

# Use of Four Grassland Types by Small Mammal Species in Southern Minnesota

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## ABSTRACT

Small mammal populations in a series of grassland plantings were studied over a five-year period spanning 2008–2014. A central aim of this study was to establish the role of specific grassland compositions in promoting the restoration of small mammal richness and abundance. Conducted near Austin, Minnesota on a 160-acre wildlife management area, the study used a series of eight identically sized (4.5 hectare) plots arrayed in a two by four rectangle, which included two replicates of each planting. Two plot types were dominated by grasses (warm-season and cool-season, respectively) and two additional types consisted of forb-dominated mixes differing in plant height and composition. We captured 1807 individuals representing seven species over the span of 7680 trap nights in the eight plots. We found high variability in species richness between years within individual plots as well as extensive turnover in the species composition of trapped animals between years. We also recorded little movement of marked individuals between plot types. Mean mass of male *Microtus pennsylvanicus* (meadow vole) was greater in cool-season grass dominated plots compared to other plot types.

**Keywords:** ecosystem function, grassland, *Microtus*, reconstructions


## Restoration Recap

- Small mammal use of four distinct seed mixes planted side by side in a 160 acre grassland was compared across five seasons. Trapping occurred on sequential nights during the first three weeks of June each year.
- *Microtus* species dominated the reconstruction types and species diversity was low with a total of seven species captured across the study. *Microtus* were found in all plot types and abundance did not vary significantly between plot types.
- A difference in mean mass of male *Microtus pennsylvanicus* between cool-season grass plots and other planting types suggests the grasses present in these reconstructions may have provided superior forage and cover. No differences were found for *M. ochrogaster* populations among planting types.

With nearly two-thirds of native mixed grass prairie having been lost (Samson and Knopf 1996), the steep decline in many native species, including birds (Sauer et al. 2008) and at least some small mammals (Bowles 1981, Ceballos et al. 2010, Davidson et al. 2012), is a cause for serious concern. Less attention has been paid to small mammal populations relative to other wildlife taxa, particularly for species considered common (Delibes-Mateos et al. 2011), despite recognition that small mammals play

key roles in grassland ecosystems. Reported roles include nutrient cycling (Danielson 1995), seed and mycorrhizal fungi dispersal (Parameter et al. 1984, Hulme 1994, Horvath et al. 2001), regulation of grassland plant diversity (Howe et al. 2002), and as nutrient sources for larger predators (Korpimäki et al. 2005).

Many reconstructions (grasslands created on areas previously used for other purposes such as intensive agriculture) are dominated by dense, warm-season grass species, although recent research suggests at least some small mammals preferentially select grasslands with a mixture of forbs and grasses (Kaufman and Kaufman 2008). Prairie remnants in the upper Midwest are commonly characterized by more than 100 plant species (Wovcha et al. 1995, Henderson 1998). It has been our observation that even abandoned agricultural lands show re-growth as a mixture

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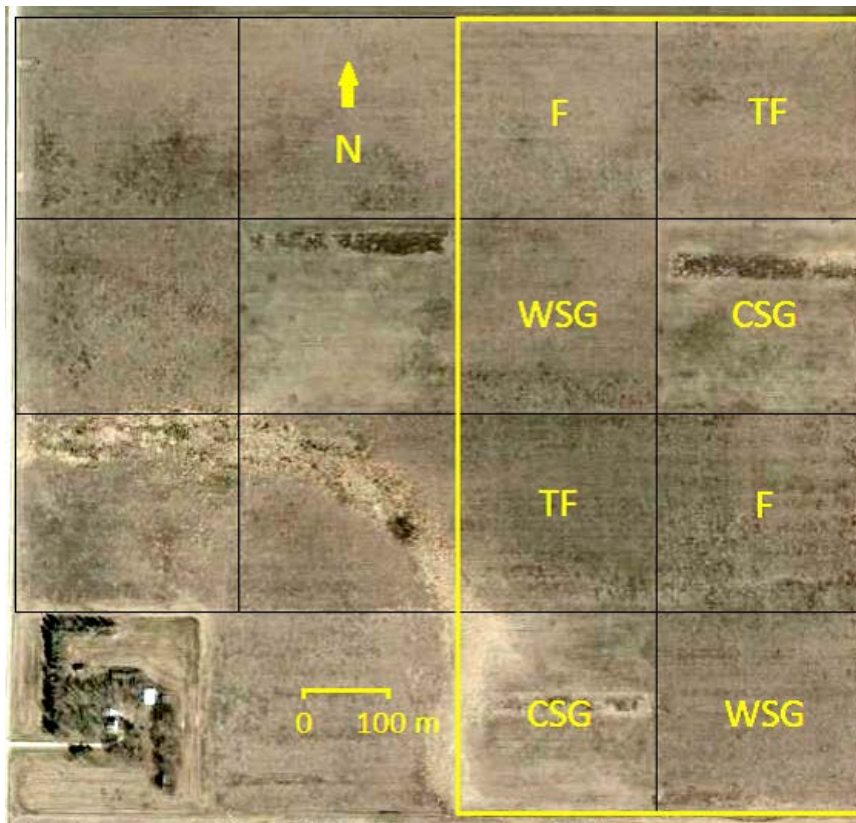


Figure 1. Planting design at the Schottler Wildlife Management Area (WMA) south of Austin, Minnesota in Mower county, SE Minnesota. CSG = cool season grass dominated fields, WSG = warm season grass dominated fields, F = forb fields lacking cup plant and compass plant, and TF = forb fields characterized by the presence of cup plant and compass plant. Both TF and F has greater than 65% forbs by rooted abundance. Each plot was approximately 11 acres in size. Study utilized approximately half of the total WMA area. Plots inside the yellow boundary were used for small mammal surveys. Photo Credit: Google Earth.

of both non-native cool-season grasses and weedy native species, containing ten or more dominant species (Fischer et al. 2012, Queiroz et al. 2014). Previous research has also suggested there are significant impacts on bird and small mammal communities based on grassland types (Bakker and Higgins 2009, DeGolier et al. 2015, Port and Schotler 2017).

A central aim of this study was to establish the role of specific grassland compositions in promoting the restoration of small mammal richness and abundance. Recent work with small mammals has examined a diverse array of factors influencing populations and biodiversity including the effect of weather and time since restoration on biomass and species diversity (Stone 2007) and habitat (e.g., remnant prairies, Kezar and Jenks 2004; intensively managed grasslands, Klimstra et al. 2015; reconstructed tall grass prairie, Schwartz and Whitson 1987, Neuhaus 2015; switchgrass fields, Sena et al. 2016; reconstructed grasslands subjected to repeated burns, DeGolier et al. 2015; successional stages, Churchfield et al. 1997; riparian habitat, Osbourne et al. 2005) but less work has been done directly comparing small mammal use of various types of planted grasslands.

The study presented here made use of a unique grassland habitat in southern Minnesota containing replicates of 4 grassland types. The objectives of this study were to 1) determine the small mammal richness and abundance in each of four types of grasslands, 2) compare the grassland small mammal communities across the mosaic of grassland

types and 3) investigate the relative quality of the four plot types using animal weights as a proxy. We predicted that small mammal species richness and abundance would differ between plot types due to preferences for particular habitat types by individual species, and that weights of animals in higher quality habitats would be greater.

## Methods

This study was conducted on the 160-acre Schottler Wildlife Management Area located 6.5 miles south of Austin, Minnesota (43°59'97.71" N and 92°92'45.58" W). A suite of 12, 4.5-hectare plots were planted in 2005 with one of four seed mixes (Figure 1). The site had been in a corn-soy rotation for at least 25 years prior to the reconstruction of grasslands. The plantings represent the only grassland habitat, other than road ditches, larger than a few acres within a one-mile radius. Post-planting management of the site was minimal with controlled burns occurring in half the plots during spring 2009 and the remaining half during spring 2010.

Eight plots were selected for this study and represented a block of side-by-side habitats with duplicate plots of each grassland type (Figure 1). Two plot types were dominated by grasses. One was predominantly tall (> 1m) native warm-season grass (WSG) such as *Andropogon gerardii* (big bluestem) and *Sorghastrum nutans* (indian grass). The other grass dominated plot type consisted of short non-native cool-season grasses (CSG) such as *Dactylis*

**Table 1. Summary of unique captures at the Schottler Wildlife Management Area south of Austin, Minnesota between 2008 and 2011–2014. Trapping occurred on successive nights during the first three weeks of June and totaled 7680 traps nights.**

| Species captured                                      | 2008 | 2011 | 2012 | 2013 | 2014 | Total |
|---|------|------|------|------|------|-------|
| Meadow vole <i>Microtus pennsylvanicus</i>            | 84   | 385  | 332  | 11   | 421  | 1233  |
| Prairie vole <i>Microtus ochrogaster</i>              | 2    | 149  | 266  | 5    | 12   | 434   |
| White footed/Deer mouse <i>Peromyscus sp</i>          | 12   | 8    | 35   | 47   | 0    | 102   |
| Northern short-tailed shrew <i>Blarina brevicauda</i> | 1    | 1    | 9    | 0    | 9    | 20    |
| Meadow jumping mouse <i>Zapus hudsonius</i>           | 0    | 3    | 1    | 0    | 0    | 4     |
| Least shrew <i>Cryptotis parva</i>                    | 0    | 0    | 3    | 0    | 0    | 3     |
| Ermine <i>Mustela erminea</i>                         | 9    | 0    | 2    | 0    | 0    | 11    |

*glomerata* (orchard grass), *Festuca pratensis* (meadow fescue), and *Phleum pratense* (Timothy grass). The other two plot types were dominated by forbs, one with a greater proportion of tall forb species such as *Silphium perfoliatum* (cup plant), *Silphium laciniatum* (compass plant) and *Aster novea-angliae* (New England aster). Other than the differences in taller forb species, both forb plots (F and TF, Figure 1) were characterized by similar species such as *Monarda fistulosa* (bergamot), *Zizia aurea* (golden alexander), *Solidago rigida* (stiff goldenrod), *Penstemon digitalis* (white beardtongue), *Rudbeckia hirta* (black-eyed susan), *Ratibida pinnata* (yellow coneflower), *Liatris pycnostachya* (prairie blazing star), and *Gentiana alba* (cream gentian). The forb dominated areas had over 45 species, with forbs contributing greater than 70% of all rooted plants. Post-planting floristic surveys were conducted in the summer of 2011, the sixth growing season, to quantify any changes in the reconstruction since seeding (see Port and Schottler 2017 for further details).

### Small Mammal Surveys

In 2008 and from 2011–2014 we surveyed the small mammal species present on each of the plots using 9-inch box traps baited with sunflower seed. We conducted a pilot study in 2008 with full scale work beginning in 2011. Traps were set in two transects running lengthwise through each plot, each approximately 100-m in length and 75-m apart with traps set at 10-m intervals for a total of 20 traps per plot and 160 traps overall. This spacing allowed for maximal coverage of each plot with the combined transects running nearly the full length of each plot and equally spaced within each. Traps were baited beginning around 1900 and checked early the following morning. In 2008 there were eight trap nights. Ten traps nights were conducted in each of the other survey years.

All trap nights occurred during the first three weeks of June each year with all plots trapped simultaneously and on sequential nights, as weather permitted. Trapping occurred in June each year to allow comparison of results between years. While trapping throughout the summer months would have provided a fuller picture of animal use of the areas over time, we believe trapping in June provided key insights into use of the plots early in the

growing season and a single, more intensive and extensive set of sequential trap nights was appropriate (Rumble and Gobeille 2001, Pearson and Ruggiero 2003, Reddin and Kremenetz 2016). All animals captured were recorded to species with *M. pennsylvanicus*, *M. ochrogaster*, *Peromyscus* and *Zapus hudsonius* (meadow jumping mouse) weighed, sexed, and aged before release. Due to the difficulty of field identification of *Peromyscus leucopus* (white-footed) and *Peromyscus maniculatus* (deer mice), these individuals were grouped together as *Peromyscus*. Any *M. pennsylvanicus*, *M. ochrogaster*, and *Peromyscus* not previously captured was also marked with a passive integrated transponder (PIT) tag (Harper and Batzli 1996) for future individual identification. New individuals were considered as first-time or only-time capture in a given reconstruction type.

For each plot type we calculated the number of unique captures for each species as well as species richness. Since all plots were of identical size, we were able to compare means for each plot type directly. Values are presented as means  $\pm$  standard error. Weights of *M. pennsylvanicus* and *M. ochrogaster* were used as a proxy of animal health within each habitat type since both were found in all plots throughout the study. Due to the complicating effects of pregnancy, only data from males were used in analysis of body weights for this study. ANOVA with a Bonferroni post hoc test was used to determine whether there were differences in male weights between plot types. All statistical tests were considered significant at  $p < 0.05$ . Data were analyzed using SPSS (SPSS Version 23.0.0.0. IBM Corp. Armonk, NY).

### Results

During a total of 7680 trap nights, 1807 animals representing at least seven different species groups were captured across the four plot types. *Microtus pennsylvanicus* were the most common animals captured ( $n = 1233$ ) with *M. ochrogaster* ( $n = 434$ ) and *Peromyscus* ( $n = 102$ ) abundant in some of the survey years. Additional species captured included *Blarina brevicauda* (northern short-tailed shrew), *Zapus hudsonius*, *Cryptotis parva* (least shrew), and *Mustela erminea* (ermine) (Table 1). Total richness over the duration of the study was seven (range 3–7, mean = 4.6).

**Table 2. Combined (2008, 2011–2014) mean number of unique captures by species and reconstruction type at the Schottler Wildlife Management Area south of Austin, Minnesota across the study period. CSG = cool season grass dominated fields, WSG = warm season grass dominated fields, F = forb fields lacking cup plant and compass plant, and TF = forb fields characterized by the presence of cup plant and compass plant. Values represent the mean  $\pm$  SE.**

| Unique captures by plot type                          | CSG           | WSG           | F             | TF            |
|---|---------------|---------------|---------------|---------------|
| Meadow vole <i>Microtus pennsylvanicus</i>            | 54 $\pm$ 18.9 | 62 $\pm$ 24.9 | 64 $\pm$ 21.9 | 67 $\pm$ 19.1 |
| Prairie vole <i>Microtus ochrogaster</i>              | 17 $\pm$ 10.9 | 27 $\pm$ 17.3 | 21 $\pm$ 12.1 | 21 $\pm$ 12.7 |
| White footed/Deer mouse <i>Peromyscus sp</i>          | 7 $\pm$ 3.4   | 4 $\pm$ 2.1   | 5 $\pm$ 3.0   | 5 $\pm$ 0.6   |
| Northern short-tailed shrew <i>Blarina brevicauda</i> | 0.4 $\pm$ 0.2 | 1 $\pm$ 1.0   | 2 $\pm$ 0.9   | 1 $\pm$ 0.4   |
| Meadow jumping mouse <i>Zapus hudsonius</i>           | 0.2 $\pm$ 0.2 | 0             | 0.4 $\pm$ 0.4 | 0.2 $\pm$ 0.2 |
| Least shrew <i>Cryptotis parva</i>                    | 0.2 $\pm$ 0.2 | 0.2 $\pm$ 0.2 | 0.2 $\pm$ 0.2 | 0             |
| Ermine <i>Mustela erminea</i>                         | 1 $\pm$ 1.0   | 1 $\pm$ 0.6   | 0.2 $\pm$ 0.2 | 0.4 $\pm$ 0.4 |

### Small Mammal Use of Grassland Reconstructions

Small mammal captures by species varied from year to year but overall all plots were dominated by voles (*M. pennsylvanicus* and *M. ochrogaster*; Table 1). *Microtus pennsylvanicus* were found consistently within each plot type across all survey years and were the most abundant animals within each plot (Table 2) in most years (Table 3).

Nearly all species recorded on the site were found in all plots, with the only exception that *Z. hudsonius* was absent from warm-season grass plots and *C. parva* was absent from tall forb fields. Given the small number of captures overall for these species, these absences may or may not reflect species habitat preferences (Table 2).

Despite the general use of all plot types by the most abundant species, little movement occurred between plots by marked individuals. Between 2008 and 2011–2014 only 11 individuals (four *M. pennsylvanicus*, three *M. ochrogaster*, four *Peromyscus*) were recaptured in plot types different from the location of their original capture. In all cases they were recaptured in the neighboring plot type in an adjacent transect. Most other recaptured individuals were found in traps within 10–20 meters of their original trap locations.

Significant differences did exist for mean weight of individual male *M. pennsylvanicus* (ANOVA,  $F_{3,1} = 2.81$ ,  $p =$

0.04) but not for *M. ochrogaster* within each plot type (ANOVA,  $F_{3,1} = 0.28$ ,  $p = 0.84$ ). *Microtus pennsylvanicus* captured in CSG plots had significantly higher mass compared to forb dominated (F) fields but not warm season grass fields (Table 4).

### Discussion

These grasslands were dominated by *M. pennsylvanicus*, *M. ochrogaster*, and *Peromyscus*. Small mammal communities in the Midwest typically have low species diversity, often with three to five species within an area (Getz and Hofmann 1999, Heske 1999). Our prediction that small mammal species richness would differ between plot types was not supported, at least not during the June trapping period. We cannot discount the possibility that patterns do exist later in the growing season as reproduction increases population densities and dispersal. It also remains possible that sampling in the greater field would have produced different results due to greater variability between and within habitats. We were only able to replicate our plots twice as opposed to three times because several plots bordered a road and a large wet meadow and were potentially structurally different from the eight plots studied. This may have affected our results as well.

**Table 3. Total unique captures for key species within the grassland reconstructions at the Schottler Wildlife Management Area south of Austin, Minnesota. Only species with a minimum of 10 captures within a year were included. CSG = cool season grass dominated fields, WSG = warm season grass dominated fields, F = forb fields lacking cup plant and compass plant, and TF = forb fields characterized by the presence of cup plant and compass plant.**

| Year | Species                        | Total | CSG | WSG | F   | TF  |
|------|--------------------------------|-------|-----|-----|-----|-----|
| 2014 | <i>Microtus pennsylvanicus</i> | 421   | 83  | 116 | 115 | 107 |
|      | <i>Microtus ochrogaster</i>    | 12    | 0   | 5   | 3   | 4   |
| 2013 | <i>Microtus pennsylvanicus</i> | 11    | 8   | 0   | 2   | 1   |
|      | <i>Peromyscus sp.</i>          | 47    | 14  | 10  | 15  | 8   |
| 2012 | <i>Microtus pennsylvanicus</i> | 332   | 74  | 84  | 91  | 83  |
|      | <i>Microtus ochrogaster</i>    | 266   | 55  | 90  | 59  | 62  |
|      | <i>Peromyscus sp.</i>          | 35    | 16  | 1   | 9   | 9   |
| 2011 | <i>Microtus pennsylvanicus</i> | 385   | 96  | 106 | 89  | 94  |
|      | <i>Microtus ochrogaster</i>    | 149   | 29  | 39  | 41  | 40  |
| 2008 | <i>Microtus pennsylvanicus</i> | 84    | 9   | 5   | 22  | 48  |
|      | <i>Peromyscus sp.</i>          | 12    | 1   | 8   | 1   | 2   |

**Table 4. Mean weight of unique captures of male *M. pennsylvanicus* by plot type. CSG = cool season grass dominated fields, WSG = warm season grass dominated fields, F = forb fields lacking cup plant and compass plant, and TF = forb fields characterized by the presence of cup plant and compass plant. \* significantly different ( $p < 0.05$ ) from forb (F) plots.**

| Plot | Mean weight (g) | Number of individuals |
|------|-----------------|-----------------------|
| CSG  | 32.0 ± 1.0*     | 110                   |
| F    | 28.5 ± 1.1      | 99                    |
| TF   | 29.4 ± 0.8      | 105                   |
| WSG  | 31.2 ± 0.9      | 124                   |

Individuals from each species were found in all plot types during the study and no plot type had biologically significant differences in the number of unique captures. We did find some evidence of movement between plot types by individuals, but these movements were rare during June, with most recaptures occurring at traps within 20 m of the original location. The ability to rapidly colonize new areas is a life history trait of *Microtus* species (Ebenhard 1990, Glorvigen et al. 2013) and it is possible dispersal occurs later in the summer as fecundity increases population pressures within plots.

*Microtus pennsylvanicus* were the dominant species throughout all plot types with unique captures ranging from 11 to 421 during the study. *Microtus pennsylvanicus* are known to exhibit pronounced population cycles every 4–5 years (Krebs 2013) but it remains unknown if this population demonstrated a similar pattern. The rapid decline in the *M. pennsylvanicus* population along with trapping success of other species in 2013 coincided with periods of heavy rainfall, localized flooding, and cooler temperatures throughout the trapping period and may reflect the impact of weather on the local population, rather than a periodic population event.

*Microtus ochrogaster* populations varied from year to year. Klatt et al. (2015) suggested at least some of this distributional pattern may be the result of interspecific interactions, with *M. ochrogaster* dominant in sparse cover and *M. pennsylvanicus* dominant in heavier cover. Batzli et al. (1999) observed that presence of *M. pennsylvanicus* resulted in lower densities of *M. ochrogaster*. While both species of voles preferentially seek out vegetative cover (Getz et al. 2005), *Microtus pennsylvanicus* are thought to favor relatively tall grass vegetation structures due to foraging preferences (DeJaco and Batzli 2013) and nesting requirements, whereas *M. ochrogaster* nest in burrows below ground and feed preferentially on forbs (Klatt and Getz 1987, Lin and Batzli 2001, Getz et al. 2005). Survival rates of *M. pennsylvanicus* are positively associated with density of cover compared to *M. ochrogaster*, perhaps as a consequence of the greater vulnerability of *M. pennsylvanicus* to predation (Lin and Batzli 2001, Getz et al. 2005). Klimstra et al. (2015) documented the movement

of *M. pennsylvanicus* out of hayed fields, potentially as the result of lost cover and increased vulnerability to predation. As a result, these species are frequently reported to have opposite habitat preferences within grassland ecosystems (Getz et al. 2005). We found little difference in the distribution of either *Microtus* species within the four different reconstruction types at any point during the study, although *M. pennsylvanicus* was far more abundant in most years across all plot types.

There was a significant difference in the mean mass of male *M. pennsylvanicus* in the cool-season grass (CSG) plots compared to forb (F) dominated fields. This may suggest higher habitat quality, at least for *M. pennsylvanicus*, for these plot types although vegetational characters were not evaluated in this study. Getz et al. (1979) reported differences in *M. pennsylvanicus* weights by habitat type although found no correlation between survival or reproduction and body weight. CSG plots were dominated by non-native species including orchard grass, meadow fescue, and Timothy grass that may have provided protective dense thatch layers as well as forage. Interestingly, young shoots of orchard and Timothy grass were reported as favored food items by *M. ochrogaster* (DeJaco and Batzli 2013) and the heavier mean mass of *M. pennsylvanicus* within these field types may reflect a higher nutritional quality of these types of graminoids for voles in general, and in particular during the June growing season when trapping occurred. Kaufman and Kaufman (2017) suggested cool season fields dominated by brome may provide higher quality forage year-round and be favored by herbivores over native prairie grasses. No differences in mass between plot types were found in *M. ochrogaster* although Cole and Batzli (1979) and Getz et al. (1979) did report differences with habitat in their studies.

*Peromyscus* are generalists and favor landscapes with less cover and avoid high cover vegetation such as brome monocultures (Henderson and Sample 1995, Getz and Hofmann 1999, Heske 1999, Stone 2007). Such traits predict that these mice would be most common early in the establishment of the grassland reconstructions. It is possible the disappearance of *Peromyscus* from the site reflects the changes in the vegetation composition, density and height, although they were not caught in large numbers at any time during the study. A shift in dominance from *Peromyscus* mice toward a community dominated by voles might be the expected trajectory for most grassland reconstruction projects in the Midwest (Mulligan et al. 2013).

In summary, we did not find significant differences in species composition or abundance between warm season or cool season grass reconstructions or forb versus grass dominated plots. In our location, *Microtus* voles, particularly *M. pennsylvanicus*, dominated all reconstruction types. Cool season grasses supported a population with a greater body mass but not a greater number of individuals, at least not during the spring period when trapping was

done. It is unknown whether the increased body mass corresponded to increased survivorship or fecundity later in the season. In contrast to other studies, we did not find clear habitat preferences between *M. pennsylvanicus* and *M. ochrogaster*, instead finding both species within all planting types. The vegetation types used in this planting may have lacked differences significant to voles, although clear differences have been reported among other taxa using these seed mixes at this location (Port and Schottler 2017) and other locations (DeGolier et al. 2015, Schottler et al. 2008).

Small mammals, especially grassland species such as *Microtus* voles and *Peromyscus* mice, remain key components of grassland ecosystems and serve as indicators of ecosystem stability and health (Clark et al. 1989, Stone 2007), and attract various predators to restored grasslands (Schmidt et al. 2008). While it may not always be practical to increase the plant diversity of seed mixes used to create these grassland ecosystems, care must be taken when reconstructing these grassland ecosystems to consider needs for these often-overlooked components of grasslands. Even if an area is small, we encourage managers to consider planting a diversity of habitat types, including some that may not be floristically rich but offer a different habitat structure. Our research, and that of others (Getz et al. 2005, DeGolier et al. 2015), suggests that while habitat requirements for many small mammal species are somewhat flexible, planting a diversity of habitats is superior for increasing animal biodiversity.

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## References

- Bakker, K. and K. Higgins. 2009. Planted grasslands and native sod prairie: equivalent habitat for grassland birds? *Western North American Naturalist* 69:235–242.
- Batzli, G.O., S.J. Harper, Y.K. Lin and E.A. Desy. 1999. Experimental analysis of population dynamics: scaling up to the landscape. Pages 107–127 in G.W. Barrett and J.D. Peles (eds), *Ecology of Small Mammals at the Landscape Level: Experimental Approaches*. New York, NY: Springer-Verlag.
- Bowles, J.B. 1981. Iowa's mammal fauna: an era of decline. *Proceedings Iowa Academy Science* 88:38–42.
- Ceballos, G., A. Davidson, R. List, J. Pacheco, P. Manzano-Fischer, G. Santos-Barrera and J. Cruzado. 2010. Rapid decline of a grassland system and its ecological and conservation implications. *PLOS One* 5:e8562.
- Churchfield, S., J. Hollier and V.K. Brown. 1997. Community structure and habitat use of small mammals in grasslands of different successional age. *Journal of Zoology* 242:519–530.
- Clark, B.K., D.W. Kaufman, E.J. Finck and G.A. Kaufman. 1989. Small mammals in tall-grass prairie: patterns associated with grazing and burning. *Prairie Naturalist* 21:177–184.
- Cole, F.R. and G.O. Batzli. 1979. Nutrition and population dynamics of the prairie vole, (*Microtus ochrogaster*), in central Illinois. *Journal of Animal Ecology* 48:455–470.
- Danielson, B.J. 1995. The relative importance of regional vs. local habitat variables in explaining the distributions of small mammals. Paper presented at the 16th Midwest Conference on Population Biology Meeting, Ames, IA.
- Davidson, A., J.K. Detling and J.H. Brown. 2012. Ecological roles and conservation challenges of social, burrowing, herbivorous mammals in the world's grasslands. *Frontiers in Ecology and the Environment* 10:477–486.
- DeGolier, T., J. Port and S. Schottler. 2015. Small mammal habitat preferences in a patchwork of adjacent reconstructed grasslands subject to semiannual burns. *Ecological Restoration* 33:388–394.
- DeJaco, C. and G. Batzli. 2013. Palatability of plants to small mammals in nonnative grasslands of east-central Illinois. *Journal of Mammalogy* 94:427–435.
- Delibes-Mateos M., A.T. Smith, C.N. Slobodchikoff and J.E. Swenson. 2011. The paradox of keystone species persecuted as pests: A call for the conservation of abundant small mammals in their native range. *Biological Conservation* 144:1335–1346.
- Ebenhard T. 1990. A colonization strategy in field voles (*Microtus agrestis*): reproductive traits and body size. *Ecology* 71:1833–1848.
- Fischer, J., H. Tibor and T. Kuemmerle. 2012. Conservation policy in traditional farming landscapes. *Conservation Letters* 5:167–175.
- Getz, L.L., L. Verner, F.R. Cole, J.E. Hofmann and D.E. Avalos. 1979. Comparisons of population demography of *Microtus ochrogaster* and *M. pennsylvanicus*. *Acta Theriologica* 24:319–349.
- Getz, L.L. and J.E. Hofmann. 1999. Diversity and stability of small mammals in tallgrass prairie habitat in central Illinois, USA. *Oikos* 85:356–363.
- Getz, L., M.K. Oli, J.E. Hofmann and B. McGuire. 2005. Habitat-specific demography of sympatric vole populations over 25 years. *Journal of Mammalogy* 86:561–568.
- Glorvigen, P., G. Gundersen, H.P. Andreassen and R. Ims. 2013. The role of colonization in the dynamics of patchy populations of a cyclic vole. *Oecologia* 173:161–167
- Harper, S.J. and G.O. Batzli. 1996. Monitoring use of runways by voles with passive integrated transponders. *Journal of Mammalogy* 77:364–369.
- Henderson, R.A. and D.W. Sample. 1995. Grassland communities. Pages 116–129 in J. Addis (ed), Wisconsin's biodiversity as a management issue: a report to Department of Natural Resources' managers. Madison: Wisconsin Department of Natural Resources.
- Henderson, R. 1998. Plant species composition of Wisconsin prairies. Wisconsin Department of Natural Resources Technical Bulletin No. 188.
- Heske, E.J. 1999. Habitat use by small mammals in an intensively managed grassland wildlife sanctuary-final year. Center for Wildlife Ecology, Illinois Natural History Survey Final report for FY 99.
- Horvath, A., I.J. March and J.H. Wolf. 2001. Rodent diversity and land use in Montebello, Chiapas, Mexico. *Studies on Neotropical Fauna and Environment* 36:169–176.

- Howe, H.F., J.S. Brown and B. Zorn-Arnold. 2002. A rodent plague on prairie diversity. *Ecology Letters* 5:30–36.
- Hulme, P.E. 1994. Post-dispersal seed predation in grassland: its magnitude and sources of variation. *Journal of Ecology* 82:645–652.
- Kaufman, D.W. and G.A. Kaufman. 2008. Effects of haying on small mammals in mixed grass prairie of central Kansas. *Transactions Kansas Academy Science* 111:275–282.
- Kaufman, D.W. and G.A. Kaufman. 2017. Small mammals in anthropogenic brome fields as compared to native tallgrass prairie in the northern Flint Hills of Kansas. *Transactions Kansas Academy Science* 120:157–169.
- Kezar, S.J. and J.A. Jenks. 2004. Relative abundance of small mammals in native and restored tallgrass prairie. *Proceedings of South Dakota Academy of Sciences* 83:33–37.
- Klatt, B.J. and L.L. Getz. 1987. Vegetation characteristics of *Microtus ochrogaster* and *M. pennsylvanicus* habitats in east-central Illinois. *Journal of Mammalogy* 68:569–577.
- Klatt, B., L. Getz and B. McGuire. 2015. Interspecific interactions and habitat use by prairie voles (*Microtus ochrogaster*) and meadow voles (*M. pennsylvanicus*). *The American Midland Naturalist* 173:241–252.
- Klimstra, R.L., C.E. Moorman, S.J. Converse, J.A. Royle and C.A. Harper. 2015. Small mammal use of native warm-season and non-native cool-season grass forage fields. *Wildlife Society Bulletin* 39:49–55.
- Krebs C. 2013. *Population Fluctuations in Rodents*. Chicago, IL: University of Chicago Press.
- Korpimäki, E., K. Norrdahl, O. Huitu and T. Klemola. 2005. Predator induced synchrony in population oscillations of coexisting small mammal species. *Proceedings of The Royal Society* 272:193–202.
- Lin, Y.K. and G.O. Batzli. 2001. The influence of habitat quality on dispersal, demography and population dynamics of voles. *Ecological Monographs* 71:245–275.
- Mulligan, M., R.L. Schooley and M.P. Ward. 2013. Effects of connectivity and regional dynamics on restoration of small mammal communities in midwestern grasslands. *Restoration Ecology* 21:678–685.
- Neuhaus, R. 2015. A comparison of the effects of burning, haying, and mowing on plants and small mammals in a tall-grass prairie reconstruction. M.S. Thesis, University of Northern Iowa.
- Osbourne, J.D., J.T. Anderson and A.B. Spurgeon. 2005. Effects of habitat on small-mammal diversity and abundance in West Virginia. *Wildlife Society Bulletin* 33:814–822.
- Parameter, R.R., J.A. MacMahon and S.B. VanderWall. 1984. The measurement of granivory by desert rodents, birds, and ants: A comparison of an energetics approach and a seed-dish technique. *Journal of Arid Environments* 7:75–92.
- Pearson, D.E. and L.F. Ruggiero. 2003. Transect versus grid trapping arrangements for sampling small-mammal communities. *Wildlife Society Bulletin* 31:454–459.
- Port, J. and S. Schottler. 2017. The effect of floristic composition on bird communities in a set of four grassland reconstruction types. *Ecological Restoration* 35:112–119.
- Queiroz, C., R. Beilin, C. Falke and R. Lindberg. 2014. Farmland abandonment: Threat or opportunity for biodiversity conservation? A global review. *Frontiers in Ecology and the Environment* 12:288–296.
- Reddin, C. and D. Krementz. 2016. Small mammal communities in eastern red cedar forest. *The American Midland Naturalist* 175:113–119.
- Rumble, M. and J. Gobeille. 2001. Small mammals in successional prairie woodlands of the northern Great Plains. U.S. Department of Agriculture Rocky Mountain Research Station Research Paper RMRS-RP-28.
- Samson, F. and F. Knopf. 1996. *Prairie conservation. Preserving North America's most endangered ecosystem*. Washington, DC: Island Press.
- Sauer, J., J. Hines and J. Fallon. 2008. The North American Breeding Bird Survey, results and analysis 1966–2007. Version 5.15.2008. USGS Patuxent Wildlife Research Center, Laurel, MD.
- Schmidt, K.A., E. Lee, R.S. Ostfeld and K. Sieving. 2008. Eastern chipmunks increase their perception of predation risk in response to titmouse alarm calls. *Behavioral Ecology* 19:759–763.
- Schottler, S., J. Port and T. DeGolier. 2008. Influence of floristic diversity on songbird nesting preferences in a suite of adjacent reconstructed grasslands (Wisconsin). *Ecological Restoration* 26:195–198.
- Schwartz, O.A. and P.D. Whitson. 1987. A 12-year study of vegetation and mammal succession on a reconstructed tall-grass prairie in Iowa. *The American Midland Naturalist* 117:240–249.
- Sena, K.L., B. Brammell and S.R. Smith. 2016. Converting abandoned hayfield to switchgrass increases small mammal relative abundance. *Journal of the Kentucky Academy of Science* 77:11–18.
- Stone, E. 2007. Measuring impacts of restoration on small mammals in a mixed-grass Colorado prairie. *Ecological Restoration* 25:183–190.
- Wovcha, D., B. Delaney and G. Nordquist. 1995. Minnesota St. Croix River Valley and the Anoka Sandplain. Minneapolis, MN: University of Minnesota Press.

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