Sweep Sampling Capture Rates for Rangeland Grasshoppers (Orthoptera: Acrididae) Vary During Morning Hours

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Sweep sampling capture rates for rangeland grasshoppers (Orthoptera: Acrididae) vary during morning hours

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Abstract

Rangeland grasshoppers have long been considered pests of serious economic importance and are key components of grassland food webs. Sampling protocols inform decisions to control grasshoppers. Preliminary observations while sampling rangeland grasshoppers indicated differences in species diversity and numbers captured, depending upon time of day. To test these differences, we used USDA-APHIS sweep-net sampling protocols at various times at four rangeland sites during 2006-2007 and compared mean numbers collected. Sweep sampling every hour from 06:00 to 12:00 revealed that adult and nymphal grasshopper numbers were significantly higher at 06:00 than either 07:00 or 08:00. Captures were similar throughout the afternoon. These patterns were also observed for adults of the most common species, *Melanoplus femurrubrum* (DeGeer). The results of this study have important implications for rangeland pest management decisions and ecological studies that estimate insect biomass as an indicator of food availability. Our results indicate that standardized sampling of grasshoppers in mixed-grass prairie rangeland should be conducted between 10:00 and 16:00.

Key words

Acrididae, sampling, sweep net, grasshopper

Introduction

Short-horned grasshoppers (Orthoptera: Acrididae) are the most important insect pests of rangelands in the United States (Rodell 1977, Olfert & Weiss 2002, Pfadt 2002, Vermeire *et al.* 2004). The estimated annual consumption of available range forage by grasshoppers in the western United States is between 21 and 23%, with an estimated $400-million economic impact (Hewitt & Onsager 1983). These estimates do not include additional damage from clipping of vegetation (Hewitt & Onsager 1983). Because of their ability to cause economic loss, grasshoppers are surveyed annually across most of the rangeland in the United States to determine potential for outbreaks. These surveys may trigger management actions if abundances are sufficient to indicate the need for treatment, usually when adult numbers exceed 9.6 per m^2 (Hewitt & Onsager 1983). Thus, accurate estimates of rangeland grasshopper densities are of the utmost importance in making these determinations.

The United States Department of Agriculture-Animal and Plant Health Inspection Service-Plant Protection and Quarantine (USDA-APHIS-PPQ) collects data on nymphal and adult grasshopper numbers in rangeland. The methods of estimating grasshopper numbers vary from state to state and include quadrat sampling, ring estimations, binomial sampling, pan trapping, roadside counts, and transect or visual estimation (Legg *et al.* 1993, 1996; Gillespie & Kemp 1996; Olfert & Weiss 2002; Fielding 2003; Gardiner *et al.* 2005). Grasshoppers are highly mobile and can be missed by transect and quadrat sampling, often resulting in underestimation of the number and species present (Gardiner & Hill 2006). Overestimations of abundance can also occur with quadrats and transects because of double counting of individuals (Larson *et al.* 1999).

Although many methods are available, sweep sampling is the most common method used to determine grasshopper numbers and species composition, because it allows rapid assessment and is cost-effective (Larson *et al.* 1999, Gardiner *et al.* 2005). Numerous factors have been shown to affect data generated from sweep netting. For example, counts from sweep sampling can differ between sampling practitioners, and also between sampling practitioners and landowners/ranchers (Legg *et al.* 1996). Vegetation structure, height and density also change the effectiveness of sweep sampling, limiting its use for accurate estimates of grasshoppers in some situations (Fielding 2003, Gardiner *et al.* 2005).

Although many insects are known to have a strong circadian rhythm of activity, very few studies have examined the impact of time of day on population estimates generated with sweep sampling. For example, Hutchison and Pitre (1982) found that sweep captures of big-eyed bugs (Hemiptera: Lygaeidae), *Geocoris punctipes* (Say), in cotton, were significantly higher in the afternoon than in the morning. In contrast, Estano and Shepard (1988) found that sweep-net capture of green leafhoppers (Hemiptera: Cicadellidae), *Nephotettix cincticeps* Uhler, in rice was higher in the morning and evening than in the afternoon. To our knowledge, the effects of time of day on sweep-net capture for insects have not been examined outside of a crop setting. In this study, we used sweep-net samples to compare grasshopper numbers during different times of the day.

Materials and Methods

Four rangeland sites in central Nebraska were chosen for sweep sampling in 2006 (Site 1: UTM Zone 14, 4507768 N, 478443 E; Site 2: 4513469 N, 478425 E; Site 3: 4516684 N, 512211 E; Site 4: 4529461 N, 489609 E). All sites were mixed-grass prairies with vegetation approximately 0.3 m tall and low grazing pressure by cattle. Vegetation consisted of native grasses and forbs as well as smooth brome (*Bromus inermis* Leyss). Each of the four sites was sampled over four consecutive days for three sampling periods between June and September of 2006. At each site, twenty low and fast sweeps (following USDA protocol in Nebraska as described by Brust *et al.* 2009) were taken. Sweep samples were collected every two hours

Table 1. Total number of adult grasshoppers by species collected during sweep samples taken every other hour from four rangeland sites in Nebraska over three dates between June and October, 2006.

	Time						
Species	06:00	08:00	10:00	12:00	14:00	16:00	18:00
Ageneotettix deorum	10	6	5	13	10	8	8
Arphia simplex	1	2	0	0	0	0	1
Campylancantha olivacea	1	0	1	0	0	3	0
Dichromorpha viridis	0	0	1	0	0	0	4
Encoptolophus costalis	1	0	1	0	1	2	0
Eritettix simplex	1	0	3	3	3	3	2
Hesperotettix speciosus	0	0	2	0	1	0	1
Melanoplus bivittatus	12	2	3	5	2	10	7
Melanoplus confusus	4	0	0	0	1	1	3
Melanoplus differentialis	0	0	1	1	0	1	0
Melanoplus femurrubrum	88	37	73	75	70	61	68
Melanoplus lakinus	1	1	0	1	1	1	1
Melanoplus sanguinipes	0	0	0	0	1	0	0
Mermeria bivittata	0	0	0	0	0	0	1
Opeia obscura	3	3	1	4	4	5	2
Orphulella speciosa	33	16	14	29	31	38	33
Phoetaliotes nebrascensis	21	14	22	21	21	17	18
Syrbula admirabilis	4	2	2	3	7	4	7
Trachyrhachys kiowa	3	0	0	0	0	0	0
TOTAL ADULTS	183	83	129	155	153	154	156

from 06:00 to 18:00; at each time interval, a different location within the site was sampled. All sweep samples were collected by S.D. Whipple. Temperature and wind speed were recorded during each sample. Captured grasshoppers were transferred from the sweep net to freezer bags which were labeled with location, date, and time of sampling. After freezing the specimens, adult grasshoppers were counted and identified to species using Brust *et al.* (2008). Voucher specimens of all species were deposited at the USDA-APHIS office in Lincoln, Nebraska.

Methods were revised in 2007 by changing site 4 to a new location (4516159 N, 512218 E), which allowed the sampling of two sites per day. Sites 1 and 2 are approximately 3.2 km apart and located north of Odessa, Nebraska. Sites 3 and 4 are approximately 1.6 km apart and located north of Gibbon, Nebraska. Close proximity of sites made it possible to sample each pair of sites within five minutes of one another. This permitted seven sampling dates for each of the four sites through the summer. Sampling times were also changed to every hour from 06:00 to 12:00, to more thoroughly examine the

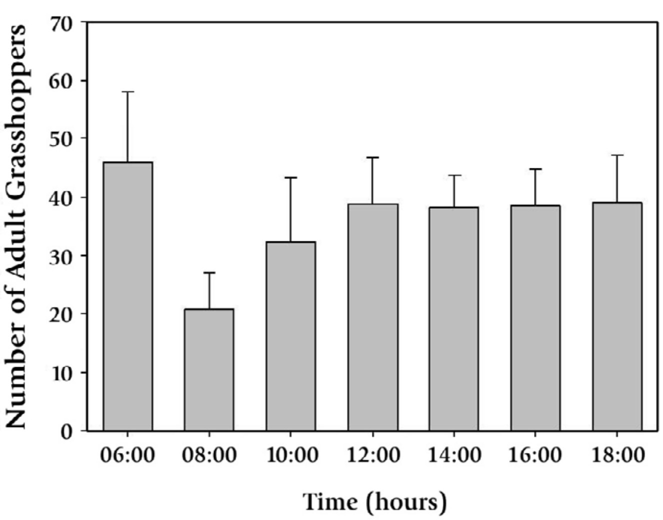

Fig. 1a. Mean ± 1 SE number of adult grasshoppers captured by times of day at four Nebraska rangeland sites for three dates in 2006. No statistical difference was found between times of day (Kruskal-Wallace ANOVA, P > 0.05).

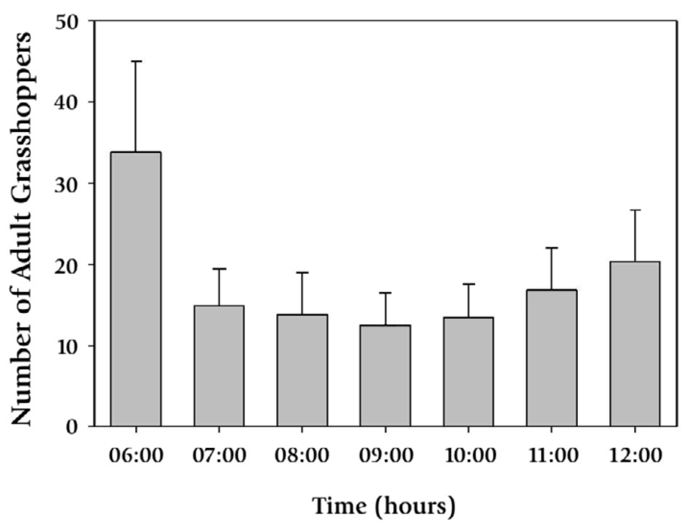

Fig. 1b. Mean ± 1 SE number of all adult grasshoppers captured by times of day at four Nebraska rangeland sites for seven dates in 2007. Although no statistical difference was found between times of day (Kruskal-Wallace ANOVA, P > 0.05), two to three times the number of grasshoppers were collected in sweep samples at 06:00 compared to other times.

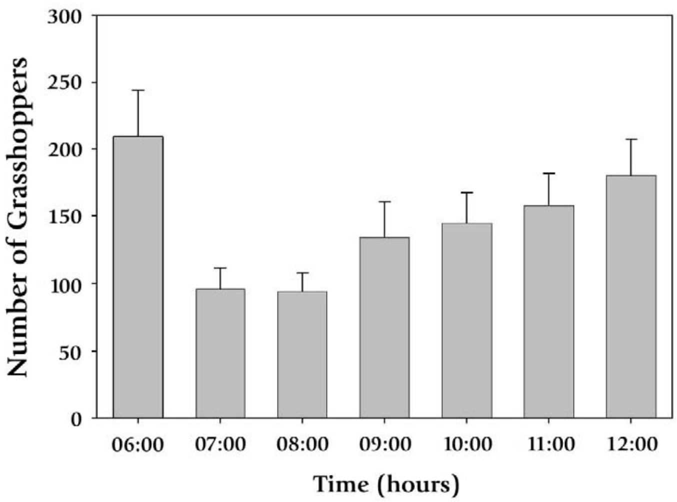

Fig. 2. Variations in nymphal and adult grasshopper numbers by times of day at four rangeland sites in 2007. Captures at 07:00 and 08:00 were significantly lower than all other times (Kruskal-Wallace ANOVA, $P < 0.05$).

observed change in capture rates during morning hours. Although immature grasshoppers were not identified to species, they were counted and included in the analysis for 2007.

Because data were not normally distributed, a Kruskal-Wallace one way ANOVA (Sigma Stat 3.1) was used to examine differences in number of grasshoppers captured by time. Significant differences in median values were tested using a Tukey Test (to make all pairwise comparisons).

Results

A total of 1,013 adult grasshoppers from 19 species were collected in 2006 (Table 1). Grasshopper captures were greatest at 06:00, lower at 08:00 and 10:00, then higher and almost constant from 12:00 to 18:00 (Fig. 1a). However, because of high variation among sites the median values were not statistically different ($P = 0.559$). Among the sites sampled in 2006, site 4 had significantly fewer grasshoppers (ANOVA, $P < 0.001$). For this reason, a different site was chosen for sampling in 2007.

In 2007, a total of 2,970 adult grasshoppers from 24 species and 24,303 nymphs (not identified to species) were collected (Table 2). The total number of adults collected at 06:00 from all four sites and across all sampling dates, was twice as great as the number of captures at 07:00 and 08:00. While there were no statistical differences

Table 2. Total number of adult and nymphal grasshoppers collected during hourly sweep samples from four rangeland sites in Nebraska on seven dates between May and August, 2007.

	Time						
Species	06:00	07:00	08:00	09:00	10:00	11:00	12:00
Ageneotettix deorum	12	6	3	3	5	8	10
Arphia simplex	1	2	1	1	1	3	3
Campylancantha olivacea	0	1	3	1	1	2	1
Chortophaga viridifasciata	0	0	0	0	0	0	2
Dichromorpha viridis	14	5	2	4	4	2	6
Encoptolophus costalis	3	2	1	2	1	5	3
Eritettix simplex	4	4	1	4	3	10	11
Hesperotettix speciosus	0	1	1	0	1	3	1
Hesperotettix viridis	0	0	1	0	0	0	0
Hypochlora alba	0	1	0	0	0	0	0
Melanoplus bivittatus	23	7	7	6	24	19	14
Melanoplus confusus	17	3	8	3	4	9	11
Melanoplus differentialis	12	7	3	4	4	2	10
Melanoplus femurrubrum	317	137	112	129	102	185	207
Melanoplus lakinus	2	0	2	3	1	0	3
Melanoplus packardii	0	0	0	0	0	0	1
Melanoplus sanguinipes	0	2	1	1	2	0	3
Mermeria bivittata	1	1	0	0	0	0	1
Opeia obscura	0	1	1	0	1	1	2
Orphulella speciosa	186	84	63	89	149	97	129
Pardalophora haldemani	3	1	3	2	3	5	1
Phoetaliotes nebrascensis	124	55	57	61	44	75	103
Syrbula admirabilis	9	5	4	10	1	11	6
Trachyrhachys kiowa	1	1	0	0	0	1	1
Adults	729	326	274	323	351	438	529
Nymphs	5,143	2,364	2,359	3,178	3,414	3,681	4,164
TOTAL GRASSHOPPERS	5,872	2,690	2,633	3,501	3,765	4,119	4,693

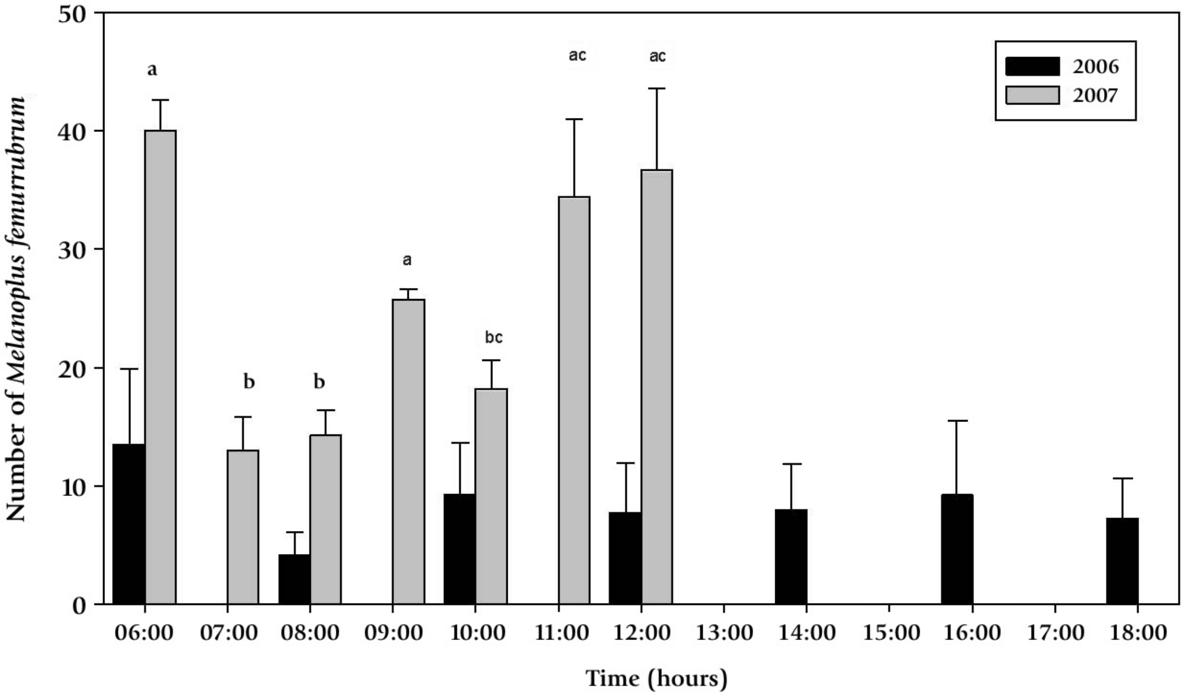

Fig. 3. Mean number of *M. femurrubrum* from dates of highest capture at each of four Nebraska rangeland sites. No significant differences were found in 2006; for 2007, bars with the same letter are not significantly different (ANOVA, $P < 0.05$).

detected among times for adult captures (Fig. 1b), when nymphs were included in the analysis, grasshopper numbers at 07:00 and 08:00 were significantly lower than at other times (Fig. 2a). The highest numbers of nymphs and adults of most species were collected at 06:00. Numbers declined for the 07:00 and 08:00 samples before gradually increasing for the remainder of the morning (Table 2). The number of nymphs was also significantly lower at 07:00 and 08:00 when analyzed without the adult data (Fig. 2) and, like the adults, the highest observed number of nymphs occurred at 06:00 (Table 2).

The most abundant adult grasshopper species collected throughout the study was *Melanoplus femurrubrum* (DeGeer). Although numbers of *M. femurrubrum* were highest at 06:00, there were no statistical differences ($P = 0.354$) in abundance across times sampled in 2006 (Fig. 3). In 2007, *M. femurrubrum* captures were significantly lower at 07:00 and 08:00 ($P<0.05$) than at other times (Fig. 3). Numbers at 11:00 and 12:00 were similar to those observed at 06:00 (Fig. 3).

Differences in grasshopper numbers at different times were not correlated with either changes in temperature or wind speed (Fig. 4). For example, although the lowest observed temperatures had the highest captures at 06:00, the second and third lowest temperatures had the lowest grasshopper captures. A linear regression of mean temperature (°C) and mean (nymphal and adult) grasshopper numbers yielded $r^2= 0.0061$.

Discussion

In this study, we observed differences in the number of grasshoppers captured by time of day. If our results apply to similar rangeland ecosystems in North America, grasshopper densities estimated by sweep sampling, and potentially other methods, will vary depending on the time of day at which the samples are obtained. Our results show the need to further test the effects of time of day on insect collections using sweep sampling.

Across all sites and dates in 2007, the number of adult grasshoppers collected at 06:00 was more than twice the number of adults collected at 07:00 or 08:00 (Table 2). The number of grasshoppers did not rebound until 12:00 (Fig. 1b). Because sampling was done in different areas of the same rangeland site, this trend was not a result of depleting local populations. Further, the differences in grasshopper numbers were not explained by either environmental temperature or wind speed (Fig. 4). In 2006 grasshopper numbers were relatively constant between 12:00 and 18:00 (Fig. 1a).

Because USDA-APHIS-PPQ personnel sample grasshoppers throughout the summer months and at various times of day, large differences in grasshopper numbers at different times during the day

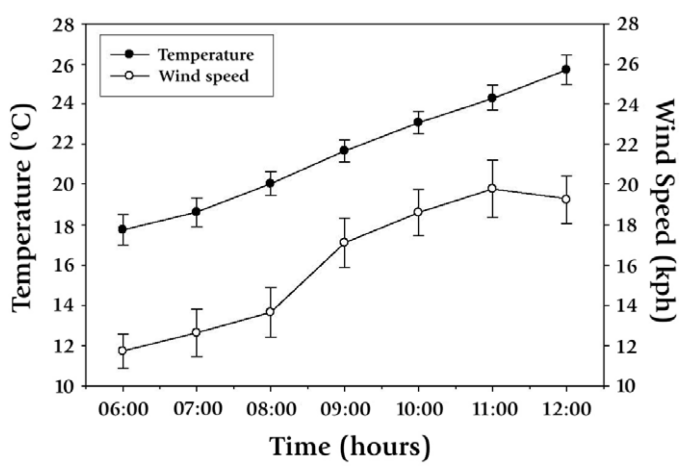

Fig. 4. Mean (± 1 SE) temperature and wind speed by time of day across all sites in 2007. Data were obtained from weatherunderground.com for the Gibbon and Odessa [Nebraska] weather stations; these are located within approximately 10 km of the survey sites.

will affect density estimates and, in turn, management decisions. Our findings add to other known factors that produce variation in data produced via sweep sampling (Evans *et al.* 1983, Larson *et al.* 1999). Previously, Hutchison and Pitre (1982) showed that sweep-net captures of *Geocoris punctipes* (Say) were significantly higher between the hours of 15:00 and 17:00, than between 07:00 and 11:00. However, Hutchison and Pitre (1982) did not sample at 06:00. Compared to these small predatory insects, accurate grasshopper sampling is potentially more difficult because grasshoppers are large and often highly mobile.

In our study, grasshoppers were collected using low-and-fast sweeps (Brust *et al.* 2009). It has previously been shown that estimates of grasshopper density taken with sweep nets can be variable depending upon speed and distance from the ground (Foster & Reuter 1996-1999). Low-and-slow sweeps yield higher capture of nymphal grasshoppers and slower moving species, while high-and-fast sweeps result in greater success in capturing fast moving, more active species (Foster & Reuter 1996-1999). Brust *et al.* (2009) found low-and-fast sweeps to be sufficient for the capture of several economically important species, including *M. femurrubrum*, which was the most common species in our study (Fig. 3).

The ability of a grasshopper sampling method to produce accurate results is often dependent on the density of grasshoppers within the sampling area (Gardiner *et al.* 2005). Spatial clustering of grasshoppers within rangelands (Schell & Lockwood 1997, Ni *et al.* 2003) led to the suggestion that night trapping may be the most appropriate method of sampling high densities of grasshoppers (Gardiner *et al.* 2005). Some rangeland grasshoppers may feed more frequently at night than during daylight hours (Lockwood *et al.* 1996) and thus night trapping may be more accurate and effective than sweep sampling during the day for such species (Evans *et al.* 1983, Browde *et al.* 1992). However, estimates of grasshopper densities are needed over large areas of rangeland in the western United States and night sampling at this scale is impractical.

Air temperatures may explain high numbers of individuals captured if grasshoppers are basking to increase body temperature. Parker (1982) showed that nymphs are found at the top of grasses and forbs at the start and end of each day, with periods of basking exhibited in the morning and afternoon. Nymphs comprised the greatest number of captured grasshoppers during early sample times (Table 2), during the coolest temperatures (Fig. 4). However, regression analysis shows no correlation between grasshopper capture and temperature (r^2= 0.0061). Air temperature does not explain the low numbers of both nymph and adult grasshoppers captured at 07:00 and 08:00.

Observed differences in grasshopper captures at different times of the day may be a result of predator avoidance. In the darkness, grasshoppers may climb to the top of the vegetation to avoid predation from nocturnal mammals and invertebrates, including wolf spiders, ground beetles, and small mammals. During early morning, individuals may climb down to the substrate to avoid avian predation, which is most intense in the early morning hours (Bednekoff & Houston 1994).

If estimated grasshopper abundances differ by time of day, there are important implications for the USDA, as well as landowners and ranchers, when making decisions for management action. Treatment recommendations made based on grasshopper estimates generated between the hours of 06:00 and 09:00 may result in over- or under-estimation of average densities. At a minimum, field personnel should document the time that sampling occurred and be aware of apparent changes in numbers among similar sites at different times during the day. Follow-up studies confirming these relationships in other rangeland ecosystems may allow development of a conversion factor to accurately estimate densities depending on time of day. In the interim, we suggest that standardized grasshopper sampling take place between the hours of 10:00 and 16:00 to generate consistent estimates of rangeland grasshopper densities. Studies involving energetics and insect biomass should also be aware of the effects of time of day on sampling results.

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