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Rangeland grasshopper numbers and species composition in Nebraska: a comparison of region and sampling location

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Abstract

Shorthorn grasshoppers (Orthoptera: Acrididae) are the most economically important pests of rangeland throughout much of North America. Their densities are estimated using a number of methods, including sweep sampling. Economic thresholds are usually set at 8 adult grasshoppers per square yard, despite differences in range conditions associated with geography and weather patterns. Several authors have concluded that grasshopper numbers are higher in ditch areas and the economic threshold in these habitats is often set substantially higher. This study compared grasshopper numbers and species composition at 120 rangeland sites across ~ 400 km of northern Nebraska in 2007 and 2010. By taking sweep net samples in the ditch, parallel with the fence inside the pasture, and approximately 30 meters into the pasture, we found the numbers and composition of grasshoppers differed significantly across this area. Mean adult grasshopper capture was highest in the ditch samples (22.4 $\pm$ 1.9 grasshoppers captured per 20 net sweeps) compared to fence (10.3 $\pm$ 1.0) and field samples (15.9 $\pm$ 1.6). Mean adult capture increased from east (4.8 $\pm$ 0.4) to west (25.5 $\pm$ 2.1). The same trends were observed when nymphal numbers were included in analysis. Based on these results, rangeland grasshopper sampling should be conducted more than 30 meters from the fenceline, and thresholds in roadside ditches should be higher than for rangeland pastures.

Key words

Acrididae, sampling, sweepnet, economic threshold

Introduction

Parker (1930) set the commonly used economic threshold (ET) for grasshoppers in rangelands at eight grasshoppers per square yard. Further work by Kemp and Dennis (1993) supported the conclusion that 9.6 grasshoppers per square meter (8 per square yard) be used as the threshold for rangeland management programs in Nebraska and elsewhere (Davis *et al.* 1992; USDA–APHIS 2006). However, ETs for field margins and roadside ditches near crop areas are normally set much higher (Hein & Campbell 2006). This is largely because rangeland grasshopper migration from field margins and roadsides can threaten production of agricultural crops (Gillespie & Kemp 1996; Olfert & Weiss 2002); however, grasshopper damage to managed ecosystems may require much higher numbers (Bastos *et al.* 2011). Although some studies have focused on the differences between grasshopper species composition in crops and rangeland, no published data were found comparing grasshopper density in roadside ditches to density in adjacent rangelands.

Effective pest management of rangeland grasshoppers requires not only accurate estimation of overall grasshopper densities, but more specific data about species composition and age distribution. For example, most rangeland grasshopper species are not actually range destructive (Vermeire *et al.* 2004). Other grasshopper species traditionally considered pests have been shown to increase plant production under the right circumstances (Belovsky & Slade 2002). Availability of diverse vegetation in disturbed areas adjacent to rangelands can result in increased density of grasshopper species typically viewed as pests (Kaplan 2001). In addition, roadside ditches provide favorable conditions for grasshopper feeding, oviposition, and development (Parker 1937; Uvarov 1956; Pickford 1963; Edwards 1964; Gillespie & Kemp 1995). This led Johnson and Henry (1987) to suggest that control of grasshoppers should be aimed at roadsides to reduce threats to crops. Support for this conclusion has been found for the grasshopper species *Melanoplus sanguinipes* (Fabricius), *Melanoplus bivittatus* (Say), and *Melanoplus packardii* (Scudder), which can move from rangeland to fields of winter wheat (Gillispie & Kemp 1996).

Roadside counts are occasionally used to quantify the potential extent of grasshopper migration from field edges into adjacent crops (Gillespie & Kemp 1996; Olfert & Weiss 2002). Although not typically applied to agroecosystems, this technique was supported by Johnson (1989a) who showed that roadside counts followed by spatial analysis could be used to generate accurate grasshopper density maps. Sweep sampling is still considered the best way to estimate both grasshopper density and species diversity (Mulkern *et al.* 1978; Evans *et al.* 1983; Larson *et al.* 1999), and is the most common method used (Larson *et al.* 1999; Gardiner *et al.* 2005). However, sweep sampling has been shown to have variation in capture depending upon many factors, most notably vegetation height, plant structure, and variation among samplers (O'Neill *et al.* 2002; Gardiner *et al.* 2005).

Previous studies have examined grasshopper species composition and density by ecoregion (Skinner *et al.* 2000), geography (Fielding & Brusven 1995; Schell & Lockwood 1997, Craig *et al.* 1999), and geographic features (Johnson 1989a, 1989b; Cigliano *et al.* 1995). Differences in assemblages have been shown to be mostly a result of weather patterns, varying plant diversity, and soil characteristics (Isley 1937, 1938; Capinera & Sechrist 1982; Kemp *et al.* 1990).

In this study, we compare grasshopper density and species composition among roadside ditches, fencelines, and pastures in rangelands in three regions of northern Nebraska (east, central, west) that differ in average rainfall patterns.

Materials and methods

Study sites.—Nebraska is largely a prairie state, with the western two-thirds remaining predominantly rangeland as a result of low annual precipitation (Veneman *et al.* 2004). This study took place in northern Nebraska along a 400-km stretch of U.S. Highway 20

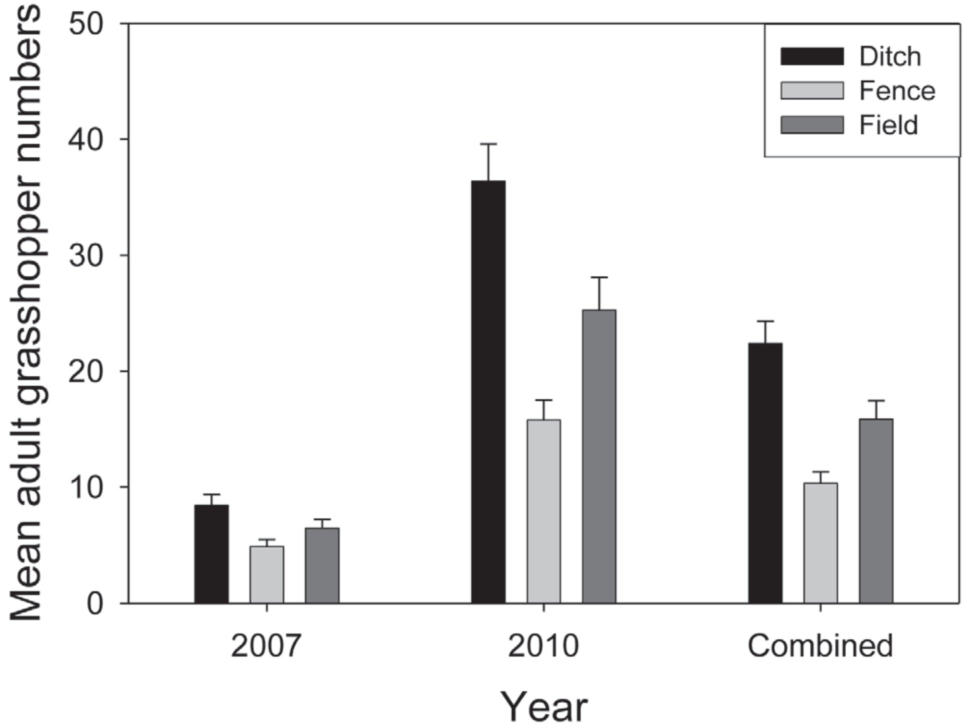

Fig. 1. Mean adult grasshopper numbers per sample in the ditch, fence and field locations by year. Each sample represents the total number of individual adult grasshoppers captured during 20 sweeps by a 15-in insect net.

which runs east to west. Much of the study took place in the Sandhills ecoregion that is primarily treeless grass-covered sand dunes, with associated wet meadows in low-lying areas (Ratcliffe & Paulsen 2008). From east to west, Nebraska is approximately 688 km and rises at a rate of approximately 2.2 m per kilometer. Northeastern Nebraska receives the highest rainfall (58 cm annually) and was historically a tallgrass prairie. In the northcentral region of Nebraska, vegetation transitions to mixed-grass prairie with declining precipitation (38 cm annually) and increasing elevation (Ratcliffe & Paulsen 2008). Dominant native grasses of the Sandhills region include big and little bluestem (*Andropogon* spp.), needle-and-thread grass (*Stipa comata* Trin.), and prairie sandreed [*Calamovilfa longifolia* (Hooker)] (Weaver 1965). A number of exotic grasses including brome and cheat grasses (*Bromus* spp.) and fescues (*Festuca* spp.) have been introduced in the rangeland and as roadside plantings. The topography and sandy soils prevent traditional rowcrop agriculture and the Sandhills region is primarily used for cattle grazing and hay production.

Sampling.—We sampled 120 rangeland sites between Plainview, Nebraska and Chadron, Nebraska along a 400-km portion of U.S. Highway 20 in August of 2007, and again in August of 2010. Each year, all sampling was conducted within a five-day period to limit the temporal effects on grasshopper populations as much as possible. Sampling sites were approximately 3.2 kilometers apart. To reflect differences in rainfall patterns and topography, the sampling

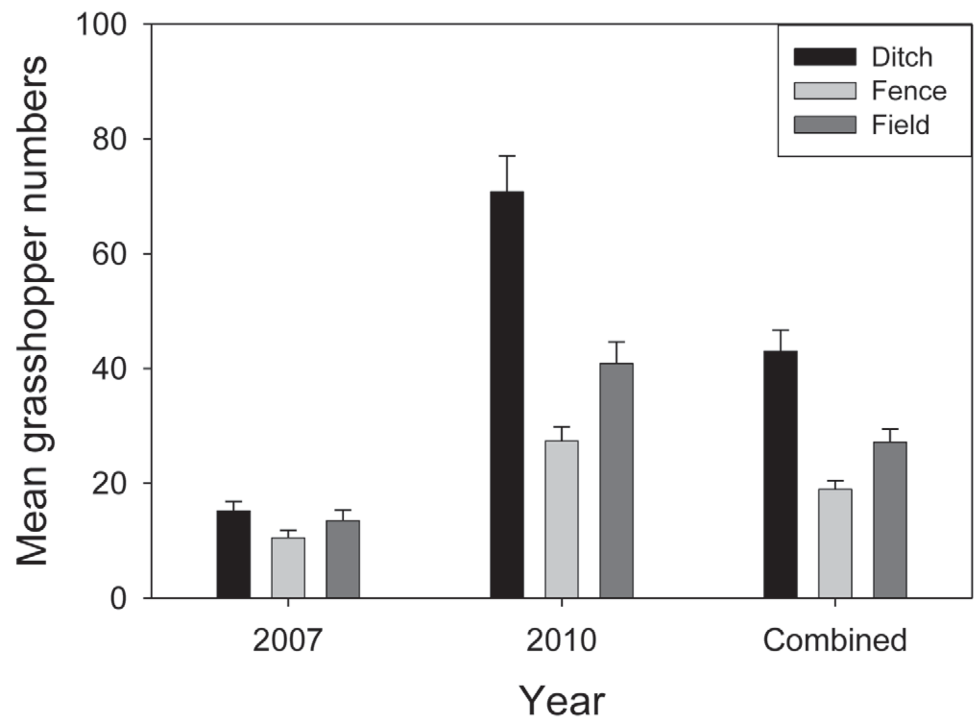

Fig. 2. Mean combined adult and nymphal grasshopper numbers per sample in the ditch, fence and field locations by year. Each sample represents the total number of individual grasshoppers captured during 20 sweeps by a 15-in insect net.

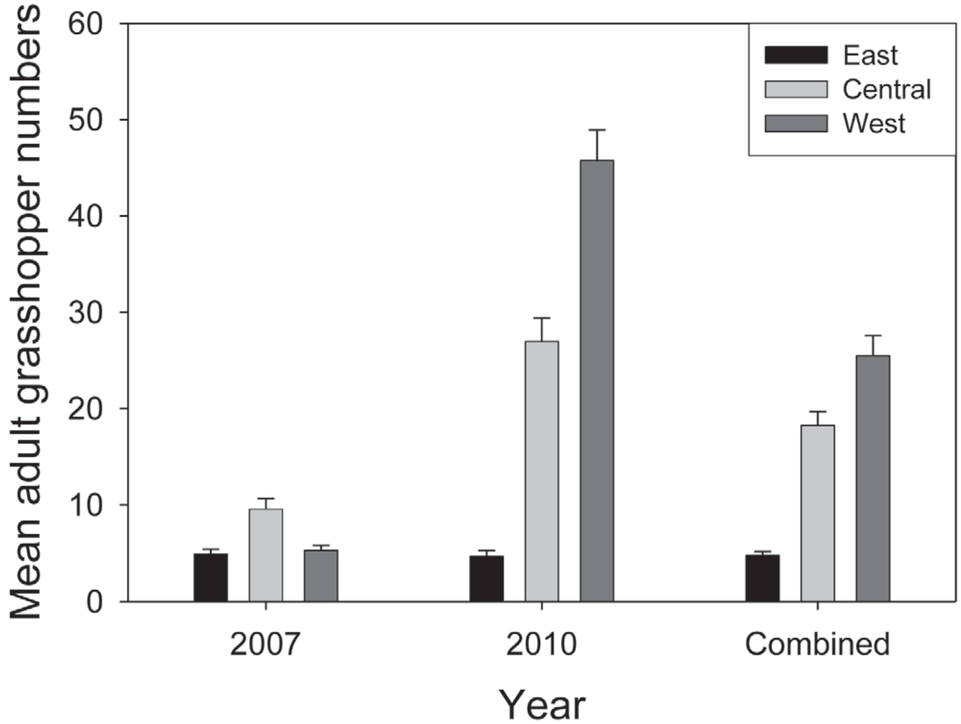

Fig. 3. Mean adult grasshopper numbers per sample in the east, central and west sampling regions by year. Each sample represents the total number of individual adult grasshoppers captured during 20 sweeps by a 15-in insect net.

area was subdivided into three regions with a total of 40 sites in eastern Nebraska (east), 40 sites in central Nebraska (central), and 40 sites in western Nebraska (west).

At each of our 120 sites, we collected 3 samples: 1) in the ditch parallel to the road (ditch), 2) in the pasture parallel and within 3 meters of the fenceline (fence), and 3) ~ 30 m from the fenceline further into the rangeland (field)—using USDA-APHIS-PPQ protocols. Each sample consisted of 20 low and fast sweeps with a 38-cm diameter heavy muslin net. Each sweep consisted of moving the net through a 180° arc, with the top of the net at the top of the vegetation (Brust *et al.* 2009). Because ditch vegetation was taller than fence and range vegetation, sweeps were highest in the ditch and higher in the range than along fences. All sampling was conducted between 10:00 and 16:00 hours as recommended by Whipple *et al.* (2010). Collected grasshoppers were placed in freezer bags and stored in a portable refrigerator until subsequent laboratory identification. In this paper, we report the number of grasshoppers collected per sample (= per 20 net-sweeps).

All grasshoppers in this study were collected only by the senior author who was trained as a grasshopper surveyor by USDA-APHIS-PPQ in Nebraska. Adult grasshoppers were counted and identified to species. Nymphs were counted, but not identified. After checking for normality, data were log (base 10) transformed and rechecked. The number of grasshoppers captured in each location (ditch, fence

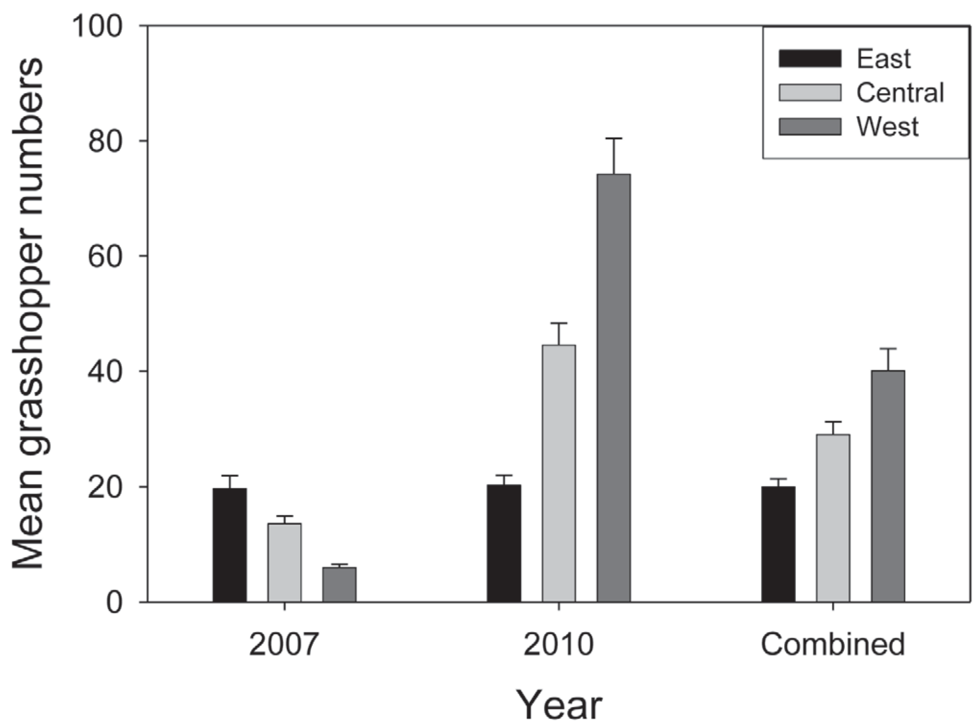

Fig. 4. Mean combined adult and nymphal grasshopper numbers per sample in the east, central and west sampling regions by year. Each sample represents the total number of individual adult grasshoppers captured during 20 sweeps by a 15-in insect net.

Table 1. Summary of Three-Way Analysis of Variance for adult and combined adult and nymphal grasshopper numbers across locations (ditch, fence, field), regions (east, central, west) and years (2007, 2010).

	Adults					Adults and Nymphs				
Source of Variation	DF	SS	MS	F	P	DF	SS	MS	F	P
year	1	39.37	39.37	226.84	<0.001	1	62.95	62.95	365.30	<0.001
region	2	43.17	21.58	124.35	<0.001	2	2.02	1.01	5.86	0.003
location	2	14.06	7.03	40.5	<0.001	2	12.12	6.06	35.17	<0.001
year × region	2	32.23	16.12	92.85	<0.001	2	31.36	15.68	90.97	<0.001
year × location	2	0.7	0.35	2.03	0.13	2	1.45	0.72	4.20	0.02
region × location	4	0.88	0.22	1.27	0.28	4	0.83	0.21	1.21	0.31
year × region × location	4	0.47	0.12	0.68	0.61	4	0.56	0.14	0.81	0.52
residual	702	121.85	0.17			702	120.98	0.17		
Total	719	252.73	0.35			719	232.27	0.32		

and field), across regions (east, central, west) and between years were compared using a Three-Way Analysis of Variance (SigmaPlot 3.1, Jandel Scientific, Corte Madera, CA). The Holm-Sidak method of multiple comparison was used to isolate treatments that differed from one another.

To compare numbers of individual grasshopper species, a Kruskal-Wallis One-Way Analysis of Variance was used in cases where > 100 individuals of a given species were captured. If differences among conditions were observed, a Tukey test was used as a *post hoc* test. Numbers in the east, central, and west regions, as well as numbers collected in the ditch, fence and field samples were analyzed by year.

Results

A total of 21,378 grasshoppers belonging to 50 species were collected across years, of which 11,657 were adults and 9,721 were nymphs. When numbers were combined across years, the mean number (± 1 SE) of adult grasshoppers captured per sample (each sample = 20 net sweeps) was 22.4 ± 1.9 in ditches, 10.3 ± 1.0 at the fences and 15.9 ± 1.6 in fields (Fig. 1). When nymphs were included, mean capture by site increased to 43.0 ± 3.7 in the ditch samples, 19.0 ± 1.5 at the fence, and 27.2 ± 2.3 in the field (Fig. 2). By region, mean adult capture was 4.8 ± 0.4 in eastern Nebraska, 18.3 ± 1.4 in the central region, 25.5 ± 2.1 in western Nebraska (Fig. 3). When adult and nymphal numbers were combined, mean capture was 19.9 ± 1.4 in the east, 29.1 ± 2.2 in the central and 40.1 ± 3.8 in the west, respectively (Fig. 4).

Analyses of mean adult grasshopper numbers, as well as combined adult and nymphal capture, revealed differences between years among east, central and west regions and among ditch, fence and field sites (Table 1). For adults, significant differences (P<0.05) were observed among all treatments (year, region, and location) with the exceptions of mean adult capture in 2007 *vs* 2010 within the eastern region (P=0.24), field *vs* fence in 2007 (P=0.09), field *vs* fence in the eastern region (P=0.07), field *vs* fence in the western region (P=0.42), west *vs* central in the ditch (P=0.44), and west *vs* central in the field (P=0.30) (Figs 1, 3).

When nymphs were included in analysis, all regions (east, central, west) had significantly different mean grasshopper numbers in the ditch and fence areas (P<0.05) (Figs 2, 4). Additionally, all regions (east, central, west) and sampling locations (ditch, fence, field) were significantly different in 2010 (P<0.05). No differences in total grasshopper numbers were found between mean numbers in the east *vs* central region in 2007 (P=0.86), 2007 *vs* 2010 within the eastern region (P=0.52), field *vs* fence in 2007 (P=0.09), field *vs* fence in the east (P=0.20), ditch *vs* field in the central (P=0.07), field *vs* fence in the west (P=0.49), or west *vs* east in the field samples (P=0.930).

Total capture of adult grasshoppers was higher in the western region than in the east (P<0.05), but not the central region (Table 2). The numbers of individuals of most species differed between years and across regions of the state. The grasshopper species with the highest numbers in the western region of Nebraska (P<0.05, Kruskal-Wallis ANOVA) were *Ageneotettix deorum* (Scudder), *Melanoplus bivittatus* (Say), *Melanoplus femurrubrum* (DeGeer), *Melanoplus sanguinipes* (Fabricius), *Paropomala wyomingensis* (Thomas), *Phoetaliotes nebrascensis* (Thomas), *Pseudopomala brachyptera* (Scudder) and *Spharageman collare* (Scudder) (Table 2). The species *Hypochlora alba* (Dodge), *Melanoplus angustipennis* (Dodge), *Melanoplus flavidus* (Scudder), and *Mermiria bivittata* (Serville) had the highest numbers (P<0.05) in the central region. No species was captured in the highest numbers in the eastern region of Nebraska, although nymphal capture was higher in the east than both the central and western region (P<0.05). No differences in capture among regions were observed for *Amphitornus coloradus* (Thomas), *Melanoplus differentialis* (Thomas), *Opeia obscura* (Thomas), or *Orphulella speciosa* (Scudder).

Species composition also differed (P<0.05) depending upon sampling location (ditch, fence, or field) (Table 3). Compared to fence and field locations, highest numbers were observed in the ditch for *M. angustipennis*, *M. bivittatus*, *M. differentialis*, *M. femurrubrum*, *M. bivittata*, *P. nebrascensis*, and *P. brachyptera* (P<0.05). Numbers in the field were greatest for *A. deorum*, *O. obscura*, and *O. speciosa* (P<0.05). No differences in numbers among the ditch, fence, and field areas were found for *A. coloradus*, *H. alba*, *M. flavidus*, *M. sanguinipes*, *P. wyomingensis* or *S. collare*. Overall adult capture differed among the ditch, fence and field areas (P<0.05), with the ditch samples containing the highest numbers (Table 3). Nymphal capture was also significantly higher in the ditch samples (P<0.05).

Discussion

In this study, we identify differences in rangeland grasshopper density and species composition in three regions of northern Nebraska (east, central, west) as well as among roadside ditches, fencelines and pastures (field) across two years of sampling. Currently, most Western states use the same economic thresholds (ETs) for rangeland grasshoppers, although ETs are often set at different levels between roadside ditches and pastures (Hantsbarger 1979; Skelly *et al.* 2002). For effective grasshopper pest management, it is essential to identify whether there is a correlation between roadside counts and grasshopper density and to establish where grasshopper numbers are most representative of populations in the rangeland.

Our study shows that across a 400-km transect in northern Nebraska, significantly more grasshoppers inhabit ditches than either fencelines or field areas (Fig. 2). This holds true whether only adults or both adults and nymphs are considered (Fig. 1). When both years of sampling are considered, grasshopper density declined from west to east in Nebraska (Figs 3, 4). These regions differ in geography, temperature, rainfall, plant species composition and variation in capture was observed depending upon year, region, and site. Grasshoppers may move to ditches, especially late in the season, when ditches retain moisture and tall grasses compared to grazed fields. This result further suggests that thresholds set based on grasshoppers in ditches should also be adjusted to reflect local conditions.

The accepted economic thresholds for rangeland grasshoppers (USDA-APHIS 2006) are 15 nymphs per square yard (17.9 per m^2) or 8 adult grasshoppers per square yard (9.6 per m^2). Differences in adult and nymphal thresholds reflect the observation that only ~ 50% of all early instar nymphs will survive to adulthood (Skelly *et al.* 2002). Sweep samples of grasshoppers can be converted to the number per m2 by dividing the number obtained in 40 sweeps by 10 (USDA-APHIS 2008). In this study, we present data as a mean number of grasshoppers obtained in 20 sweeps and thus, estimates of the number of grasshoppers per m^2 can be calculated by dividing by 5. When this conversion is applied, adult grasshopper numbers exceeded economic thresholds in western Nebraska during 2010 (Fig. 3). The calculated mean grasshopper number per m^2 also approached economic thresholds for western Nebraska in 2010 when nymphs were included (Fig. 4). Because data in this study were collected in early August, USDA-APHIS would only be concerned with adult density when considering management actions and predicting grasshopper numbers for the next season (USDA-APHIS 2008). Converting to the mean number of grasshoppers per m^2, no location reached the economic threshold for adults (Fig. 1) or combined adults and nymphs (Fig. 2), although ditch samples approached economic thresholds in 2010. Differences in grasshopper numbers across locations could be minimized if samples were collected away from ditches and fences.

Differences in grasshopper species composition should also be factored into treatment decisions for management of rangeland grasshoppers. In our study, composition varied significantly from east to west, despite all sites being fenced land used for grazing located along Highway 20 (Table 2). Although there are over 400 species of short-horned grasshoppers in the United States (Lockwood 2001), only 14 are considered serious pests of rangeland (Pfadt 2002). Species with the highest capture in this study were *A. deorum*, *M. angustipennis*, *M. femurrubrum* and *P. nebrascensis*, which together accounted for over 61% of total capture. In Nebraska, only *A. deorum*, *M. angustipennis*, and *P. nebrascensis* are considered serious potential pests of rangeland (Campbell *et al.* 2001). During grasshopper outbreaks, numerous species are usually present; however, one species typically accounts for over 50% of the total number of individuals (Pfadt 2002). In the mixed-grass prairie of northern Nebraska, *A. deorum* often comprises over half of all grasshoppers present and is one of the more economically important species (Pfadt 1984, 2002).

Grasshopper nymphs occurred in significantly higher numbers in the east than the central and western regions (Table 2) with 3,637 nymphs caught in the east compared to 2,588 in the central and 3,496 in the western part of the state. This is likely a result of hatching and time of development for late-emerging species such as *M. femurrubrum* and *P. nebrascensis* (Pfadt 2002), which are both prevalent in the eastern region of Nebraska. In contrast, adult numbers were significantly higher in the western part of the state, mainly as a result of higher abundance of *M. angustipennis*, *M. sanguinipes*, *P. wyomingensis* and *P. nebrascensis* in the west (Table 2, Fig. 3).

Numerous factors influence grasshopper abundance and distribution, including soil characteristics, plant diversity, vegetation structure, microclimate and oviposition preference (Caplan 1966; Uvarov 1977; Heidorn & Joern 1987; Joern & Gaines 1990; Fielding & Brusven 1992; Craig *et al.* 1999; Beckerman 2000; Skinner & Child 2000; Skinner *et al.* 2000; Whipple *et al.* 2009; Whipple *et al.* 2010). Plant diversity and feeding preference also correlate with grasshopper density and habitat preference (Fielding & Brusven 1992). The differences observed in the numbers of each species found in the ditch, fence and field may be a result of feeding preferences and a higher proportion of forbs in ditch areas. However, because no data were gathered for plant communities, this cannot be tested.

As discussed above, the regions of Nebraska are divided by geology, soil type, vegetation communities, hydrology, and climate (Omernik 1987, 1995). Eastern, central, and western Nebraska have different native vegetation communities, largely as a result of differences in rainfall (Johnsguard 2001). Eastern Nebraska receives the highest rainfall and is mainly tallgrass prairie, while the mixed-grass prairie of central Nebraska and short-grass prairie of western Nebraska receive considerably less precipitation (Johnsguard 2001). Numerous studies have focused on precipitation as it pertains to grasshopper density with mixed results. Both Fielding and Brusven (1990) and Nerney (1960, 1961) found high grasshopper numbers to result from precipitation. Other studies have found precipitation to hinder grasshopper abundance (Parker 1933; Smith 1954; Edwards 1960; Gage & Mukerji 1977; Skinner & Child 2000). Our study shows overall grasshopper numbers decreasing from west to east (Figs 3, 4), which may indicate an inverse correlation with average regional precipitation. However, we found significant differences in grasshopper abundance between years and regions (Figs 3, 4), as well as in nymphal density by region and year, which further stresses that grasshopper abundances vary over time and space (Fielding & Brusven 1990; Skinner & Child 2000). Added plant growth from precipitation and moist soils are favorable for grasshopper survival. However, cloudy days and cold rains can affect thermoregulation, predator avoidance, and pathogen prevalence (Chappell & Whitman 1990; Stauffer & Whitman 1997). Thus, timing of precipitation and sunny weather may be more important in determining grasshopper density (Chappell & Whitman 1990; Stauffer & Whitman 1997) and annual precipitation should be used with caution when predicting grasshopper density and species composition over a broad geographic scale.

Mean grasshopper numbers were lowest in the fence samples (Figs 1, 2), but suffered no reduction in number of species captured (Table 2). Fencelines were generally heavily grazed, and in many cases, bare ground was present as result of grazing and trampling. Ditches were ungrazed and had dense vegetation. Grasshoppers are known to warm themselves by basking in areas of bare soil thereby increasing metabolism and growth (Chappell & Whitman 1990; Belovsky *et al.* 2000). Bare ground is also favored for oviposition by many species (Stauffer & Whitman 1997; Belovsky *et al.* 2000). Grasshoppers are also often attracted to bare ground for courtship displays (Otte 1970). These factors may explain the high species diversity observed in fenceline areas despite less vegetation. These results also suggest that studies aimed at quantifying species assemblages could use fence areas to obtain accurate measures of diversity, while limiting the effects of vegetation height and diversity on results.

This study shows that grasshopper density and species composi-

Table 2. Total number of grasshoppers captured in the eastern, central, and western portions of Nebraska from 40 sites sampled by sweep net in 2007 and 2010. When more than 100 total individuals of a species were captured, a Kruskal-Wallis One-Way ANOVA with a Tukey post hoc test was used to test for differences in mean number of grasshopper captured by region for each year and overall. Different letters designate significant (P < 0.05) differences.

	2007			2010			Combined		
Species	East	Central	West	East	Central	West	East	Central	West
Aerolophitus hirtipes	0	2	0	0	0	0	0	2	0
Aeropedellus clavatus	0	0	2	0	8	64	0	8	66
Ageneotettix deorum	20a	153b	159b	31a	511b	1192b	51a	664b	1351b
Amphitornus coloradus	0	7	3	0a	70b	44a	0a	77a	47a
Arphia pseudonietana	0	3	1	1	10	21	1	13	22
Arphia xanthoptera	0	0	0	0	4	0	0	4	0
Brachystola magna	0	1	3	0	0	0	0	1	3
Camnula pellucida	0	0	0	0	0	37	0	0	37
Campylancantha olivacea	14	9	3	39	13	1	53	22	4
Cordillacris occipitalis	0	1	7	0	4	12	0	5	19
Chorthippus curtipennis	4	4	3	6	14	34	10	18	37
Dactylotum bicolor	0	2	0	0	0	1	0	2	1
Dichromorpha viridis	13	1	0	7	2	0	20	3	0
Dissosteira carolina	0	0	0	0	0	7	0	0	7
Encoptolophus costalis	2	2	0	2	1	0	4	3	0
Hesperotettix speciosus	0	4	3	3	52	27	3	56	30
Hesperotettix viridis	1	12	12	4	14	39	5	26	51
Hippiscus ocelote	1	0	0	2	10	1	3	10	1
Hypochlora alba	4	54	5	3	30	29	7a	84b	34b
Melanoplus angustipennis	9a	193b	86c	11a	686b	424c	20a	879b	510c
Melanoplus bispinosus	6	0	0	0	0	0	6	0	0
Melanoplus bivittatus	3	6	9	36a	52a	301b	39a	58a	310b
Melanoplus confusus	0	2	3	1	3	8	1	5	11
Melanoplus dawsoni	0	3	2	0	27	8	0	30	10
Melanoplus differentialis	17	3	0	47a	12a	60a	64a	15a	60a
Melanoplus discolor	0	0	0	0	1	0	0	1	0
Melanoplus femurrubrum	264a	86b	68b	155a	147a	453b	419a	233b	521ab
Melanoplus flavidus	0	14	5	0	57	34	0a	71b	39ab
Melanoplus foedus	0	3	0	0	7	9	0	10	9
Melanoplus gladstoni	0	2	0	0	0	0	0	2	0
Melanoplus infantilis	0	0	0	0	0	5	0	0	5
Melanoplus keeleri	12	8	0	13	8	0	25	16	0
Melanoplus lakinus	0	0	0	2	2	0	2	2	0
Melanoplus occidentalis	0	0	0	0	0	1	0	0	1
Melanoplus packardii	0	0	0	0	0	5	0	0	5
Melanoplus sanguinipes	0	14	33	5a	81b	633c	5a	95b	666c
Mermeria bivittata	6	40	15	6a	173b	158b	12a	213b	173b
Opeia obscura	17	36	20	13a	94a	121a	30a	130a	141a
Orphulella pelidna	1	14	8	2	4	26	3	18	34
Orphulella speciosa	58a	38ab	10b	96a	164a	114a	154a	202a	124a
Pardalophora haldemani	0	0	0	1	1	1	1	1	1
Paropomala wyomingensis	0a	138b	82b	0a	57b	71ab	0a	195b	153b
Phlibostroma quadrimaculatum	0	5	0	0	14	2	0	19	2
Phoetaliotes nebrascensis	108a	254a	57a	63a	801b	1227b	171a	1055b	1284b
Pseudopomala brachyptera	1	3	9	2a	20a	120b	3a	23a	129b
Schistocerca lineata	0	1	0	1	4	0	1	5	0
Spharageman collare	3	28	15	1a	70b	125b	4a	98b	140b
Spharageman equale	0	0	2	0	0	12	0	0	14
Syrbula admirabilis	21	0	0	2	0	0	23	0	0
Trachyrhachys kiowa	3	3	9	5	8	63	8	11	72
Nymphs	1768a	479b	79c	1869a	2109a	3417a	3637a	2588b	3496c
Adults	588a	1149b	634a	560a	3236b	5490c	1,148a	4385b	6124b

Table 3. Total number of grasshoppers captured in ditch, fence line, and field across Nebraska from 120 sites sampled by sweep net in 2007 and 2010. When more than 100 total individuals of a species were captured, a Kruskal-Wallis One-Way ANOVA with a Tukey post hoc test was used to test for differences in mean number of grasshopper captured by region for each year and overall. Different letters designate significant (P < 0.05) differences.

	2007			2010			Combined		
Species	Ditch	Fence	Field	Ditch	Fence	Field	Ditch	Fence	Field
Aerolophitus hirtipes	0	2	0	0	0	0	0	2	0
Aeropedellus clavatus	1	1	0	29	19	24	30	20	24
Ageneotettix deorum	44a	127ab	161b	514a	433a	787a	558a	560ab	948b
Amphitornus coloradus	0	3	7	13a	29a	72a	13a	32a	79a
Arphia pseudonietana	2	0	2	6	7	19	8	7	21
Arphia xanthoptera	0	0	0	2	0	2	2	0	2
Brachystola magna	4	0	0	0	0	0	4	0	0
Camnula pellucida	0	0	0	0	9	28	0	9	28
Campylancantha olivacea	13	9	4	14	19	20	27	28	24
Cordillacris occipitalis	0	4	4	2	4	10	2	8	14
Chorthippus curtipennis	6	2	3	36	14	4	42	16	7
Dactylotum bicolor	1	1	0	1	0	0	2	1	0
Dichromorpha viridis	6	5	3	4	3	2	10	8	5
Dissosteira carolina	0	0	0	3	3	1	3	3	1
Encoptolophus costalis	1	2	1	1	1	1	2	3	2
Hesperotettix speciosus	5	1	1	54	17	11	59	18	12
Hesperotettix viridis	15	6	4	34	9	14	49	15	18
Hippiscus ocelote	0	0	1	1	1	11	1	1	12
Hypochlora alba	28	17	18	16	15	31	44a	32a	49a
Melanoplus angustipennis	125a	65a	98a	605a	204a	312a	730a	269b	410ab
Melanoplus bispinosus	0	1	5	0	0	0	0	1	5
Melanoplus bivittatus	9	5	4	243a	88b	58b	252a	93b	62b
Melanoplus confusus	1	1	3	3	6	3	4	7	6
Melanoplus dawsoni	0	2	3	14	13	8	14	15	11
Melanoplus differentialis	14	6	0	93a	18ab	8b	107a	24ab	8b
Melanoplus discolor	0	0	0	1	0	0	1	0	0
Melanoplus femurrubrum	226a	94b	98b	335a	221b	199b	561a	315b	297b
Melanoplus flavidus	14	3	2	69	12	10	83a	15a	12a
Melanoplus foedus	1	0	2	7	3	6	8	3	8
Melanoplus gladstoni	1	0	1	0	0	0	1	0	1
Melanoplus infantilis	0	0	0	0	0	5	0	0	5
Melanoplus keeleri	14	1	5	10	7	4	24	8	9
Melanoplus lakinus	0	0	0	1	2	1	1	2	1
Melanoplus occidentalis	0	0	0	0	0	1	0	0	1
Melanoplus packardii	0	0	0	2	2	1	2	2	1
Melanoplus sanguinipes	35	9	3	298a	163b	258ab	333a	172a	261a
Mermeria bivittata	37	11	13	205a	49b	83b	242a	60b	96b
Opeia obscura	5	16	52	6a	41a	181b	11a	57a	233b
Orphulella pelidna	0	8	15	3	5	24	3	13	39
Orphulella speciosa	12a	32a	62a	59a	100ab	215b	71a	132a	277b
Pardalophora haldemani	0	0	0	2	1	0	2	1	0
Paropomala wyomingensis	73a	61a	86a	46a	46a	36a	119a	107a	122a
Phlibostroma quadrimaculatum	0	0	5	0	2	14	0	2	19
Phoetaliotes nebrascensis	289a	65b	65b	1399a	251b	441b	1688a	316b	506b
Pseudopomala brachyptera	11	2	0	128a	9b	5b	139a	11b	5b
Schistocerca lineata	0	0	1	3	1	1	3	1	2
Spharageman collare	13	10	23	98a	31a	67a	111a	41a	90a
Spharageman equale	0	0	2	0	9	3	0	9	5
Syrbula admirabilis	5	3	13	0	1	1	5	4	14
Trachyrhachys kiowa	2	8	5	3	25	48	5	33	53
Nymphs	808a	675a	843a	4132a	1390b	1873b	4940a	2065b	2716b
Adults	244a	139b	205b	4363a	1893b	3030b	5376a	2476b	3805c

tion vary among ditch, fence, and field areas of rangeland across three regions of northern Nebraska. These data suggest the need to develop site-specific economic thresholds that are calculated based upon both region and location of sampling. Based on our results, sampling practitioners should take caution when using roadside surveys to estimate overall grasshopper density and species composition of both nymphal and adult grasshoppers. In addition, these results serve as a warning that samplers must be an adequate distance from the fenceline to accurately estimate grasshopper numbers in rangeland. We recommend that standardized sampling of rangeland grasshoppers be conducted at least 30 meters into a pasture.

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