

Lesser prairie-chicken brood habitat in sand sagebrush: invertebrate biomass and vegetation

Christian A. Hagen, G. Curran Salter, James C. Pitman, Robert J. Robel, and Roger D. Applegate

Abstract Invertebrates are an important food source for grouse chicks, especially within the first 2 weeks of life. Invertebrate abundance is highly patchy and dependent upon herbaceous cover and vegetation structure. We examined the relationship between invertebrate biomass (from sweepnet samples) and habitat structure at lesser prairie-chicken (*Tympanuchus pallidicinctus*) brood-use and non-use areas during 2001 and 2002 in a sand sagebrush (*Artemisia filifolia*) prairie vegetation community of southwestern Kansas. We delineated use and non-use areas from paired sampling points within and outside 95% utilization distributions of radiomarked brood females, respectively, during the first 60 days post-hatch. We measured vegetation cover and invertebrate biomass (Acrididae and "other" invertebrates) at 71 paired points on 2 study sites (Site I=4 broods, Site II=12 broods). Both Acrididae and other invertebrate biomasses were greater at brood areas than non-use areas on both study sites, suggesting this food source likely had a greater influence on brood habitat use than vegetation type. Vegetation structure described brood-use areas better than vegetation type because brood-use areas had greater visual obstruction readings (VORs) than non-use areas regardless of dominant cover type. We also examined the predictive relationship between vegetation type and invertebrate biomass. Sand sagebrush density was the best linear predictor of Acrididae biomass, with lower densities having the greatest Acrididae biomass. We propose experiments to determine best management practices that produce abundant invertebrate biomasses for lesser prairie-chicken brood habitat, using our study as a baseline.

Key words Acrididae, *Artemisia filifolia*, habitat use, invertebrate biomass, Kansas, lesser prairie-chicken, sand sagebrush, *Tympanuchus pallidicinctus*

Invertebrates are an important food source for galliform chicks, especially within the first 2 weeks of life (Hill 1985, Dahlgren 1990, Panek 1997). Low invertebrate biomass in brood-use areas has been associated with lower chick survival and slower growth rates in studies of captive (Johnson and Boyce 1990, Park et al. 2001, Liukkonen-Anttila et al.

2002) and wild birds (Baines et al. 1996, Park et al. 2001). These associations are important to management because chick survival can have substantial effects on population dynamics (Baines et al. 1996, Peterson et al. 1998, Wisdom and Mills 1998, Park et al. 2001, Hagen 2003). In the wild, invertebrate abundance is highly patchy and dependent

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Lesser prairie-chicken female being fitted with an 11-g radio-transmitter.

upon herbaceous cover and structure (Stuen and Spidso 1988, Storch 1994, Baines et al. 1996, Panek 1997). Understanding the habitats in which invertebrates (and consequently broods) can flourish is critical because there is potential to manipulate vegetation to favor increased invertebrate abundances (Quinn and Walgenbach 1990, Boyd and Bidwell 2001).

The lesser prairie-chicken (*Tympanuchus palidicinctus*) currently is "warranted but precluded" from protection under the Endangered Species Act (United States Fish and Wildlife Service 2002). Continued population declines, despite a decreased rate of large-scale habitat loss in most of the range, have led to concern for this species. Lesser prairie-chicken population trends in Kansas have reflected those across the range (Jensen et al. 2000), but the state possibly hosts the largest population of the 5 states where lesser prairie-chickens occur. Consequently, identifying limiting factors of lesser prairie-chickens has become a conservation priority (Mote et al. 1999) for all states within its range. It has been hypothesized that chick survival is a primary factor limiting lesser prairie-chicken populations (Jamison 2000, Hagen 2003). If so, it is important to identify management strategies to increase this vital rate. Previous work has demonstrated the

importance of invertebrates in the diets of lesser prairie-chicken broods (Schwilling 1955, Jones 1963, Davis et al. 1980). Using pitfall traps and sweepnets, Jamison et al. (2002) documented greater invertebrate biomasses in lesser prairie-chicken use areas during summer but also found greater forb abundance in these areas. Because Jamison et al. (2002) simultaneously examined use areas of both broods and adults without broods, it was difficult to discern which factors were more important to brood habitat use. Thus, it is important to clarify relationships between lesser prairie-chicken brood habitat use and invertebrate biomass and between habitat and invertebrate communities.

We compared habitat use by lesser prairie-chicken females with broods (broods) between 2 study sites with contrasting sand sagebrush (*Artemisia filifolia*; hereafter sandsage) plant densities. Our objectives were to determine 1) what factors best described brood habitat (i.e., vegetation or invertebrate biomass), and 2) whether sandsage density, forb cover, or vegetation height (as indexed by visual obstruction readings) was the best predictor of invertebrate biomass.

Study area

The study region was comprised of 2 fragments (~5,000 ha each) of native sandsage prairie near Garden City, Finney County, Kansas. Site I (37°52' N, 100°59' W) and Site II (37°51' N, 100°46' W) were southwest and southeast of Garden City, respectively, and were separated by 19 km of unsuitable habitat between fragment centroids (Hagen 2003). These areas were grazed annually from approximately early May to October. Vegetation on both sites was comprised of sandsage, yucca (*Yucca* spp.), sandreed grasses (*Calamovilfa* spp.), bluestem grasses (*Andropogon* spp.), sand dropseed (*Sporobolus cryptandrus*), six-weeks fescue (*Vulpia octoflora*), and sand lovegrass (*Eragrostis trichodes*). Primary forb species in the region included ragweed (*Ambrosia* spp.), sunflower (*Helianthus* spp.), and Russian thistle (*Salsola iberica*) (Hulett et al. 1988, Jamison 2000).

Methods

We captured lesser prairie-chicken females during the spring on leks with walk-in funnel traps (Haukos et al. 1990) during late March and early April of 2001 and 2002. We fitted females with an



Sand sagebrush pasture with about 9,000 plants/ha in southwest Kansas.

11-g necklace-style transmitter and monitored them daily with a vehicle-mounted twin-Yagi null-peak telemetry system (Advanced Telemetry Systems, Isanti, Minn.). Daily locations were triangulated from known tracking stations. Once females had localized in an area and their azimuth bearings from fixed tracking stations were identical for 3 successive days, we located the female and her nest with a handheld Yagi antenna. We monitored nesting activity remotely with the telemetry system, and nests were not revisited until the eggs hatched or were depredated.

We monitored brood females (females of nests hatching ≥ 1 egg) daily (as described above) and estimated locations using a maximum-likelihood estimator in program Locate II (Nams 2000). We used flush counts of brood females at fixed intervals to determine number of chicks in each brood. Flush counts occurred first at 14 days post-hatch (chicks are capable of flight at this age) and at 5 fixed intervals (24, 34, 44, 54, and 60 days post-hatch) thereafter (Pitman 2003). We classified females that flushed long distances, flushed with other adult birds, or made unexpected long-dis-

tance (>1 -km) movements as having lost their brood and no longer included them in our sampling. We used subsequent flushes to verify this classification. The systematic flush dates and locations defined "brood-areas" for our vegetation and invertebrate biomass sampling; thus, we obtained representative samples throughout the brood-rearing period and minimized disturbance to the brood. Vegetation and invertebrate sampling occurred within 2 days of the flush. We sampled random points in non-use areas the same time of day either immediately before or after sampling its paired brood-use point.

Determining use non-use areas

We determined locations of non-use areas using a Geographic Information System (GIS) in Arcview 3.1 (Environmental Systems Research Institute 1998). We estimated a 95% utilization distribution (UD) for each brood from hatch to a given flush interval. Thus, UD's varied with the numbers of locations used (e.g., 14 for the first interval and 60 for the last interval) and were cumulative in the area covered. We imported the daily locations into

the GIS and used Animal Movements (Hooge and Eichenlaub 2000) extension for ArcView 3.1 to estimate 95% fixed-kernel UD's (Worton 1989) of all broods through a given flush interval. We created a 300-m buffer (maximum daily movement of broods) around each home range and generated a random point (random points generator extension) within the buffer. If a random point fell within the UD of another brood, it was discarded and another was generated. This process continued until the point was located outside the known brood-area for the given time interval. We recorded Universal Transverse Mercator (UTM) coordinates for the random point and located it using a handheld Global Positioning System (GPS) unit.

Vegetation sampling

We estimated vegetation canopy cover (%) at brood- and non-use areas using Daubenmire (1959) frames (20 cm × 50 cm) and visual obstruction readings (VOR) using a VOR pole (Robel et al. 1970). We centered sampling plots (15 × 15 m) on the brood-area (i.e., a flush location) or non-use area (i.e., UTM coordinates of a random point). We recorded canopy cover and VORs (taken from a distance of 2 m and a height of 0.5 m) at 7.5-m intervals along 2 perpendicular lines emanating from the center of the plot. We made ocular estimates to the nearest 2.5% of sandsage canopy cover, grass canopy cover, and forb canopy cover within each Daubenmire frame. Sandsage density was estimated using the point-centered quarter method (Cottam and Curtis 1956); the perpendicular arrangement of the sampling plot was used to define quadrants for which the distance to nearest shrub (out to 15 m) was measured (m). We recorded height and diameter (cm) of all shrubs for which distances were measured.

Invertebrate sampling

We estimated invertebrate biomass at brood-use and non-use areas from sweepnet samples. We used a standard 30-cm insect net to sample invertebrates along 3 parallel lines (10 m apart) with 100 sweeps per plot; we conducted these on days with no precipitation and wind speed <16 km/hour and during times of day when broods would be foraging (early morning or evening). The same individual conducted all sweepnet sampling during both years. We restrained collected invertebrates in the sweepnet and placed them in killing jars containing ethyl acetate until dead. We removed dead invertebrates

from the sweepnet, placed them in resealable plastic bags, and stored them frozen until sorted. We separated invertebrates into 2 groups, short-horned grasshoppers (Family Acrididae) and other taxa; placed them in petrie dishes, where they were allowed to air-dry for 1 day; and then oven-dried them at 60°C for 1 week. An electronic balance determined biomass (nearest 0.01 g) of oven-dried invertebrates.

Data analysis

We used a split-plot repeated-measures MANOVA (PROC GLM, SAS Institute 2000) to evaluate differences in vegetation composition and invertebrate biomass between brood- and non-use areas. We treated year as the whole plot (block) and Study Site (Site) as the split plot and took repeated measures among the number of flushes per brood.

Because there were 8 explanatory variables, we used MANOVA as a conservative approach to multiple comparisons and to examine the dimensionality of the alternative hypothesis using canonical variates analysis (Johnson 1998). Thus, we reported means and standard errors of each habitat and invertebrate variable, and resulting *P*-values from multiple comparisons. We examined the possibility of explaining these areas in a reduced parameter space (i.e., the dimensionality of the alternative hypothesis). If the population means lie in a subspace (data reduction), then linear combinations (canonical variates) can be used to explain the relationship between brood- and non-use areas. We examined differences in mean canonical variates using differences of means (\bar{d}) and 95% confidence limits around the differences and the degree of overlap of 95% ellipses in >2-dimensional spaces. We conducted these univariate analyses using mixed-model ANOVAs (PROC MIXED, SAS Institute 2000).

Using the information-theoretic approach (Burnham and Anderson 1998) and least-squares regression, we modeled Acrididae biomass as a function of sandsage density, forb cover, and VORs to determine which of these habitat characteristics best-predicted invertebrate biomass (Jamison et al. 2002). Because of potential conflicting effects of points in brood- and non-use areas, we limited our modeling only to points that were brood areas and from broods that had >4 locations. We averaged the values of sandsage density, forb cover, VOR, and Acrididae biomass across flushing periods per brood. This resulted in independent estimates for each predictor variable based on individual broods.

Table 1. MANOVA model statistics for determining lesser prairie-chicken brood habitat usage by invertebrate biomass and vegetation composition in southwest Kansas, 2001–2002. Higher-order interactions were examined first.

Model	Λ^a	F-value	df ^b	P-value
Use	0.423	8.00	8/47	<0.0001
Site	0.513	5.56	8/47	<0.0001
Time	0.100	3.62	40/207.7	<0.0001
Use × time	0.523	0.92	40/229.5	0.614
Site × time	0.161	2.74	40/207.7	<0.0001
Site × use	0.682	2.74	8/47	0.015
Site × time × use	0.213	1.06	80/306.7	0.363

^a Wilk's Λ is a likelihood ratio statistic.

^b Degrees of freedom in the numerator / denominator for the F-value.

Results

We monitored 67 nests and 19 hatched, but 3 broods were lost prior to the first flush (14 days post-hatch). We measured vegetation cover and invertebrate biomass at 42 and 29 paired points in 2001 (Site I=3 broods, Site II=6 broods) and 2002 (Site I=1 brood, Site II=6 broods), respectively. The 3-way interaction between time × site × use was not

strongly supported by the data ($P=0.363$; Table 1), but there were significant interactions between site × time ($P<0.001$) and site × use ($P=0.015$; Table 1), and we derived our parameter estimates from the latter 2 models. Because of the 2-way interactions, we could not make inference from the simple effects (Table 1). There was marked variability between Site I and Site II in nearly all the explanatory variables over the sampling period (Figure 1). Under the site × time model, Acrididae biomass (g) on Site I had the largest linear ($\bar{a} = 5.38$ g, 95% CL: 3.32 to 7.45 g) increase over the 46-day sampling period (Figure 2); the increase was not as large on Site II ($\bar{a} = 1.45$ g, 95% CL: 0.12 to 2.79 g). Alternatively, other biomass changed non-linearly on both areas (Figure 2). Forb cover changed little on both sites during this period, except for the last period when a sharp increase was observed on Site II (Figure 1). The site × use model indicated that Site I typically had greater Acrididae biomass in brood areas than non-use areas ($\bar{a} = 2.01$ g, 95% CL: 1.02 to 2.99 g; Table 2), and this relationship was true for Site II but the effect size was much smaller ($\bar{a} = 0.70$ g, 95% CL: 0.01 to 1.39 g; Figure 2). Biomass of other invertebrates was slightly greater in brood

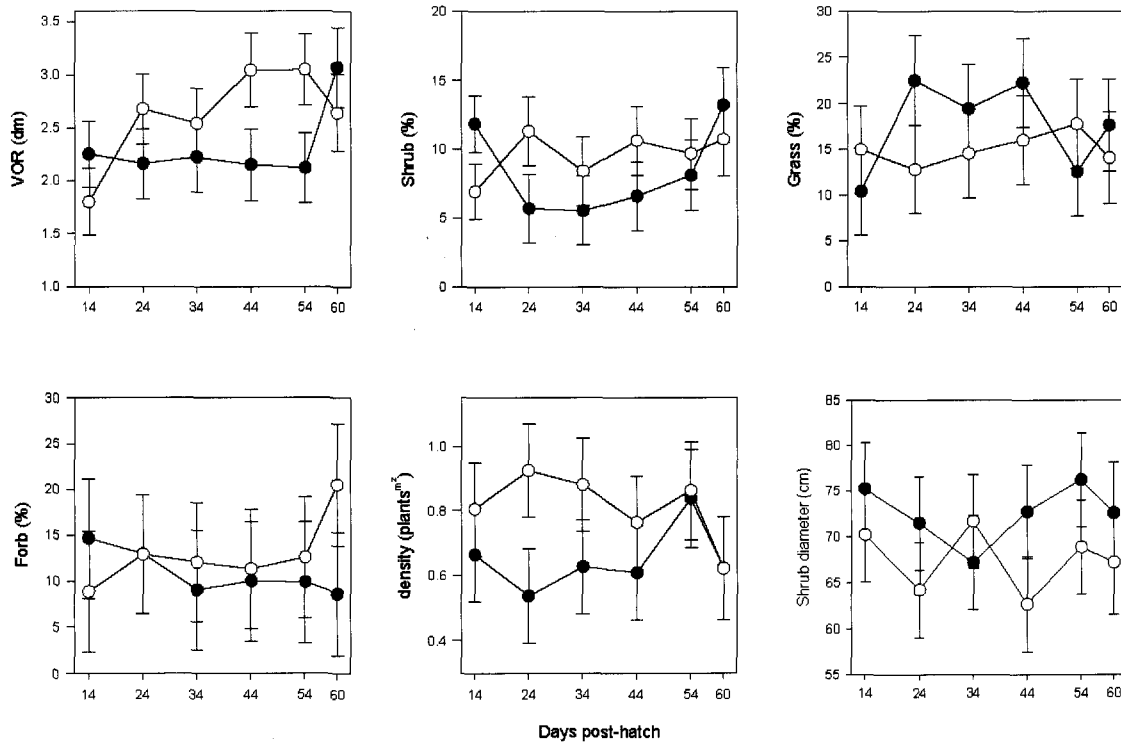


Figure 1. The site × time interaction from the MANOVA of lesser prairie-chicken brood use indicated considerable variation in plant phenology and structure between Site I (black circles ± SE) and II (white circles ± SE) over the 46-day sampling period in Finney County, Kansas 2001–2002. The estimated mean and SE were derived from mixed-models with repeated measures.

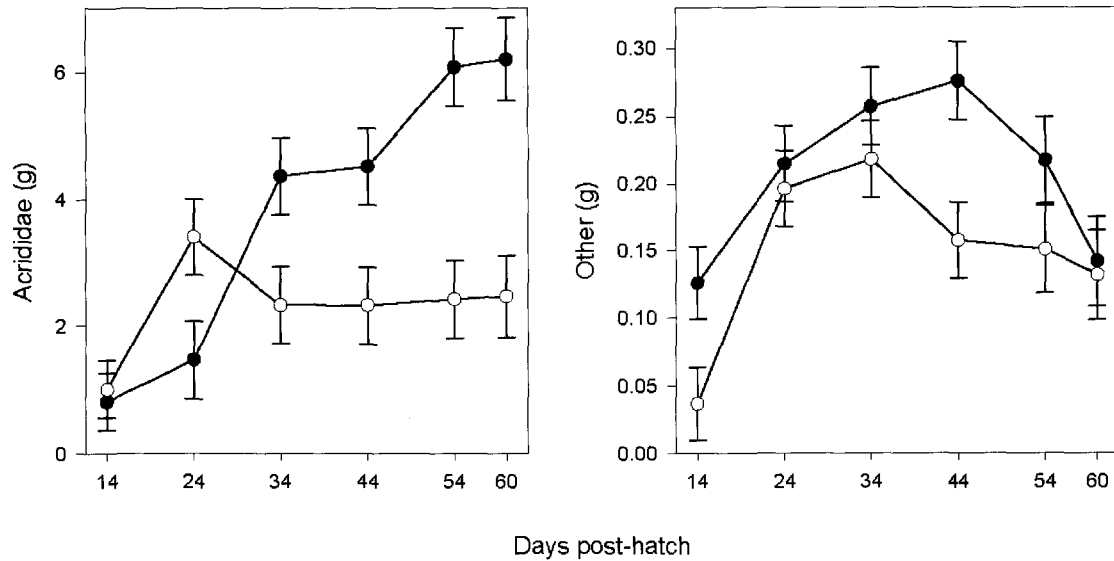


Figure 2. The site \times time interaction from the MANOVA of lesser prairie-chicken brood use indicated considerable variation in Acrididae and other invertebrate biomass between Site I (black circles \pm SE) and II (white circles \pm SE) over the 46-day sampling period in Finney County, Kansas 2001–2002. The estimated mean and SE were derived from mixed-models with repeated measures.

areas than non-use areas on both Site I ($\bar{d} = 0.08$ g, 95% CL: -0.01 to 0.17 g) and II ($\bar{d} = 0.02$ g, 95% CL: -0.03 to 0.08 g). Visual obstruction and forb cover were greater and grass cover less at brood- than non-use areas on both study sites (Table 2).

Canonical variates

The site \times time model could be explained by canonical variate-1 and -2 (CAN-1 and CAN-2), which accounted for 68 and 17% of the variability in the model, respectively (Table 3). Because the site \times time model did not appear to affect use, we did not summarize this model in terms of its linear

combinations. However, there were marked changes in shrub cover, VOR, and Acrididae biomass on both study sites during the 46 day sampling period (Figure 1).

The site \times use model could be reduced to CAN-1 (canonical variate-1, $F_{8,47} = 2.74$, $P < 0.015$), which was best explained by brood areas with high forb cover (i.e., Site I-use, canonical score = -1.18), shrub cover (i.e., Site II-use, canonical score = 0.98), and Acrididae biomass (i.e., Site I and II-use, canonical score = -0.81) (Figures 3 and 4). Thus, brood habitat use could be generalized as areas with greater forb cover and invertebrate biomass

(both Acrididae and other) and less sandsage cover, although the pattern for shrub cover was the inverse for Site II, with brood areas having greater sandsage cover. This suggested that habitats with greater sandsage cover yielded less invertebrate biomass than habitats with more forbs, and regardless of the vegetation type, habitats were selected with greater invertebrate biomass than

Table 2. Simple effects ($\bar{x} \pm$ SE) of lesser prairie-chicken brood use and paired non-use areas in Finney County, Kansas 2001–2002.

Measurement	Site I ($n = 4$) ^a		Site II ($n = 12$)	
	Use ^b	Non	Use	Non
VOR (dm)	2.62 ± 0.37	2.04 ± 0.37	3.00 ± 0.33	2.25 ± 0.33
Shrub (%)	6.86 ± 2.65	10.15 ± 2.65	11.02 ± 2.22	8.23 ± 2.22
Grass (%)	13.45 ± 4.87	21.44 ± 4.87	12.48 ± 4.71	17.55 ± 4.71
Forb (%)	14.65 ± 5.06	7.03 ± 5.06	13.58 ± 4.72	12.45 ± 4.72
Sage density (plants m^2)	0.66 ± 0.17	0.54 ± 0.17	0.90 ± 0.15	0.72 ± 0.15
Sage diameter (cm)	77.16 ± 4.78	67.94 ± 4.78	68.94 ± 3.51	66.16 ± 3.51
Acrididae biomass (g)	4.91 ± 0.65	2.91 ± 0.65	2.64 ± 0.63	1.97 ± 0.63
Other biomass (g)	0.24 ± 0.05	0.17 ± 0.05	0.16 ± 0.05	0.13 ± 0.05

^a All estimates were derived from repeated measures ANOVA on 4 and 12 broods from Site I and II, respectively.

Table 3. Standardized canonical scores from the 2 models best supported by MANOVA of lesser prairie-chicken brood use, in southwest Kansas, 2001 and 2002. The larger the values the stronger the correlation with the listed canonical variate (e.g., CAN-1 for Site × Use is most correlated [ranked 1, 2, and 3] with forb cover, shrub cover, and Acrididae biomass).

Measurement	Site × Use		Site × Time	
	CAN-1	CAN-2	CAN-1	CAN-2
VOR (dm)	-0.47	0.12	1.33	
Shrub (%)	0.98	0.06	0.82	
Forb (%)	-1.18	1.37	0.05	
Grass (%)	0.06	0.25	0.23	
Sage density (plants m ²)	0.00	-0.18	-0.53	
Sage diameter (cm)	0.02	0.17	-0.79	
Acrididae biomass (g)	-0.81	-1.67	0.32	
Other biomass (g)	0.19	0.32	-0.25	

would be expected at random.

Predicting invertebrate biomass

Sandsage density was the best predictor of invertebrate biomass ($w_i=0.70$), and forb cover was the

second best predictor ($\Delta AIC_c = 3.12$, $w_i = 0.15$) (Table 4). Sandsage density had a relatively large and negative effect ($\beta_{sandsage} = -3.04$, 95% CI: -5.87 to -0.22) and forb cover had a relatively small but positive effect ($\beta_{forb} = 0.07$, 95% CI: -0.04 to 0.17) on Acrididae biomass (Figure 5). VOR was weakly supported as an explanatory variable ($\Delta AIC_c = 4.49$, $w_i = 0.07$) for Acrididae biomass as it was 10 times ($w_{sandsage} = 0.70 / w_{VOR} = 0.07$) less likely to be the best model. Parameter estimates from the VOR model indicated a relatively small and negative effect size that was not measurably different from 0 ($\beta_{VOR} = -0.48$, 95% CI: -1.64 to 0.68; Figure 5)

Discussion

Our study indicated a strong relationship between invertebrate biomass and areas of lesser prairie-chicken brood use. Because the 2 study sites varied in amounts of forb and shrub cover and invertebrate biomasses, we provided some evidence that greater invertebrate biomass at brood

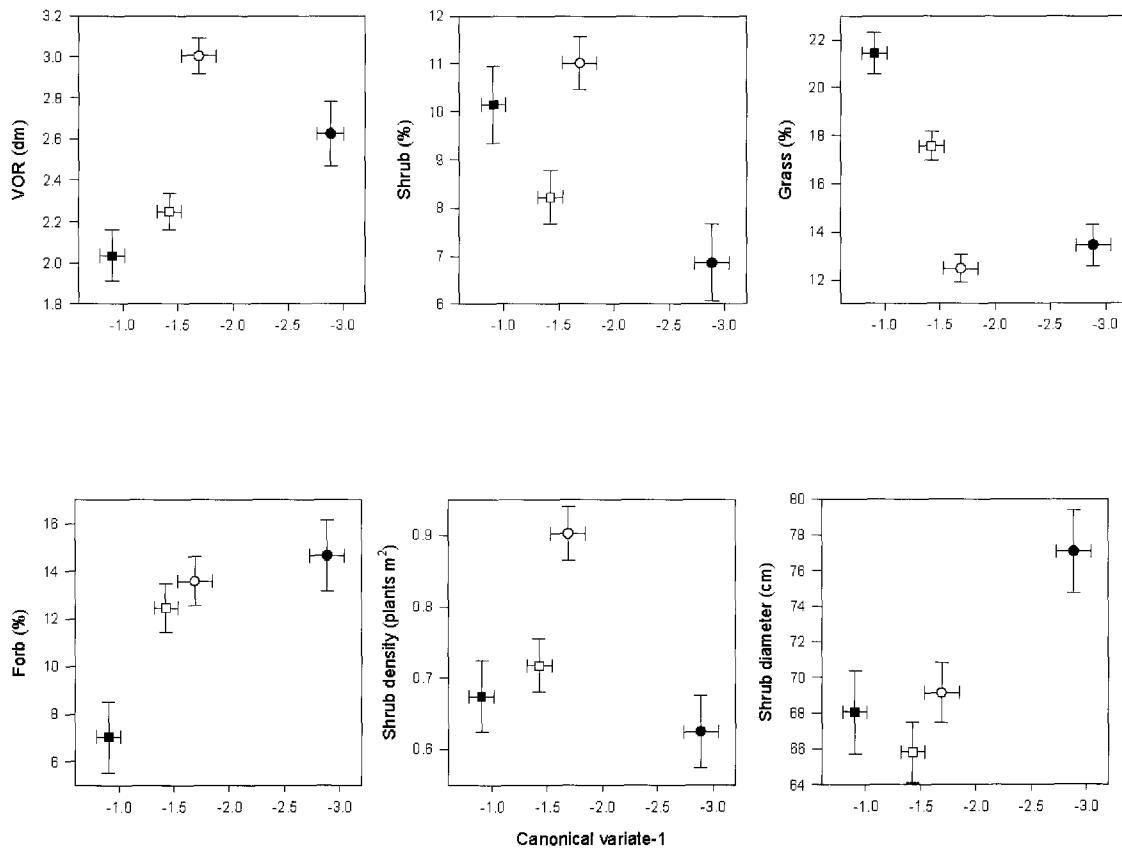


Figure 3. Mean canonical scores (± SE) plotted against mean vegetation variables (± SE) for lesser prairie-chicken brood use (o) and non-use areas (□) for Sites I (black) and II (white) from Finney County, Kansas 2001–2002.

Table 4. Candidate models for predicting invertebrate biomass with 3 habitat variables from 12 lesser prairie-chicken broods in Finney County, Kansas 2001–2002. Akaike Information Criteria corrected for small sample size was used for selection criteria (AIC_c), the model with the smallest AIC_c value is the model that best fits the data.

Model	K^a	$\log(\mathcal{L})^b$	AIC_c	ΔAIC_c	w_i^c
Density	3	-5.57	20.13	0.00	0.70
Forb	3	-7.12	23.25	3.12	0.15
VOR	3	-7.81	24.62	4.49	0.07
Density + VOR	4	-6.15	26.01	5.88	0.04
Density + Forb	4	-6.36	26.43	6.29	0.03
Forb + VOR	4	-7.22	28.14	8.01	0.01
Density + Forb + VOR	5	-6.79	33.58	13.45	0.00

^a K = number of parameters which includes the intercept, slope, and error and other covariates.

^b $\log(\mathcal{L}) = -0.5 \log(RSS / n)$, where RSS = residual sums of squares and $n = 12$ (Burnham and Anderson 1998).

^c The ratio of Akaike weights (w_i / w_j) between two models was used to quantify the relative degree that a pair of models was supported by the data.

areas may have been more important to habitat use than forb cover. Brood areas on Site II had markedly greater shrub cover and density compared to their paired non-use areas, and all areas on Site I. Conversely, forb cover was similar between brood and non-use areas on Site II but differed markedly within Site I. Both Acrididae and other invertebrate biomasses were greater at brood-use areas than non-use areas at both study sites, suggesting that this high-protein food source (Stiven 1961) likely was more important than vegetation type. However, vertical density of vegetation also was important,

as indicated by greater VORs at brood areas on both study sites. These measurements suggested that vegetation structure was more important to brood usage than vegetation type because brood areas had greater VORs than non-use areas regardless of the dominant cover type. Sandsage density was the best linear predictor of Acrididae biomass, with lower densities (0.2–0.4 plants m^2) having the greatest Acrididae biomass, but brood areas

with moderate sandsage densities (0.5–0.7 plants m^2) also had considerable Acrididae biomasses. Therefore, areas with an interspersed of low to moderate sandsage densities may provide habitat supporting a substantial invertebrate forage base. We did not examine the potential of non-linear relationships between vegetation and invertebrate biomass, because of our limited data. Identifying thresholds in such relationships can be important to managers and should be examined in future work. Our inference is somewhat limited because none of our data come from experimental manipu-

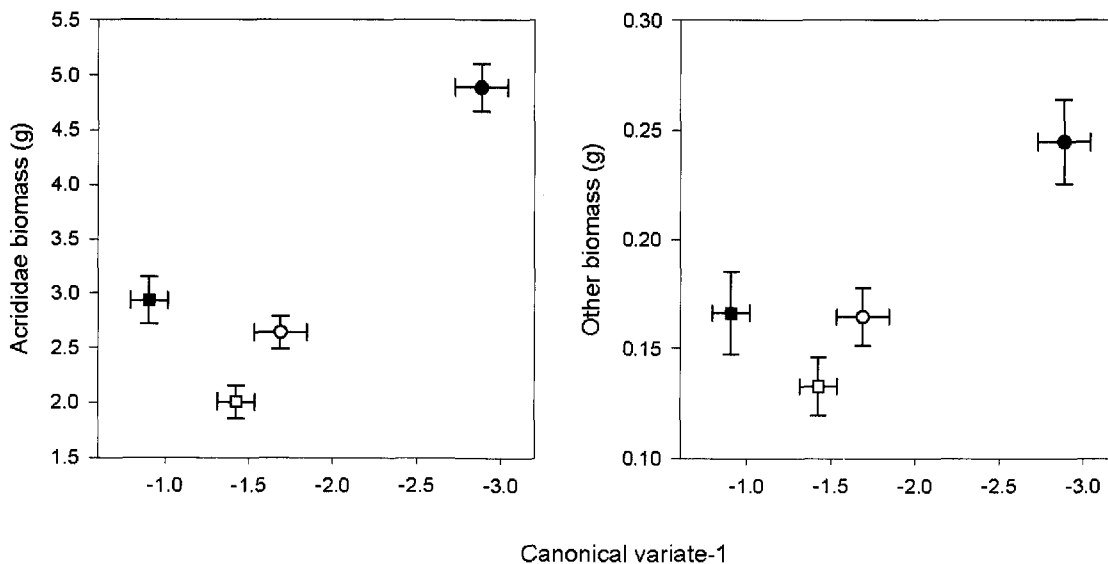


Figure 4. Mean canonical scores (\pm SE) plotted against invertebrate variables (\pm SE) for lesser prairie-chicken brood use (o) and non-use areas (\square) for Sites I (black) and II (white) from Finney County, Kansas 2001–2002.

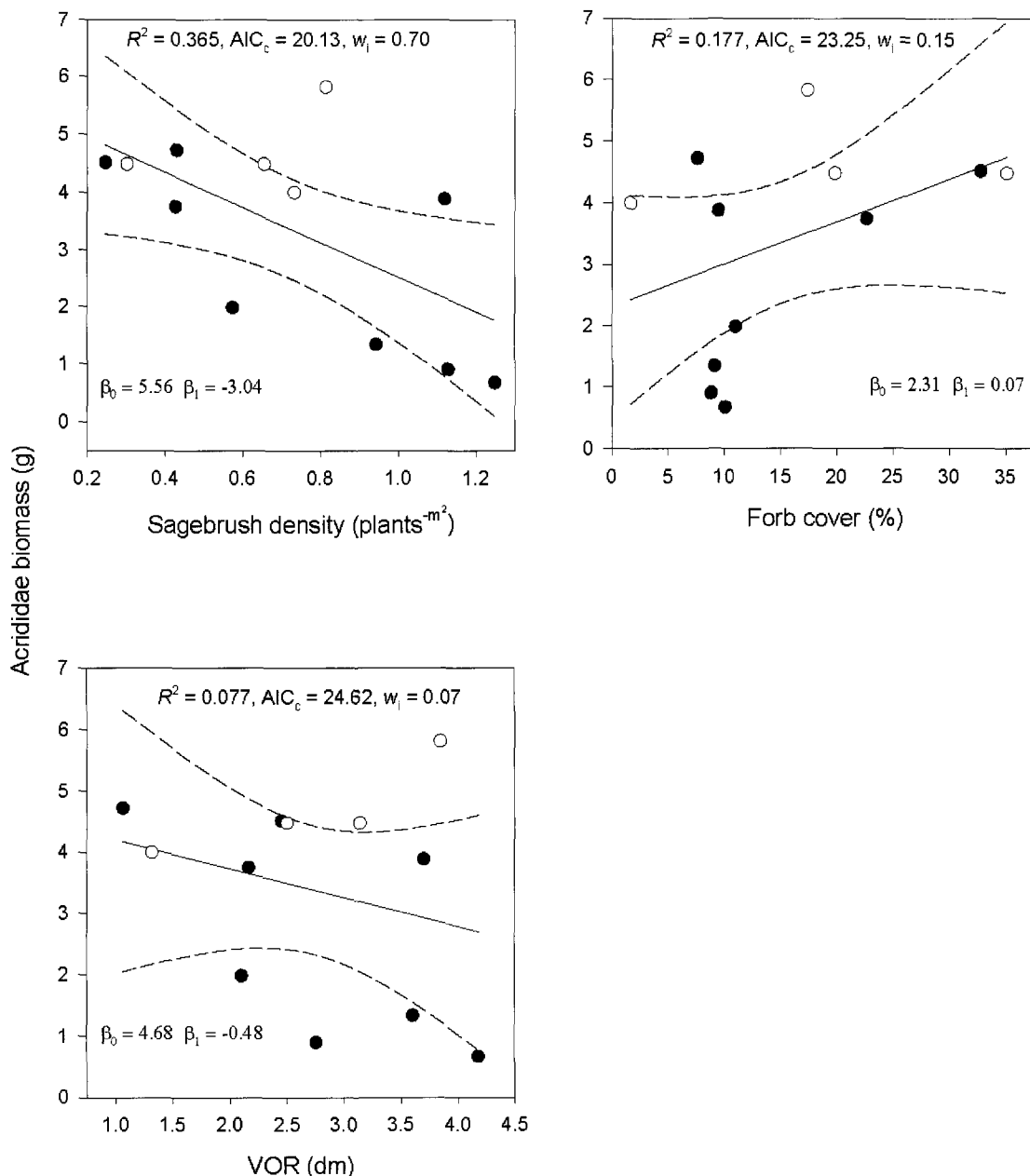


Figure 5. The best 3 regression models predicting Acrididae biomass from 12 lesser prairie-chicken broods in Sites I (black) and II (white) from Finney County, Kansas 2001–2002.

lations, and observed patterns are associations rather than cause-and-effect relationships.

Our findings support those of several studies on grouse broods that found important relationships between invertebrates and vegetation cover. Generally, grouse broods use sites with moderate canopy cover (i.e., shrub or woody cover) and taller herbaceous cover relative to the surrounding vegetation (Borset and Krafft 1973, Storch 1994, Baines

et al. 1996). Baines et al. (1996) suggested that taller vegetation, regardless of species or type, would yield greater abundances of invertebrates in black grouse (*Tetrao tetrix*) brood habitat. Given the demands of chick growth and survival (Park et al. 2001), we hypothesize that grouse broods are using areas preferentially based on invertebrate biomass and second on vertical density. Our study indicated that factors driving habitat use were not measura-

bly different during the sampling period, despite the fact that invertebrate biomass and plant phenology likely were changing markedly. Broods were consistently using areas with greater proportions of invertebrate biomass than non-use areas. Grass cover was inversely related to the probability of use. Areas managed to maximize grass cover are likely detrimental to brood growth and survival because of potential reductions in invertebrate biomass (Baines et al. 1996).

Chick body mass and survival varied markedly between our 2 study sites (Pitman 2003). A post hoc analysis of covariance on body mass (i.e., on the linear portion of the growth curve, 24 to 68 days post-hatch, described in Pitman et al. [2005a]) revealed that chicks captured on Site I ($n=10$) were possibly 50.8 g (95% CI = -47.1 to 148.9 g) heavier than chicks on Site II ($n=25$) from 24 to 68 days post-hatch. We suspect this potential difference in body mass of chicks likely was due to the greater invertebrate biomasses found on Site I compared to Site II. Additionally, Pitman (2003) reported that chick survival during the first 14 days of life was 60% and 44% for Sites I and II, respectively. Park et al. (2001) found that red grouse (*Lagopus lagopus scoticus*) chicks (<10 days post-hatch) survived better and had faster growth in areas of greater invertebrate biomass. Niewold (1990; as cited in Baines et al. 1996) documented reduced survival and growth for black grouse chicks in areas of poor invertebrate abundance. Similarly, greater sage-grouse (*Centrocercus urophasianus*) broods had increased survival rates in an area with greater forb and invertebrate abundance (Drut et al. 1994). Pitman (2003) documented similar patterns in chick survival from 14 to 60 days post-hatch on Site I (55%) and Site II (27%). Invertebrate biomass was steadily increasing on Site I during this period but had stabilized on Site II (Figure 2). These data further support the idea that greater invertebrate biomass may result in increases in chick survival.

Management implications

Generally, large-scale conversion of lesser prairie-chicken habitat has slowed over the last 20 years (Hagen et al. 2004). New Mexico currently is experiencing a surge in natural gas and oil exploration that likely will result in large losses in habitat. However, aside from New Mexico, the continued decline in population trends suggests that it is the

quality of the remaining habitats that are limiting lesser prairie-chicken populations from recovery (Hagen et al. 2004). Specifically, the quality of nesting and brood-rearing habitats can affect population size and persistence (Hagen 2003). Therefore identifying the characteristics of high-quality brood-habitats and management practices that promote such may greatly improve our chances to recover populations. Our study indicated that quality brood habitats were comprised of abundant invertebrates and may result in increased growth and survivorship of lesser prairie-chicken chicks. However, the abundance of invertebrates is dependent upon local vegetation, and management practices to increase this biomass likely will vary across lesser prairie-chicken range.

Large-scale controlled experiments are needed to identify best management practices that create and maintain optimal habitats for lesser prairie-chicken brood use. Management practices in sandsage prairie should be identified that increase invertebrate biomass, maintain $\geq 15\%$ forb cover, and maintain moderate plant height (2.5–3.0 dm). Experiments should be conducted to evaluate which stocking rates and grazing systems provide Acrididae biomass (Quinn and Walgenbach 1990) and canopy cover of forbs and grasses (Manely et al. 1997, Sims and Gillen 1999) most beneficial to lesser prairie-chicken broods. Management experiments should assess mechanical, chemical, and burning methods (Boyd and Bidwell 2001, Hagen et al. 2004) to increase the diversity of sandsage stand density. This might include thinning dense stands of sandsage ($> 8,000$ plants^{-ha}) to create a mosaic of nesting and brood-rearing habitats (Hagen et al. 2004). However, several patches of dense sandsage should remain because these are important to successful nesting (Pitman et al. 2005a).

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