 5: Mean biomass (g) per transect of dominant arthropod orders in OWB monocultures and native mixed-grass prairie in a) July 2007 and b) 2008. Error bars represent SE.

CHAPTER II

INFLUENCE OF SEEDED EXOTIC GRASSLANDS ON WINTERING SONGBIRDS IN MIXED-GRASS PRAIRIE

Introduction

In North America, grassland birds have shown persistent and widespread declines since at least 1966 (Peterjohn and Sauer 1999, Askins et al. 2007, Sauer et al. 2007). Habitat loss, degradation, fragmentation (Vickery and Herkert 2001), changes in grazing management (Kantrud 1981, Baker and Guthery 1990), increased acreage of row-crops (Warner 1994), and invasions by exotic grasses (Delisle and Savidge 1997, Sutter and Brigham 1998, Hickman et al. 2006) have been identified as possible causes of these declines during the breeding season. Yet, many species that rely on grassland habitat in the southern Great Plains are winter residents, and these species also may be undergoing regional declines (Root 1988, Best et al. 1998, Sauer et al. 2007). Grasslands in the southern plains may support winter assemblages dominated by Nearctic migrants like longspurs (*Calcarius* spp.) that breed in northern grasslands and tundra and are therefore poorly sampled by monitoring programs such as the North American Breeding Bird Survey.

Habitat requirements of wintering grassland birds often contrast with those of species that rely on grasslands for breeding. For example, breeding passerines are usually insectivorous while winter residents are granivorous. Non-breeding season use of grassland habitat includes protection from predators and adverse weather as well as aplace to rest and restore energy reserves (Gottfried and Franks 1975, Kricher 1975, Lima 1993, Marra et al. 2005). Therefore, effects of anthropogenic disturbance on breeding birds could differ from on winter residents.

In the mid 1980s, > 30% of the grassland cover in the Great Plains states was seeded monocultures (USDA 1986). After the Conservation Reserve Program (CRP) was established as part of the 1985 Food Security Act, millions of additional hectares of cropland were converted to seeded grassland (Schenk and Williamson 1991, Baker 2000). The CRP provides financial incentives to landowners who retire cropland from production and place it in permanent cover under 10- or 15-year contracts (USDA 2008b), but because the CRP's primary goal was erosion control, the original sign-up often promoted the planting of exotic grasses such as weeping lovegrass (*Eragrostis curvula*), crested wheatgrass (*Agropyron cristatum*), or Old World bluestems (OWB; *Bothriochloa* spp). While these grasses may be widely tolerant of environmental conditions and are relatively easy to establish and manage, they also may become invasive, with negative consequences for native grasslands ecosystems (D'Antonio and Vitousek 1992). Despite more stringent requirements to plant native vegetation in the CRP after 1996, exotic monocultures are still widespread throughout the southern Great Plains. More than 1 million ha of OWB were planted in Oklahoma and Texas alone during a 10-year period (White and Dewald 1996), and in some western Oklahoma counties, more than 50% of the CRP land has been planted to OWB (Ripper and VerCauteren 2007). Despite the invasive potential and widespread use of OWB, only a few studies have compared OWB monocultures to native grasslands with respect to wildlife habitat (McIntyre and Thompson 2003, Chapman et al. 2004, Hickman et al. 2006), and none have examined the effects of OWB during winter.

My objectives were to compare 1) abundance and community composition of wintering birds and 2) vegetation structure and composition between OWB monocultures and native mixed-grass prairie during the winter season.

Methods

I conducted this study in December–March, 2007–2009 in the Prairie Tableland ecoregion of north-central Oklahoma (Woods et al. 2005), which is characterized by level to slightly rolling plains (local relief, 3–42 m) and deep, fertile soils. Mean high and low daily temperatures range from -1.76°C to 11.43°C in December–March. Mean precipitation is 37.1 cm in December–March; 20.07 cm of which is snow or ice (Oklahoma Climatological Survey 2008). Land use in the area is dominated by small grain agriculture or alfalfa. Grasslands seeded and managed as OWB monocultures are widespread throughout the region (Ripper and VerCauteren 2007). The natural vegetation is classified as mixed-grass prairie; dominants include little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), side-oats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), indiangrass (*Sorghastrum nutans*), switchgrass *(Panicum virgatum*), and buffalograss (*Buchloe dactyloides*). Rangeland is more common where topography is not suitable for cropland (Woods et al. 2005). Study sites were selected within a broad agricultural matrix interspersed with grassland cover. Dominant land cover in the area consisted of about 68% cropland and 26% native rangeland and exotic grass pastures (USDA 2008a).

I selected 12 study sites in Alfalfa, Grant, and Garfield counties to provide 6 replicates each of OWB monoculture and native mixed-grass prairie (Fig. 1). Study site selection was based on similarity in topography and management to what is typical in the region. Some of the native fields contained small patches of woody vegetation, including sand plum (*Prunus angustifolia*) and fragrant sumac (*Rhus aromatica*) although this was a minor landscape feature. Grazing intensity was visually estimated in each field (Smith 1998). Eleven of the fields had a higher proportion of vegetative cover than bare ground and were classified as lightly grazed by livestock; one field of native grasses had a higher proportion of bare ground than vegetative cover and was classified as heavily grazed. Four of the OWB fields were hayed once or twice annually in mid-July to mid-August. Two of the OWB fields were fertilized at an unknown date prior to the study to promote hay production.

I estimated bird abundance by counts conducted along transect lines following methods described by Bibby et al. (2000). I used aerial photos to establish 750-m transects in each field. I avoided placing transects parallel to and within 50 m of field edges and riparian areas. The same transects were resampled throughout the duration of the study. Each field was sampled approximately biweekly from mid-December through mid-February on days with no rain and light winds (<10 km/hr), with each field sampled 4x per winter. I sampled between early morning (>1 hr after sunrise) and late afternoon (>2 hr before sunset) by slowly walking each transect and recording all individuals seen or heard. Flyovers were only counted if they were actively foraging over the field.

I restricted statistical comparisons to bird species comprising at least 5% of all individuals detected within a field type, in at least one season. Abundance was calculated as number of individuals/km of transect. Distance to transect was not considered because Short-eared Owls (*Asio flammeus*) and virtually all passerines were detected by flushing within 10 m of the transect line, while most Northern Harriers (*Circus cyaneus*) and other diurnal raptors were observed in flight. Therefore, reliable estimates of density or detectability by distance could not be attained. I estimated abundance for Savannah Sparrow (*Passerculus sandwichensis*), meadowlarks (*Sturnella* spp.), Northern Harrier, Smith's Longspur (*Calcarius pictus*), Short-eared Owl, Song Sparrow (*Melospiza melodia*), and American Tree Sparrow (*Spizella arborea*). Because of difficulty in distinguishing between the two, all Eastern (*Sturnella magna*) and Western (*Sturnella neglecta*) meadowlarks were counted as meadowlarks. Bird abundance was estimated for each visit to a site and averaged within years for statistical analyses. Data from both years were pooled when no year effect was detected. A Wilcoxon signed-rank was used to test for differences between years within field types and a Mann-Whitney *U*-test was used to detect differences between field types.

I measured vegetation during the third week of February in 2008 and 2009. At 30 random distances along each transect, vertical obstruction was measured from 4 directions using a Robel pole (Robel et al. 1970; $n = 120$ points/field). Maximum vegetation height and the lowest visible point on the pole from 4 m at a height of 1 m above the ground were recorded. Standard deviations of vertical obstruction at each point (4 m radius) and across each sampling transect (750 m) were used as measurements of structural heterogeneity at the point and field scales (e.g. Fuhlendorf and Engle 2004). I estimated canopy cover of vegetation directly in front of the Robel pole in the direction of the transect using a 1-m^2 frame (Daubenmire 1959). I only recorded plants rooted completely inside the frame. Percent cover of grasses, forbs, litter, and bare ground were estimated in cover classes (0%, 1-5%, 6-25%, 26-50%, 51-75%, 76-95%, 96-100%). Litter was defined as any plant material on the soil surface which did not appear rooted in the ground. I used the midpoints of each cover class to calculate percent canopy cover of vegetation (Towne et al. 2005). I used repeated-measures ANOVA to compare vegetation structure and composition characteristics between the two field types with year as the repeated measure.

To investigate compositional differences in wintering bird communities between OWB and native grasslands, I calculated and compared bird species richness, the Shannon index of diversity (H'; Magurran 2003), and two indices of conservation value (CV) for each field. Partners in Flight priority scores were used to derive CVs (Carter et al. 2000, Nuttle et al. 2003), which were calculated as:

$$CV_1 = \sum_{i=1}^{S} p_i w_i \text{ and } CV_2 = \sum_{i=1}^{S} r_i w_i,$$

where S was the number of species i in the community, p was presence or absence (0 or 1) of species, r was relative abundance of species, and w was a weighting factor derived from each species' PIF regional conservation score. The CV_2 score weighed each species' conservation score according to its relative abundance (% of total bird community) and the CV_1 score weighed each species' conservation score equally, given that it was detected in a study site. Therefore, the CV_1 score was more sensitive to uncommon species. Diversity, species richness, and conservation values were compared between field types with the Mann-Whitney U-test. All data were analyzed using SPSS 16.0 (SPSS Institute, Chicago IL). A significance level of $P \leq 0.10$ was used for comparisons of bird abundance and $P \leq 0.05$ for comparisons of community composition and vegetation variables between field types.

Results

In winter 2007–2008 and 2008–2009, I observed 26 bird species using native grass fields and 14 using OWB monocultures (Tab. 1). Of the species comprising $\geq 5\%$ of all individuals observed, Smith's Longspur was the most abundant, followed by Chestnut-collared Longspur, meadowlarks, Savannah Sparrow, Short-eared Owl, and Northern Harrier (Tab. 2). Year effects were detected for five species. In native fields, Smith's Longspurs ($Z = 1.34$, $P = 0.09$) were more abundant during the second year, and Savannah ($Z = 1.83$, $P = 0.03$), American Tree ($Z = 1.46$, $P = 0.07$), and Song sparrows ($Z = 1.34$, $P = 0.09$) were more abundant during the first year. In OWB fields, Savannah Sparrows ($Z = 1.57$, $P = 0.06$) were more abundant in the first year, and Short-eared Owls ($Z = 1.83$, $P = 0.03$) were more abundant in the second year. Field-type effects were detected for six species. Smith's Longspurs ($U = 3.0$, $P < 0.01$) were more abundant in OWB fields, and Song ($U = 12.0$, $P = 0.07$) and American Tree ($U = 9.0$, $P = 0.03$) sparrows were more abundant in native fields in the first year. In the second year, Savannah Sparrows ($U = 10.0$, $P = 0.10$), Northern Harriers ($U = 7.00$, $P = 0.04$), and Short-eared Owls ($U = 8.00$, $P = 0.04$) were more abundant in OWB fields and American Tree Sparrows ($U = 12.0$, $P = 0.07$) were more abundant in native fields.

Year effects were detected for four vegetation variables in both OWB and native fields (Tab. 3). Grass cover ($F = 15.36$, $P < 0.01$), forb cover ($F = 14.83$, $P = 0.01$), and litter cover ($F = 24.4$, $P < 0.01$), were higher in the first year, and bare ground ($F = 9.2$, $P = 0.02$) was higher in the second year. Field type effects were only detected for forb cover, which was higher in native fields in both years ($F = 115.94$, $P < 0.01$; $F = 79.37$, $P < 0.01$).

Mean Shannon-Weiner diversity, species richness, and the CV_1 score did not differ between field types (Tab. 4). The CV_2 score was significantly higher in OWB fields ($U = 6.0$, $P = 0.03$).

Discussion

Several studies have reported that OWB may have negative impacts on native grasslands in the southern Great Plains where it has been widely introduced, including potential threats to breeding bird communities (Eck and Sims 1984, Gabbard and Fowler 2007, Hickman et al. 2006). Yet, the influence of OWB monocultures on wintering grassland birds is largely unknown. While I found low bird species richness during winter, and significantly lower numbers of Song Sparrow and American Tree Sparrow in OWB fields during at least one year, my results suggest that OWB monocultures may provide suitable wintering habitat for several grassland bird species, including Smith's Longspur, Chestnut-collared Longspur, Short Eared Owl, and Savannah Sparrow. Differences in response were likely due to differences in wintering habitat affinities among the species surveyed.

Song and American Tree sparrows use areas with at least some woody vegetation during winter, including field edges. Both species often forage on the ground in open areas and use nearby woody cover to roost or escape predators (West 1967, Naugler 1993, Arcese et al. 2002). Because I was concerned primarily with grassland bird species, I intentionally chose study fields without woody vegetation whenever possible and placed sampling transects to avoid edges. While not included in my vegetation analysis, some of the native fields in this study contained small patches of sand plum (*Prunus angustifolia*) and fragrant sumac (*Rhus aromatica*). I attribute the presence of Song and American Tree sparrows in native fields to the presence of woody vegetation. Any influence of OWB on these two species was likely indirect because fields managed as monocultures were less likely to have forbs or woody plants.

Smith's Longspurs are grassland specialists with a winter range limited to the southern plains (Anstey et al. 1995, Briskie 2009). In the first year of my study, this species was observed in large flocks in a single field seeded to OWB but was concentrated in heavily grazed areas with slight depressions, similar to those described by Kemsies (1968). Grzybowski (1982; 1983) found Smith's Longspurs in fields with moderate to heavy grazing pressure and near patches of three-awn (*Aristida* spp.) and silver bluestem (*Bothriochloa laguroides*). I likewise found Smith's Longspurs in relatively small flocks (<50 individuals) in patches of shorter grass, including three-awn. Grass seed availability may be an important mechanism affecting Longspur populations during the non-breeding season. Grzybowski (1982) showed a positive correlation between seed density and grazing pressure in habitats selected by Longspurs. Future studies on wintering Longspurs should focus on microhabitat use as it relates to grass species composition and food availability in both native and exotic grasslands.

Savannah Sparrows, the most commonly encountered species in my study, were more abundant in OWB monocultures than native grasslands during the second year. Savannah Sparrows are grassland generalists during both the breeding and wintering seasons (Wheelwright and Rising 2008). However, few studies have addressed habitat selection by Savannah Sparrows during winter (Gordon 2000, Smith et al. 2005). It is likely that some populations have undergone increases resulting from human disturbance such as pasture and hayfield management (Wheelwright and Rising 2008), and in some cases, this species may benefit from exotic grasses (Mattice et al. 2005). Stobo and McLaren (1975) suggested that populations may be regulated in part by density-dependent over-wintering survival in areas where carrying capacity is limited by food availability. While Savannah Sparrows eat a variety of seeds during the non-breeding season, it remains unclear to what extent OWB serves as a food source. Chapman et al. (2004) suggested that grassland birds avoid OWB because it produces "chaffy seeds." If this is true, OWB fields may serve as ecological traps (Dwernychuck and Boag 1972) for Savannah Sparrows and other seed-eating bird species. For example, wintering grassland birds may select OWB fields as wintering habitat because they provide adequate shelter from predators and adverse weather, but OWB seeds may not meet dietary requirements for winter survival. However, studies have not yet addressed OWB seed morphology and nutritional composition as it relates to food availability for birds.

Because vegetation structure was similar between the OWB monocultures and native grasslands in my study, it is possible that the higher abundance of Northern Harriers and Short-eared Owls in OWB fields was caused by differences in prey abundance and availability. Both species are nomadic, and populations are regulated by local food availability during the breeding and non-breeding seasons (Grant et al. 1991, MacWhirter and Bildstein 1996, Wiggins et al. 2006). In the southern part of their wintering range, diets of both species include a combination of rodent and bird prey, the latter of which is apparently available in fields seeded to OWB. Sammon and Wilkins (2005) showed that hispid cotton rats (*Sigmodon hispidus*), an important food source for raptors, can use OWB litter for cover throughout the year, although at lower densities than in native fields, and found a positive relationship between litter cover and density of cotton rats. Guthery et al. (1979) found cotton rat densities up to four times greater during August in exotic grass fields, including OWB, than in native grasslands, likely caused by an increase in standing vegetative biomass. However, because I did not find differences in vegetation structure between field types and did not measure rodent abundance, the extent to which predator prey dynamics factor into differences in raptor densities between OWB monocultures and native grasslands remains unclear.

While OWB fields supported higher numbers of some wintering bird species, overall, native fields supported more species. Other studies have shown that invasions by exotic grasses can reduce habitat quality for breeding birds by altering vegetation structure and composition (e.g., Bock et al. 1986, Flanders et al. 2006, Hickman et al. 2006). Differences in plant species composition between the two field types may have contributed to the absence of some species from OWB fields. Some bird species may select habitats on the basis of plant species composition (Block and Brennan 1993, Rotenberry and Wiens 1998). Old World bluestem fields typically are managed as monocultures, and while other plant species may persist alongside OWB, the vegetation community diversity is drastically reduced compared with native mixed-grass prairie. Effects of this simplification may be amplified during winter, when most grassland birds rely heavily on vegetative material for food.

My findings are consistent with other studies that suggest grass species composition is not an important determinant of grassland bird assemblages, provided species-specific structural needs are met (e.g., Scott and Lima 2004, Jones and Bock

2005). In some cases, exotic grasses meet those needs. However, studies addressing food availability and survival of wintering birds are needed to determine whether OWB monocultures represent superior wintering habitat or an ecological trap.

Nuttle et al. (2003) presented an index based on PIF priority scores to be used along with traditional measurements of community composition when determining a habitat's overall conservation value. However, PIF-derived indices have not been widely used and a standard has not been developed as to how to incorporate *CV*s with other methods for habitat assessment. To test for differences in community composition between field types, I used two measurements of *CV* based on the indices described by Nuttle et al. (2003), in addition to species richness and diversity. I found only the CV_2 score to be significantly different and higher in OWB fields than native fields. This higher score reflects my findings that OWB fields supported higher densities of several bird species of high conservation priority, such as Smith's Longspur and Short-eared Owl, than native fields. By revealing important differences in bird species composition, these results provide further evidence that priority based *CV*s should be used in habitat assessment.

Compared with cropland, seeded exotic grasslands may provide better habitat for grassland birds (Johnson and Schwartz 1993, Best et al. 1997) and may attract select bird species during both the breeding and winter seasons. Native grasslands, however, support more complex bird communities during the breeding season (Flanders et al. 2006, Hickman et al. 2006). Negative effects of exotic species on native plants and animals have been well established (e.g., Mack et al. 2000), and potential benefits to select species will rarely justify their use in conservation programs. That OWB can provide adequate wintering habitat for some species of conservation priority, however, should be considered when managers make decisions regarding grassland restoration.

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Table 1. Partners in Flight Continental Combined Scores (PIF CCS), total abundance (*n*), and frequency of sites in which detected (%) of all bird species observed using OWB monocultures and native grasslands in winter 2007–2008 and 2008–2009. Only species assigned as landbirds by PIF were assigned CCS.

			OWB		Native	
Species	Scientific name	*PIF CCS*	*n*	%	*n*	%
Smith's Longspur	*Calcarius pictus*	15	920	83	14	33
Chestnut-collard Longspur	*Calcarius ornatus*	13	291	33	0	0
Savannah Sparrow	*Passerculus sandwichensis*	9	193	100	89	67
meadowlark spp.	*Sturnella* spp.	11	157	100	323	100
Short-eared Owl	*Asio flammeus*	13	75	67	2	17
Northern Harrier	*Circus cyaneus*	11	49	100	21	83
Red-tailed Hawk	*Buteo jamaicensis*	6	5	67	11	50
Prairie Falcon	*Falco mexicanus*	12	4	67	1	17
Killdeer	*Charadrius vociferus*	–	4	17	0	0
Loggerhead Shrike	*Lanius ludovicianus*	12	2	33	1	17
Sedge Wren	*Cistothorus platensis*	9	2	17	0	0
Ring-necked Pheasant	*Phasianus colchicus*	8	1	17	11	67
Common Snipe	*Gallinago gallinago*	–	1	17	0	0
Horned Lark	*Eremophila alpestris*	8	1	17	0	0
Mourning Dove	*Zenaida macroura*	5	0	0	580	17
American Tree Sparrow	*Spizella arborea*	10	0	0	36	67
Northern Bobwhite	*Colinus virginianus*	12	0	0	13	17
Song Sparrow	*Melospiza melodia*	8	0	0	13	33
Brown-headed Cowbird	*Molothrus ater*	7	0	0	6	33
Eastern Bluebird	*Sialia sialis*	7	0	0	5	33
American Goldfinch	*Carduelis tristis*	6	0	0	4	33
Dark-eyed Junco	*Junco hyemalis*	8	0	0	4	33
American Crow	*Corvus brachyrhynchos*	6	0	0	3	17
Great Horned Owl	*Bubo virginianus*	7	0	0	2	17
Red-bellied Woodpecker	*Melanerpes carolinus*	9	0	0	2	17
Rough-legged Hawk	*Buteo lagopus*	8	0	0	2	17
Ferruginous Hawk	*Buteo regalis*	13	0	0	1	17
Great Blue Heron	*Ardea herodias*	–	0	0	1	17
Harris's Sparrow	*Zonotrichia querula*	14	0	0	1	17
Le Conte's Sparrow	*Ammodramus leconteii*	13	0	0	1	17
Northern Mockingbird	*Mimus polyglottos*	8	0	0	1	17

Table 2. Mean abundance (birds/km) and standard error of bird species comprising $\geq$ 5% of the total abundance of all birds observed in OWB monocultures and native mixed-grass prairie in winters 2007–2008 and 2008–2009.

	Year 1						Year 2					
	OWB			Native			OWB			Native		
	$\bar{x}$	±	SE	$\bar{x}$	±	SE	$\bar{x}$	±	SE	$\bar{x}$	±	SE
Smith's Longspur [a b]	33.98	±	31.62	–	±	–	3.01	±	2.92	0.42	±	0.38
Mourning Dove	–	±	–	–	±	–	–	±	–	13.66	±	13.66
meadowlark spp.	3.81	±	1.23	7.70	±	4.24	2.13	±	1.02	5.00	±	3.10
Chestnut-collared Longspur	13.08	±	13.08	–	±	–	0.02	±	0.02	–	±	–
Savannah Sparrow [a b]	4.80	±	1.76	2.32	±	0.77	2.22	±	0.76	0.77	±	0.29
American Tree Sparrow [a b]	–	±	–	2.75	±	2.38	–	±	–	0.17	±	0.12
Short-eared Owl [a b]	–	±	–	–	±	–	1.39	±	0.92	0.05	±	0.05
Northern Harrier [b]	0.34	±	0.15	0.25	±	0.15	0.96	±	0.27	0.40	±	0.14
Northern Bobwhite	–	±	–	–	±	–	–	±	–	0.38	±	0.38
Song Sparrow [a b]	–	±	–	0.49	±	0.37	–	±	–	–	±	–

[a] = $P \leq 0.10$ between field types [b] = $P \leq 0.10$ between years

Table 3. Vegetation characteristics (mean and SE) measured OWB monocultures and native mixed-grass prairie in north-central Oklahoma during winters 2007–2008 and 2008–2009.

	Year 1						Year 2					
	Native			OWB			Native			OWB		
	$\bar{x}$	±	SE	$\bar{x}$	±	SE	$\bar{x}$	±	SE	$\bar{x}$	±	SE
Grass cover (%) [b]	64.41	±	16.06	61.58	±	5.05	72.91	±	7.29	78.46	±	3.71
Forb cover (%) [a b]	6.75	±	1.21	0.14	±	0.10	4.06	±	1.06	0.1	±	0.04
Litter cover (%) [b]	20.97	±	12.44	3.49	±	1.07	38.6	±	8.44	27.33	±	1.35
Bare ground (%) [b]	29.70	±	17.25	43.89	±	6.18	23.63	±	7.38	21.61	±	3.79
Veg. Height (cm)	68.92	±	15.17	43.8	±	3.41	74.96	±	14.03	37.92	±	3.72
Vert. Obstruction (dm)	1.26	±	0.5	0.73	±	0.14	1.2	±	0.27	0.65	±	0.11
Point heterogeneity	0.63	±	0.22	0.49	±	0.06	0.78	±	0.20	0.38	±	0.04
Field heterogeneity	1.00	±	0.34	0.6	±	0.09	0.87	±	0.21	0.58	±	0.11

[a] = $P \leq 0.05$ between field types [b] = $P \leq 0.05$ between years

Table 4. Community composition parameters (mean and SE): Shannon-Weiner diversity (*H'*), species richness, and conservation values (CV_1 and CV_2) of OWB monocultures and native mixed-grass prairie in north-central Oklahoma during winters 2007–2008 and 2008–2009.

	Native			OWB		
	$\bar{x}$	±	SE	$\bar{x}$	±	SE
Richness	8.00	±	0.73	7.33	±	0.67
H'	1.16	±	0.27	1.21	±	0.10
CV_1	73.17	±	5.46	76.67	±	5.85
CV_2*	9.18	±	0.88	11.55	±	0.73

* = $P \leq 0.05$

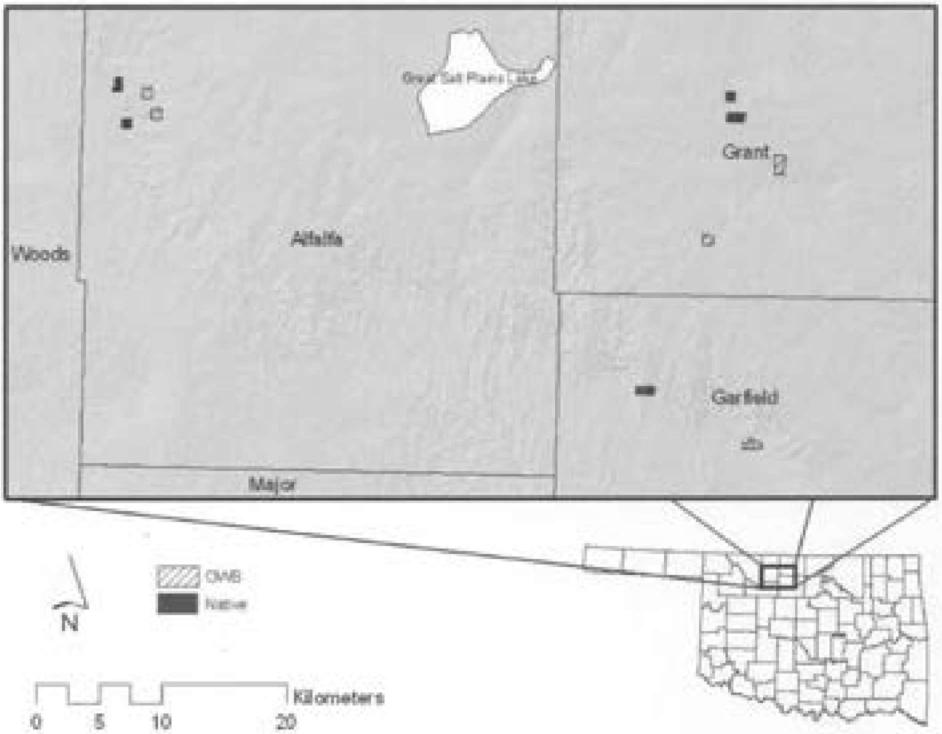

Figure 1. Map of study area showing all study sites: 6 OWB monocultures and 6 native fields in Alfalfa, Grant, and Garfield Counties in north-central Oklahoma.

VITA

Andrew D. George

Candidate for the Degree of

Master of Science

Thesis: AVIAN RESPONSE TO OLD WORLD BLUESTEM (*BOTHRIOCHLOA ISCHAEMUM*) MONOCULTURES IN MIXED-GRASS PRAIRIE.

Major Field: Natural Resource Ecology and Management

Biographical:

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Major Field: Natural Resource Ecology and Management

Scope and Method of Study: Despite persistent and widespread declines of grassland birds in North America, few studies have assessed differences between native and exotic grasslands as songbird habitat. In the Great Plains, many fields enrolled in the Conservation Reserve Program have been seeded to Old World bluestems (OWB), but there is evidence to suggest that OWB may not provide suitable conditions for several grassland bird species. My objectives were to investigate the influence of OWB monocultures on grassland bird abundance and community composition by identifying patterns in vegetation structure and food availability. In the breeding and winter seasons of 2007–2009, I used distance sampling to survey breeding and wintering songbirds, and conducted vegetation and arthropod surveys in 6 native 6 OWB fields in Garfield, Grant, and Alfalfa counties, Oklahoma.

Findings and Conclusions: While OWB fields supported a higher abundance of some bird species, native fields supported more complex bird communities during the breeding and winter seasons, including several species of conservation priority. Additionally, native fields supported higher arthropod biomass, an important food source for breeding birds. Some bird species were correlated with vegetation characteristics, regardless of field type, suggesting that management may be more important than plant species composition for some bird species. Native vegetation is superior to OWB monocultures for grassland bird habitat and should be promoted in conservation programs such as the CRP.

ADVISER'S APPROVAL: Dr. Timothy J. O'Connell