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Original Article

Small Mammal Use of Native Warm-Season and Non-Native Cool-Season Grass Forage Fields

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ABSTRACT Recent emphasis has been put on establishing native warm-season grasses for forage production because it is thought native warm-season grasses provide higher quality wildlife habitat than do non-native cool-season grasses. However, it is not clear whether native warm-season grass fields provide better resources for small mammals than currently are available in non-native cool-season grass forage production fields. We developed a hierarchical spatially explicit capture–recapture model to compare abundance of hispid cotton rats (*Sigmodon hispidus*), white-footed mice (*Peromyscus leucopus*), and house mice (*Mus musculus*) among 4 hayed non-native cool-season grass fields, 4 hayed native warm-season grass fields, and 4 native warm-season grass–forb ("wildlife") fields managed for wildlife during 2 summer trapping periods in 2009 and 2010 of the western piedmont of North Carolina, USA. Cotton rat abundance estimates were greater in wildlife fields than in native warm-season grass and non-native cool-season grass fields and greater in native warm-season grass fields than in non-native cool-season grass fields. Abundances of white-footed mouse and house mouse populations were lower in wildlife fields than in native warm-season grass and non-native cool-season grass fields, but the abundances were not different between the native warm-season grass and non-native cool-season grass fields. Lack of cover following haying in non-native cool-season grass and native warm-season grass fields likely was the key factor limiting small mammal abundance, especially cotton rats, in forage fields. Retention of vegetation structure in managed forage production systems, either by alternately resting cool-season and warm-season grass forage fields or by leaving unharvested field borders, should provide refugia for small mammals during haying events.

KEY WORDS forage production, haying, *Mus musculus*, native warm-season grass, non-native cool-season grass, *Peromyscus leucopus*, *Sigmodon hispidus*.

Widespread establishment of non-native, cool-season grasses as cattle forage, conversion of native grasslands to row-crops, and the recent intensification of agricultural practices likely has reduced habitat quality for small mammals (Bowles 1981, Kaufman and Kaufman 1989). Non-native grass forage fields planted as dense monocultures have low plant species diversity and limited structural diversity, which limits resource availability (Collins and Gibson 1990, Sietman et al. 1994). Furthermore, frequent haying of cool-season grass forage fields early in the growing season drastically changes groundcover structure and temporarily can displace individual small mammals and potentially reduce long-term population densities (Lemen and Clausen 1984, Sietman et al. 1994, Kaufman and Kaufman 2008).

Conventional wisdom that native warm-season grasses are of better quality for various wildlife species than are non-native cool-season grasses (hereafter, cool-season grass) has contributed to the recent emphasis on establishing these grasses for forage production throughout the southeastern United States (Washburn et al. 2000, Ryan and Marks 2005). However, similar to cool-season grasses, native warm-season grass management likely influences resource availability and small mammal use. Densely stocked native grass monocultures intensively managed as hay forage may lack the same critical food (i.e., diversity of grasses and forbs) and cover resources that are absent from intensively managed cool-season grass forage fields. Specifically, hispid cotton rats (*Sigmodon hispidus*) avoid hayed forage systems and select grasslands with persistent overhead cover and access to native warm-season grasses and forbs (Kincaid and Cameron 1982,

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Kaufman and Kaufman 2008). Although the white-footed mouse (*Peromyscus leucopus*) is considered a woodland species, a study by Kaufman and Kaufman (2008) found it to be positively associated with native grasslands that were not hayed. In contrast, the house mouse (*Mus musculus*) is an introduced habitat generalist species commonly found in woodlands, croplands, and grasslands, and it likely is less sensitive to variation in structure and composition connected to forage field management (Kaufman et al. 2000).

Consideration of small mammal populations in forage production systems is warranted as they play a key role as predators and prey, as well as seed dispersers (Korpimäki 1984, Hulme 1994). Declines in small mammal populations could lead to reduced numbers of avian and mammalian predators and alterations in seed dispersal (French et al. 1976, Korpimäki et al. 2005). Korschgen and Stuart (1972) suggested that abundant small mammal populations provide a prey source to predators, thereby reducing alternative predation of desirable game species (e.g., eastern cottontail [*Sylvilagus floridanus*] and northern bobwhite [*Colinus virginianus*]). Although small mammals are a key component of trophic dynamics, there is limited research on the effects of forage grassland management on these species. Specific management actions associated with forage systems could differentially affect small mammal populations and could lead to changes in grassland ecosystems.

To determine small mammal population response to cattle-forage production systems, we compared abundance of 3 rodent species—hispid cotton rat, white-footed mouse, and house mouse—as a function of field type, including hayed cool-season grass fields, hayed native warm-season grass fields, and native warm-season grass–forb fields managed for wildlife (hereafter, "wildlife fields"). The wildlife fields were not managed for forage production, but rather served as a reference condition for comparison with the more intensively managed (i.e., hayed) native and non-native forage production systems. We hypothesized 1) small mammal abundance would be greater in wildlife fields where cover and food resources were available more consistently than in native warm-season grass and cool-season grass forage fields hayed during spring and summer months; 2) small mammal abundance would be greater in native warm-season grass hayed fields than in cool-season grass hayed fields because of the unique structure produced by native warm-season grasses, especially at ground level; and 3) abundance of the non-native house mouse, because of its generalist nature, would be less likely to differ among the field types.

STUDY AREA

During the summers of 2009 and 2010, we documented small mammal use of forage fields on privately owned fields in Iredell and Davie counties in the western piedmont of North Carolina, USA. In 2009, we captured small mammals in 4 hayed native warm-season grass fields (1.89–9.06 ha, $\bar{x} = 6.18$ ha), 4 hayed cool-season grass fields (1.54–9.51 ha, $\bar{x} = 6.16$ ha), and 4 wildlife fields (1.62–3.32 ha, $\bar{x} = 2.71$ ha). In 2010, we captured small mammals in 4 hayed native warm-season grass fields (1.89–9.06 ha, $\bar{x} = 5.43$ ha), 4 hayed cool-season grass fields (1.54–7.85 ha, $\bar{x} = 5.10$ ha), and 4 wildlife fields (1.62–3.32 ha, $\bar{x} = 2.71$ ha). One native warm-season grass field and one cool-season grass field from 2009 were not available to trap in 2010 and were replaced for the 2010 field season; therefore, we trapped in 14 fields over the entire study. All study fields during both years were located within a 48-km radius of Statesville, North Carolina (N35.81476, W80.85512). Of the 5 hayed cool-season grass fields, 4 were dominated by tall fescue (*Festuca arundinacea*), and 1 was dominated by orchardgrass (*Dactylis glomerata*). Of the 5 hayed native warm-season grass fields, 2 were converted from tall fescue to single-species forage production stands of big bluestem (*Andropogon gerardii*), and 3 were planted as a forage production stand with a mix of little bluestem (*Schizachyrium scoparium*), big bluestem, and indiangrass (*Sorghastrum nutans*). Of the 4 wildlife fields, 2 were planted in a mix of indiangrass, little bluestem, sideoats grama (*Bouteloua curtipendula*), and partridge pea (*Chamaecrista* spp.), and 2 were planted in a mix of switchgrass (*Panicum virgatum*) and eastern gamagrass (*Tripsacum dactyloides*). Wildlife fields were managed to maintain a mix of native grasses and forbs and to provide food and cover resources for a variety of wildlife. One wildlife field was enrolled in the Conservation Reserve Program in 2005 and mowed in alternating thirds every year and the other 3 were burned in 2007 and scheduled to be burned approximately every 3 years; however, they were not burned during either year of this study. The native warm-season grass fields and 3 of the wildlife fields were chosen because they were enrolled in the Cooperative Upland Restoration and Enhancement program by the North Carolina Wildlife Resources Commission and planted between 2002 and 2008; hence, native warm-season grass and wildlife fields varied from 1 year to 8 years since planting. The cool-season grass fields were planted between 1999 and 2007; hence, cool-season grass fields varied from 2 years to 11 years since planting. Although the fields within each of the field types varied in age and plant composition, the fields represented a cross-section of habitat characteristics present in each field type and, therefore represent the range of habitat conditions available to small mammals in forage production systems in this region.

METHODS

Vegetation Sampling

We used vegetation sampling to quantify structure and composition across the entire field, which included the area sampled for small mammals. We sampled vegetation during July and August 2010. We did not sample vegetation in 2009 because of resource limitations, but believe the data for 2010 were similarly representative of vegetation conditions in 2009. All cool-season grass and native warm-season grass fields were hayed after seedheads were produced. We were unable to record exact haying dates because management occurred without notice when weather and the schedule of the farmer permitted. Therefore, vegetation sampling sometimes occurred after a recent haying event in both cool-season grass and native warm-season grass fields, but more commonly in cool-season grass fields because they are typically hayed earlier than

Table 1. Mean and standard error (SE) for profile board vegetation cover estimates (i.e., 1 = 0–25%, 2 = 26–50%, 3 = 51–75%, 4 = 76–100%) in 25-centimeter increments and index of cover in native warm-season grass (NWSG), non-native cool-season grass (CSG), and wildlife fields. Means in the same row followed by the same letter were not statistically different according to an analysis of variance ($P \geq 0.050$). Vegetation data were collected in July–August 2010 (Iredell and Davie counties, NC, USA).

	Treatment					
	NWSG		CSG		Wildlife	
Variable	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Profile board						
25 cm	4.00^{A}	0.00	3.50^{B}	0.10	4.00^{A}	0.00
50 cm	3.94^{A}	0.06	1.00^{B}	0.00	4.00^{A}	0.00
75 cm	3.71^{B}	0.11	1.00^{C}	0.00	3.98^{A}	0.02
100 cm	2.54^{B}	0.33	1.00^{C}	0.00	3.56^{A}	0.16
125 cm	1.58^{B}	0.24	1.00^{C}	0.00	2.85^{A}	0.27
150 cm	1.04^{B}	0.03	1.00^{B}	0.00	2.02^{A}	0.33
175 cm	1.00^{B}	0.00	1.00^{B}	0.00	1.33^{A}	0.14
200 cm	1.00	0.00	1.00	0.00	1.08	0.06
Index of cover						
Native grass	102.87^{A}	9.94	0.00^{B}	0.00	103.45^{A}	15.13
Non-native grass	5.28^{B}	3.54	79.33^{A}	7.39	2.80^{B}	1.68
Forbs	16.95^{B}	10.64	9.98B	6.25	42.55^{A}	10.93
Woody	2.17	2.00	0.00	0.00	0.43	0.43
Bare ground	16.72^{A}	7.14	7.07^{A}	3.26	0.00^{B}	0.00
Leaf litter–thatch	1.30^{B}	0.94	68.67^{A}	7.10	84.13^{A}	8.65

native warm-season grass fields. We measured vegetation structure and composition along 3 30-meter transects in each of the 12 fields in which small mammals were trapped in 2010. Each field was divided into 3 equal-area units, and a single transect was randomly positioned in each unit. If a transect extended outside the field, we discarded it and generated a new transect position. We used a vegetation profile board (2.0 m tall × 30.5 cm wide with alternating colors every 25 cm along the length of the board) to measure visual obstruction from 2 positions (i.e., 0-meter and 15-meter mark) at each transect (Nudds 1977). An observer remained at each position while the board was placed 15 m away in each cardinal direction. The observer estimated and recorded the percentage (i.e., 1 = 0–25%, 2 = 26–50%, 3 = 51–75%, 4 = 76–100%) of vegetation obscuring their view of the profile board for all 8 of the 25-centimeter sections. We recorded centimeters of vegetation coverage by species, bare ground, and leaf litter directly beneath the first 5 m of each transect. However, we ended up grouping plant species into 4 categories (i.e., native grass, non-native grass, forb, and woody) to simplify analyses. This approach resulted in multiple observations in a fixed distance within each transect and produced values >5 m that we treated as an index of cover (e.g., when viewed from above, a 10-centimeter section beneath the transect could be recorded as >10 cm of native warm-season grass if >1 species of this plant type occurred in this section). Density scores for each 25-centimeter section of the vegetation profile board and the index of cover by plant species, bare ground, and leaf litter were averaged for each field.

Small Mammal Trapping

We captured small mammals using 50 Sherman live traps (7.6 × 8.9 × 22.9 cm) spaced 15 m apart in a 5 × 10 rectangular grid (11,250 m^2) at each of the 14 fields sampled over 2009 and 2010. We placed the short side of the rectangular trapping grid along the edge in all fields with the longer side extending toward the field interior. If field shape did not permit this configuration, we spaced traps evenly throughout. During both 2009 and 2010, we trapped 6 of 12 fields at a time in each of 2 trapping sessions, with approximately 1 week between sessions and approximately 3 weeks before trapping the same fields a second time. All fields were trapped twice during May–July. We used a combination of peanut butter and oatmeal to bait traps for 5 consecutive nights. We set traps each afternoon and checked them before 1000 hr the following morning to limit trap mortality. We ear-tagged, weighed, and sexed all captured individuals. We identified and weighed recaptures. After processing, we released individuals as quickly as possible. We closed traps until late afternoon to avoid having animals in traps during the heat of the day. We conducted all trapping, handling, and marking of small mammals in accordance with the North Carolina State University Institutional Animal Care and Use Committee (protocol 09–071-O).

Statistical Analysis

We conducted individual analysis of variance tests for differences among field types for each of the profile board and index of cover vegetation variables (SAS Institute Inc., Cary, NC). We averaged vegetation variable data across all subsamples within a field prior to analysis. We log-transformed vegetation profile board data and we square-root-transformed percent cover data for the analysis; however, we report all means for vegetation variables in their original form. We considered statistical significance at $P < 0.050$.

We used a hierarchical spatial capture–recapture model (Royle and Young 2008) to formally account for the problem—common to many capture–recapture experiments—that the area to which abundance estimates apply is unknown and to adjust for detectability. We used the approach of Royle and Converse (2014) to account for replicated capture–recapture

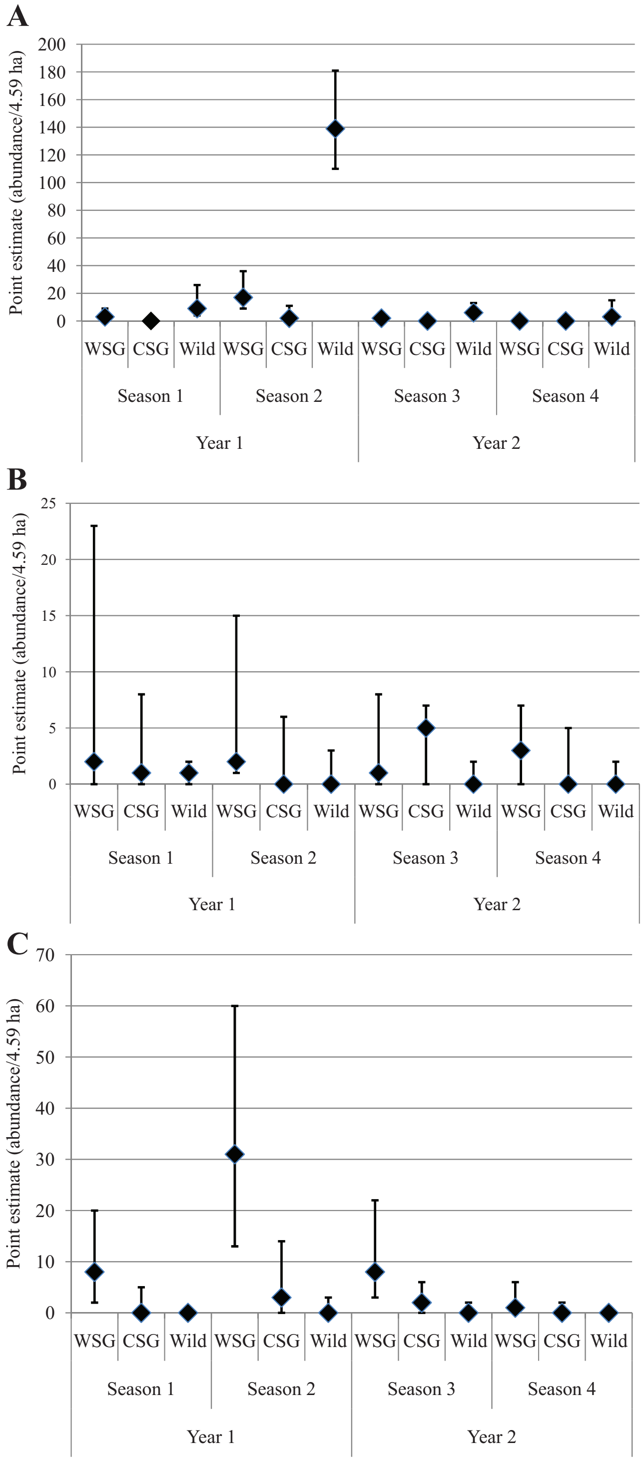

Figure 1. Point estimates (mode of Markov chain Monte Carlo chains) of abundance in the area of augmented state space (i.e., 4.59 ha) and 95% credible intervals for cotton rat (*Sigmodon hispidus;* A), white-footed mouse (*Peromyscus leucopus;* B), and house mouse (*Mus musculus;* C) in native warm-season grass (WSG), non-native cool-season grass (CSG), and wildlife fields (Wild) based on 2 trapping periods (i.e., seasons 1–4) in Iredell and Davie counties, North Carolina, USA, 2009 and 2010.

experiments, in which the purpose is to model variability in abundance over space and/or time (see also Converse and Royle 2012). Our abundance model included fixed effects of trapping period (i.e., season-year) and field type. Detection was modeled as a function of distance between the trap and an individual's latent activity center. The implementation of the hierarchical spatial capture–recapture model requires specification of a region around each trapping grid which defines where individual activity centers may be located (the "state-space"). This region is specified such that all animals with a non-zero probability of capture on the grid should have home range centroids in the state-space. We used a 4-trap buffer around our 5 × 10 grid, with 15-meter spacing between traps, resulting in a state space of 4.59 ha. We fit the model via Markov chain Monte Carlo methods in JAGS (Plummer 2009) using the R2Jags library in the R programming environment (R Development Core Team 2012) using standard vague priors for parameters. We assessed convergence based on $\hat{R} < 1.050$ as recommended by Gelman et al. (2004).

RESULTS

Vegetation

In 2010, visual obstruction was generally greater in native warm-season grass and wildlife fields than in cool-season grass fields (Table 1). Native warm-season grass and wildlife fields had less visibility from 25 cm to 125 cm than did cool-season grass fields, and wildlife fields had less visibility from 75 cm to 175 cm than did all other fields. Vegetation at 150 cm and 175 cm was not different in native warm-season grass and cool-season grass fields, and there was no difference in vegetation among field types above 175 cm.

Coverage of native grass was greater in native warm-season grass and wildlife fields than in cool-season grass fields, and coverage of non-native grass was greater in cool-season grass fields than in native warm-season grass and wildlife fields (Table 1). Coverage of forbs was 2.5 times greater in wildlife fields than in native warm-season grass and 4 times greater than in cool-season grass fields. Amount of bare ground was greater in warm-season grass and cool-season grass fields than in wildlife fields. Coverage of leaf litter and thatch was greater in cool-season grass and wildlife fields than in native warm-season grass fields. Very little woody vegetation was present and coverage did not differ among field types.

Variation in Abundance

A total of 6,000 trap-nights of sampling during 2009–2010 yielded 379 individual captures representing 3 small mammal species, which were used to produce individual estimates of abundance by field type and year (Fig. 1). More individuals were captured in 2009 than in 2010: 307 and 72, respectively. We captured 202 hispid cotton rats, 59 white-footed mice, and 46 house mice during 2009. We captured 23 cotton rats, 35 white-footed mice, and 14 house mice during 2010.

Cotton rat abundance was greater in wildlife fields than in native warm-season grass (effect = −1.79; 95% CI = −2.16 to −1.44) and cool-season grass (effect = −3.48; 95% CI = −4.38 to −2.83) fields (Table 2); also, effect estimates for native warm-season grass and cool-season grass did not overlap, indicating that abundance was clearly greater in

Table 2. Hierarchical spatial capture–recapture model results for examining the effect of field type on density of cotton rats (*Sigmodon hispidus*) where D = mean density of individuals/ha across all fields, N = total abundance estimate of individuals across all fields, α_d = the distance effect from the spatial observation model, $\beta_{s[1-3]}$ = season-within-year temporal effects from the abundance process model, β_{WSG} = warm-season grass field type effect from the abundance process model, and β_{CSG} = cool-season grass field type effect from the abundance process model (Iredell and Davie counties, NC, USA, 2009–2010).

	Model results			
Model effects	**Mode**	**Mean**	**Lower CI**	**Upper CI**
D	4.17	4.22	3.43	5.15
N	646.85	654.68	533.00	800.00
α_d	–1.32	–1.32	–1.56	–1.08
$\beta_{s[1]}$[a]	–0.17	–0.18	–0.59	0.21
$\beta_{s[2]}$[a]	2.04	2.07	1.82	2.34
$\beta_{s[3]}$[a]	–0.79	–0.81	–1.29	–0.36
β_{WSG}[b]	–1.79	–1.79	–2.16	–1.44
β_{CSG}[b]	–3.48	–3.54	–4.38	–2.83

[a] The 3 seasonal effects represent the divergence of these seasons from the mean. Although there were 4 seasons (i.e., 2 trapping periods in each year), our model has an intercept and only the first 3 seasonal effects are estimable.

[b] The field type effects represent differences between the native warm-season and non-native cool-season grass fields and the reference, which were wildlife fields (composed primarily of native grasses and forbs managed for wildlife).

native warm-season grass than in cool-season grass. Cotton rat abundance was markedly greater during trapping period 2 in 2009 (effect = 2.04; 95% CI = 1.82–2.34; Table 2; Fig. 1) than in other trapping periods. Overall density of cotton rats was approximately 4.2 individuals/ha.

White-footed mouse abundance was greater in both native warm-season grass (effect = 2.05; 95% CI = 1.34–3.13) and cool-season grass (1.42; 95% CI = 0.66–2.50) fields when compared with wildlife fields (Table 3), whereas abundance estimates in native warm-season grass and cool-season grass fields were not statistically different from each other. Overall density of white-footed mice was 1.2 individuals/ha.

House mouse abundance estimates were lower in wildlife fields than in native warm-season grass (effect = 3.84; 95% CI = 2.31–7.21) and cool-season grass (effect = 2.26; 95% CI = 0.42–5.51) fields, but abundance estimates in native warm-season grass and cool-season grass fields were not statistically different (Table 4). Only one house mouse ever was captured in a wildlife field. Overall density of house mice was 1.23 individuals/ha.

DISCUSSION

In support of our initial hypothesis, cotton rat abundance estimates were greatest in wildlife fields, which we suggest was because these fields provided consistent sources of cover and food, especially later in the spring when perennial vegetation had matured, whereas vegetation structure was reduced greatly in native warm-season grass and cool-season grass forage fields following haying. Additionally, wildlife fields likely served as refugia for individuals dispersing following haying of nearby forage fields or harvesting of other agricultural crops, although we did not capture any individuals in multiple study fields (Klimstra 2013). Movements by individuals out of the extensive landscape of hayed cool-season grass forage fields, not included in this study, and into wildlife fields could explain the large increase in cotton rats captured in wildlife fields late in the 2009 field season. Similar to wildlife fields, native warm-season grasses in forage fields provided tall, dense vegetation cover, and a food source commonly selected by cotton rats; however, vegeta-

Table 3. Hierarchical spatial capture–recapture model results for examining the effect of field type on density of white-footed mice (*Peromyscus leucopus*) where D = mean density of individuals/ha across all fields, N = total abundance estimate of individuals across all fields, α_d = the distance effect from the spatial observation model, $\beta_{s[1-3]}$ = season-within-year temporal effects from the abundance process model, β_{WSG} = warm-season grass field type effect from the abundance process model, and β_{CSG} = cool-season grass field type effect from the abundance process model (Iredell and Davie counties, NC, USA, 2009–2010).

	Model results			
Model effects	**Mode**	**Mean**	**Lower CI**	**Upper CI**
D	1.19	1.20	1.04	1.39
N	128.03	128.92	112.00	150.00
α_d	–1.76	–1.79	–2.10	–1.51
$\beta_{s[1]}$[a]	0.35	0.34	0.01	0.67
$\beta_{s[2]}$[a]	0.21	0.20	–0.15	0.54
$\beta_{s[3]}$[a]	–0.09	–0.12	–0.51	0.24
β_{WSG}[b]	2.05	2.17	1.34	3.13
β_{CSG}[b]	1.42	1.51	0.66	2.50

[a] The 3 seasonal effects represent the divergence of these seasons from the mean. Although there were 4 seasons (i.e., 2 trapping periods in each year), our model has an intercept and only the first 3 seasonal effects are estimable.

[b] The field type effects represent differences between the native warm-season and non-native cool-season grass fields and the reference, which were wildlife fields (composed primarily of native grasses and forbs managed for wildlife).

Table 4. Hierarchical spatial capture–recapture model results for examining the effect of field type on density of house mice (*Mus musculus*) where $D =$ mean density of individuals/ha across all fields, $N =$ total abundance estimate of individuals across all fields, $\alpha_d =$ the distance effect from the spatial observation model, $\beta_{s[1\text{–}3]} =$ season-within-year temporal effects from the abundance process model, $\beta_{WSG} =$ warm-season grass field type effect from the abundance process model, and $\beta_{CSG} =$ cool-season grass field type effect from the abundance process model (Iredell and Davie counties, NC, USA, 2009–2010).

	Model results			
Model effects	**Mode**	**Mean**	**Lower CI**	**Upper CI**
D	0.00	1.23	–0.73	2.02
N	235.24	259.12	153.00	427.00
α_d	–1.05	–1.03	–1.52	–0.57
$\beta_{s[1]}{}^{a}$	–0.08	–0.09	–0.55	0.73
$\beta_{s[2]}{}^{a}$	1.36	1.40	0.92	1.96
$\beta_{s[3]}{}^{a}$	0.22	0.27	–0.32	0.88
$\beta_{WSG}{}^{b}$	3.84	4.32	2.31	7.21
$\beta_{CSG}{}^{b}$	2.26	2.56	0.42	5.51

[a] The 3 seasonal effects represent the divergence of these seasons from the mean. Although there were 4 seasons (i.e., 2 trapping periods in each year), our model has an intercept and only the first 3 seasonal effects are estimable.

[b] The field type effects represent differences between the native warm-season and non-native cool-season grass fields and the reference, which were wildlife fields (composed primarily of native grasses and forbs managed for wildlife).

tion was never hayed in wildlife fields, so food and cover remained continuously available. Similarly, Moorman et al. (2013) reported large numbers of cotton rat captures in field borders planted with native warm-season grasses and wildflowers that retained food and cover throughout the growing season, and they reported no captures in mowed borders where resources were removed.

House mice and white-footed mice are omnivorous habitat generalists; therefore, plant community composition likely is of less importance to these species than it is to herbivorous cotton rats (Whitaker 1966, Randolph et al. 1991). After vegetation was hayed and little overhead cover remained in cool-season grass and native warm-season grass fields, house and white-footed mice continued to be captured along woody field edges where they likely fed on insects and various seed-bearing plants and used the adjacent shrubs and trees for cover and travel corridors (Whitaker 1966, Baker 1968, Wegner and Merriam 1979). Moreover, nearby anthropogenic features (e.g., row crops, barns, or houses) likely supplemented both species' diet and cover requirements and may help explain a lack of difference in abundance estimates between forage field types. Unlike cotton rats, mice were not directly dependent on the species of grasses or forbs present in forage fields and were able to use other food and cover resources before and after fields were hayed (Whitaker 1966, Wegner and Merriam 1979, Kaufman and Kaufman 2008).

We speculate that haying during our study reduced overhead protection from avian predators, displaced individuals, and resulted in direct mortality (Kaufman and Kaufman 2008, Klimstra 2013). Kaufman and Kaufman (2008) reported that several grassland small mammal species avoided hayed fields, which is consistent with our lack of captures of other grassland-associated small mammals that we expected to be present (e.g., meadow jumping mouse [*Zapus hudsonius*] and meadow vole [*Microtus pennsylvanicus*]). Kaufman and Kaufman (2008) reported low or no cotton rat captures in native warm-season grass (e.g., big bluestem, indiangrass, and little bluestem) fields before and after haying. Similarly, we estimated low cotton rat abundance in native warm-season grass and cool-season grass hayed fields compared with wildlife fields that never were hayed. Moreover, we located the shredded remains (i.e., by mechanical means) of one cotton rat that we had radiocollared in a recently hayed native warm-season grass field, which suggests direct mortality from forage harvest (Klimstra 2013). Additionally, 2 predation events on cotton rats were observed after forage harvest in native warm-season grass fields, indicating an increased mortality risk for individual small mammals that disperse from hayed fields (Klimstra 2013). We did not address haying effects directly because we were unable to track producer schedules in a manner that would allow us to sample before and after haying occurred.

Although haying removed food and cover from all forage fields (Kincaid and Cameron 1982, Kaufman and Kaufman 2008), there was a slightly greater abundance of cotton rats in native warm-season grass fields than in cool-season grass fields, as we hypothesized before the study. Similarly, greater point estimates for white-footed mice and house mice in native warm-season grass fields suggest cool-season grass fields in this study may have been less beneficial for both species. Greater edge-to-area ratios in typically smaller native warm-season grass fields allowed greater access to adjacent cover following haying and likely contributed to greater point estimates for all small mammal species in that field type. Additionally, open ground structure in native warm-season grass fields allowed easier small mammal movement than did the dense thatch layers formed in cool-season grass fields.

One important caveat to our results is that low initial capture and recapture rates made it impossible for us to model variation in detection probability across fields. In particular, our models do not account for the possibility that field type may affect the detectability of animals, rather than, or in addition to, their abundance. Future research in these systems should focus on extending trap density and/or trapping period length to produce larger sample sizes of captured individuals.

Although it is impractical to expect producers to alter forage production systems to accommodate small mammals, a majority of the forage producers we worked with had an interest in wildlife, especially game animals, such as eastern cottontails and northern bobwhite. Wildlife managers working with forage producers can explain the ecological role of small mammals and encourage producers to manage fields with consideration of the small mammal community. Moderately grazing forage fields as an alternative to haying can increase forb diversity and provide structure selected by some grassland songbirds, and similarly may benefit grassland small mammals (Birckhead 2012, Klimstra 2013). Incorporating both native warm-season and cool-season forage as separate but adjacent units or fields in the same forage production system will provide a continual high-quality forage resource and provide small mammals with nearby escape cover because the 2 field types should be hayed at different times. Additionally, leaving small fields or field borders unharvested will create refugia for small mammals after cover is removed from forage fields (Moorman et al. 2013).

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