

USING RADIO-TELEMETRY TO DETERMINE RANGE AND RESOURCE
REQUIREMENTS OF UPLAND SANDPIPERS AT AN EXPERIMENTALLY
MANAGED PRAIRIE LANDSCAPE

by

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ABSTRACT

The native grasslands of North America are highly fragmented, and remaining tracts are intensively managed for grazing. Loss of tallgrass prairie and changing land management practices has caused many grassland birds that rely on these areas for breeding to decline in population numbers. To investigate resource selection and area use requirements of the upland sandpiper, we outfitted birds with radio transmitters at the experimentally managed Konza Prairie Biological Station in northeast Kansas.

Two logistical challenges for wildlife telemetry projects are: minimizing the impact of radios on survival and movement, and optimizing the duration of transmitter attachment. We compared 4 methods of radio attachment for upland sandpipers under field conditions at breeding sites in tallgrass prairie. The daily probabilities of radio retention (DRR) for our 4 attachment methods were: 0.9992 (SE = 0.0005, $n = 85$) for a leg loop harness, 0.9801 (SE = 0.0099, $n = 11$) for radios glued to clipped feathers, 0.9627 (SE = 0.0085, $n = 25$) for radios glued directly to feathers and 0.8538 (SE = 0.0322, $n = 20$) for radios glued to plucked skin. The expected duration of radio attachment ranged from 1290 days for the leg loop harness, and 6 to 50 days for the glue attachment techniques. Survival rates of males (DSR = 0.9987, SE = 0.0009, $n = 53$) and females (DSR = 0.9988, SE = 0.0008, $n = 71$) were similar, and the probability of surviving the 90-day breeding season was about 0.90 in both sexes. We recommend attaching radios with glue to clipped feathers for short-term telemetry studies and a leg loop harness if longer retention is desired.

The unique landscape of Konza Prairie allowed us to investigate specific tallgrass management strategies, and their impact on the range and habitat requirements of a bird that relies on the prairie for breeding. We found that upland sandpipers have large home ranges during the breeding season (male: $\bar{X} = 199.0 \text{ ha} \pm 40.5 \text{ SE}$, $n = 21$, female: $\bar{X} = 247.7 \text{ ha} \pm 51.7 \text{ SE}$, $n = 23$). Male home ranges were twice as large during brood-rearing ($\bar{X} = 200.8 \text{ ha} \pm 69.1 \text{ SE}$, $n = 9$) than during the nesting period ($\bar{X} = 67.02 \text{ ha} \pm 11.84 \text{ SE}$, $n = 14$, $\chi^2_1 = 5.14$, $P = 0.023$). Upland sandpipers selected home range sites that had been burned the same spring ($n = 44$, $\chi^2_3 = 31.65$, $P < 0.001$), but did not show preference for certain habitat types within their home range ($\chi^2_3 = 1.49$, $P = 0.685$). During brood rearing upland sandpipers used sites with higher percentages of bare ground, herbaceous and short woody vegetation, and low amounts of vegetative litter.

Management strategies for the upland sandpiper should seek to preserve large contiguous tracts of tallgrass prairie that receive a heterogeneous mix of burning and grazing.

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I dedicate this thesis to my parents, DeWayne and Gloria, who have always been there for me, my sisters, Julie and Denise and my brother, Ed who all made sacrifices early in my life which have given me a life full of opportunity.

Chapter 1

Optimizing radio retention in free-living birds: a comparison of transmitter attachment techniques in the upland sandpiper

Tony W. Mong and Brett K. Sandercock

Abstract: Radio telemetry is a valuable technique in wildlife biology for obtaining information on animal survival and movements. Two logistical challenges for wildlife telemetry projects are minimizing the impacts of radios on survival and optimizing the duration of transmitter attachment. We compare 4 methods of radio attachment for upland sandpipers under field conditions at breeding sites in tallgrass prairie. We obtained robust estimates of radio retention and daily survival rates by using the ‘nest survival’ model of Program MARK, a general procedure for analysis of known fate data. A model with effects of attachment method only (S_{trt}) was the best fit to our radio retention data. The daily probabilities of radio retention (DRR) for our 4 attachment methods were 0.9992 (SE = 0.0005, $n = 85$) for a leg loop harness, 0.9801 (SE = 0.0099, $n = 11$) for radios glued to clipped feathers, 0.9627 (SE = 0.0085, $n = 25$) for radios glued directly to feathers and 0.8538 (SE = 0.0322, $n = 20$) for radios glued to plucked skin. The expected duration of radio attachment was 1290 days for the leg loop harness, and 6 to 50 days for the glue attachment techniques. Survival rates of males (DSR = 0.9987, SE = 0.0009, $n = 53$) and females (DSR = 0.9988, SE = 0.0008, $n = 71$) were similar, and the probability of surviving the 90-day breeding season was about 0.90 in both sexes. We recommend attaching radios with glue to clipped feathers for short-term telemetry studies and a leg loop harness if longer retention is desired. Use of the nest survival model in Program MARK allowed us to estimate daily retention and survival rates while

accounting for uncertainty in the date of transmitter loss and mortality. In the future, inclusion of additional covariates could be used to explore ecological factors that determine radio retention and survival rates.

Introduction

Radio telemetry is an important technique for gathering information on the movement patterns and survival rates of wildlife species (Millspaugh and Marzluff 2001). Two key issues in wildlife telemetry are: development of attachment techniques that do not affect the movement or survival of marked animals, and optimization of the duration of radio attachment. The two main techniques for attaching radios to shorebirds and songbirds have been glue (Rain 1978, Warnock and Warnock 1993) and body harnesses (Rappole and Tipton 1991, Sanzenbacher et al. 2000). Use of glue ensures that radios will be shed when feathers are molted, and short retention periods may facilitate recovery of expensive transmitters. Potential drawbacks to use of glue include the handling time required for adhesives to set, irritation of skin, and premature loss of radios (Schulz et al. 2001). Harnesses have the potential to allow long-term tracking of individuals throughout their annual cycle, but may be more intrusive if they cause entanglement, restrict movement of the limbs, impede growth or abrade the body surface (Keedwell 2001, Schulz et al. 2001, Bowman et al. 2002). Appropriate attachment techniques are of particular concern for small-bodied birds where the limits of battery size constrain radio life and signal strength.

Trials with captive shorebirds and songbirds have reported little or no behavioral changes when radios are attached with glue or harnesses (Sanzenbacher et al. 2000, Bowman and Aborn 2001, Wells et al. 2003, Woolnough et al. 2004). Studies under field

conditions have concluded that these same attachment techniques have little effect on demographic parameters. Kålås et al. (1989) and Hill and Talent (1990) used glue to attach transmitters to 2 shorebird species and found no adverse effects on fecundity or survival. Powell et al. (1998) found that the leg harness method did not affect return rates of wood thrush (*Hylocichla mustelina*). Estimates of retention rates for different radio attachment techniques are relatively rare. Schulz et al. (2001) compared retention rates for three different radio attachment techniques in a captive study of mourning doves (*Zenaida macroura*). Implanted radios and backpack harnesses had greater retention rates than glue methods, based on the percentage of transmitters still attached at the end of a 63-day study period.

Studies evaluating radio attachment techniques have used a variety of statistical procedures to estimate daily retention rates. Rohweder (1999) calculated ‘mean retention rate’ as the total duration of radio attachment for all individuals divided by total number of individuals. Other authors have used Kaplan-Meier non-parametric survival analyses (Woolnough et al. 2004). The ‘nest survival’ model of Program Mark was originally developed to estimate daily survival rates of nests where nest status and fate have been determined by systematic monitoring (Dinsmore et al. 2002).

The nest survival model is a general procedure, however, that can be applied to other types of known fate data, including radio retention and survival rates. The nest survival model is an improvement over mean retention rate, Mayfield (1975) and Kaplan-Meier (1958) models for 3 reasons: 1) it is possible to build models that allow retention rates to vary with time, 2) it permits inclusion of environmental and individual covariates, and 3) model selection can be conducted in an information theory framework by use of

Akaike's Information Criterion (AIC, Burnham and Anderson 2001). In this field study of upland sandpipers (*Bartramia longicauda*), we evaluated radio retention for 4 different transmitter attachment techniques, and estimated daily survival rates of males and females during the breeding season.

Upland sandpipers are long distant migrants that breed in the temperate grasslands of North America and winter on the Pampas flats of Argentina. Widespread population declines have led to the species being listed as threatened or endangered by at least 12 states, and as a species of special concern by an additional 10 states and provinces (Houston and Bowen 2001). During the breeding season, females lay a 4-egg clutch in a ground nest, both sexes incubate but only males attend the broods.

Our project is the first comprehensive telemetry study of upland sandpipers, and one of the few studies to estimate radio retention and daily survival for free-living shorebirds. One previous study used radio telemetry with upland sandpipers but marked only 2 birds (Ailes and Toepfer 1977). Robust estimates of radio retention will allow researchers to select radio attachment techniques that best meet their study goals.

Methods

Field methods

Fieldwork was conducted at Konza Prairie Biological Station (hereafter, 'Konza Prairie') during April to August of 2002 to 2004. Konza Prairie is a 3,487 ha tallgrass prairie preserve located in the Flint Hills region of northeastern Kansas (39° 05'N, 96° 34'W). Roosting upland sandpipers were captured at night using spotlights and a long-handled net. In 2002, blood samples were collected from the brachial wing vein and upland sandpipers were sexed with a molecular marker by a commercial lab (Zoogen

Inc., Davis, California, USA). Morphometric criteria for distinguishing males and females were developed from the subsample of known sex birds. In 2003 and 2004, birds were sexed by total body mass during the pre-laying period: males were < 160 g, whereas females were \geq 160 g (B.K. Sandercock, Kansas State University, unpublished data).

Radio transmitters (PD-2, ca. 3.8 g, Holohil Systems Ltd., Ontario, Canada) were mounted to the lower back of adult (AHY) sandpipers so that the radio was positioned over the synsacrum, behind the wings and above the uropygial gland. All radio-marked birds were then monitored until they shed the radio, died or left the site. Radio-marked birds were relocated with a vehicle mounted null-peak triangulation system fitted with a digital compass (Sailcomp[®] 103AC, KVH Industries Inc., Middletown, Rhode Island, Cox et al. 2002). Each sandpiper was relocated twice daily and six days a week for the duration of the breeding season. In addition to triangulation, we used portable receivers to walk up and flush birds every 1 to 5 days. Thus, the date a transmitter was dropped or a sandpiper was killed was usually known to within 2-3 days.

Gluing methods. We used three types of surface preparation and two types of glue to attach radio transmitters to sandpipers in 2002. In the 'glue/none' method, transmitters were glued directly to the feathers of the back using ethyl cyanoacrylate glue (Quik-tite[®], Perry et al. 1981). In the 'glue/clip' method, we clipped back feathers to a length of ~0.5 mm and then glued transmitters to the feather stubble with cyanoacrylate glue. In the 'glue/pluck' method, feathers were gently removed from a small area of the back and transmitters were glued directly to bare skin with cyanoacrylate glue. An additional 4 sandpipers had radios attached to bare skin with a hexane-based glue designed for attachment of colostomy products (Skin Bond[®]). All 4 of these birds shed

their radios within 1 to 7 days and were not considered further. Warnock and Warnock (1993) recommended use of a marine epoxy to attach radios to sandpipers but this product is no longer in commercial production.

Harness method. We used a modified version of a leg loop harness technique to attach radio transmitters to sandpipers in 2003 and 2004 (Rappole and Tipton 1991, Sanzenbacher et al. 2000). Radios were assembled with 3 transverse tubes through the epoxy resin surrounding the transmitter: one at the front and two at the back near the antenna (Figure 1A). We used elastic cord (Stretchrite[®], #3961, Rhode Island Textile Company,) that was 1 mm in diameter and initially cut to a harness length of 29.5 cm (~0.26 g). The harness was threaded through the tube at the front of the transmitter and anchored with knots on either side of the transmitter to prevent the transmitter from slipping to either side (Figure 1B). The remaining ends of the harness were threaded through the two tubes at the posterior end of the transmitter, with one elastic cord per tube running in opposite directions. Once the harnesses were threaded, we tied loose knots to create two large loops for the legs (Figure 1B).

To attach a transmitter to a sandpiper, the bird was held upright with both legs free. We slid one leg through a loop, and stretched the transmitter over the back until the bottom of the transmitter rested against the body. The bird was then rotated upside down, the transmitter was pulled snug across the back, and the opposite leg was placed through the second loop of the harness. The bird was returned to an upright position and the harness was tightened by pulling the ends of the harness loops until the harness was snug under the leg at the top of the femur and did not catch on the joint of the leg. Loose knots were then tied to hold the harness in place. Once both loops of the harness were snug, we

tested harness fit by pulling the transmitter up away from the back. A harness was judged to be secure if the transmitter could be raised 1-2 cm above the back of the upland sandpiper. If the gap was > 2 cm we tightened the harness and retested the transmitter fit. Once fit was judged satisfactory, we tightened knots, clipped excess harness material and placed one drop of cyanoacrylate glue on all knots to prevent unraveling or slippage.

Estimation of daily probability of radio retention

Survival model. The daily probability of radio retention (\hat{S} , hereafter ‘daily retention rate’ or ‘DRR’) was estimated using the ‘nest survival’ model (Dinsmore et al. 2002) in Program Mark (White and Burnham 1999). Originally developed for nest monitoring, this general model can be used to analyze other types of known fate data, but encounter histories must be coded in a particular format. Encounter histories for the radio retention analysis required five types of information: 1) the initial date of radio attachment (k), 2) the last date radio transmitter was checked and was known to be attached (l), this was either a sighting or movement of a radio signal while tracking a bird on foot, 3) the last date radio was checked (m), this was either the date a dropped radio was recovered or the last day a signal was recorded on the study site, 4) the fate of the transmitter (f), where 0 = radio was still attached, 1 = transmitter was dropped and recovered, and 5) the number of sandpipers (n) with this encounter history (Appendix 1). To transform our Julian date information into an acceptable format for the nest survival model, we set the date of first capture each year as $k = 1$ and calculated k , l and m relative to that date.

Model selection. Daily probability of radio retention was modeled as a function of attachment technique (trt) and day since marking (time). We expected that retention

rates might vary with technique and that rates of loss might be greater immediately after first marking or after some period of abrasion. Our global model (S_{trt^*t}) included both factors and an interaction term. We also fit a main effects model with no interaction term ($S_{\text{trt}+t}$), single factor models (S_{trt} , S_t), and a constant model (S_c). Model selection was based on the information theoretic approach, models with $\Delta\text{AIC}_c \leq 2$ were considered equally parsimonious (Burnham and Anderson 2001).

Goodness-of-fit tests are not available for the nest survival model in Program Mark. We conducted a sensitivity analysis by manually increasing the inflation factor (\hat{c}) from 1 to 6 by increments of 0.5. If there were no changes in model rankings across a range of \hat{c} -values, our conclusions should be robust to moderate levels of overdispersion.

Duration of radio retention. The expected duration of radio retention (\hat{E} , in days) was estimated as (Brownie et al. 1985: 208):

$$\hat{E} = -1 / \ln(\hat{S})$$

Estimation of daily survival

The ‘nest survival’ model was also used to estimate the daily probability of survival of radio-marked upland sandpipers during the summer breeding season. For this analysis, encounter histories were constructed with five types of information: the initial date of radio attachment (k), the last date the bird was known to be alive (l), the date that the bird was alive or discovered dead (m), the fate of the sandpiper (f) where 0 = survived and 1 = a mortality event, and the number of individuals with this encounter history (n , Appendix 2). The daily probability of survival (DSR) was estimated as described above. However, DSR was modeled as a function of sex (sex) and day since marking (time).

Two models were equally parsimonious, and we used the model averaging procedure in Program Mark to obtain overall parameter estimates (Burnham and Anderson 1998).

Results

In total, 138 upland sandpipers were radio-marked during our 3-year study. During 2002, 53 upland sandpipers received one of the 3 different glue treatment radio attachment methods. Three individuals were used twice in two separate treatments. Transmitters attached with glue were ~2.4% of mean body mass ($\bar{x} = 156$ g, SD = 24.6, $n = 53$). In 2003 and 2004, 85 sandpipers received the harness treatment method. Transmitters attached with harnesses were ~2.5% of the mean body mass ($\bar{x} = 167$ g, SD = 31.9, $n = 85$). Six radio-marked birds were never relocated after the date of initial capture. We presume these birds were passage migrants using Konza Prairie as a stopover site and did not include these individuals in our analyses of radio retention or daily survival.

Daily probability of radio retention. Five models were fit to the radio retention encounter histories (Table 1). A model with attachment technique only (S_{trt}) received virtually all of the support ($w_i > 0.99$, Table 1). Parameter estimates from model S_{trt} indicated that the harness treatment had the highest rate of daily transmitter retention rate, followed by the glue/clip, glue/none and glue/pluck methods (Table 2). The expected duration of attachment (\hat{E}) for the 4 attachment techniques ranged from a low of 7 days for the glue/pluck method to 1290 days for the harness method (Table 2). Radio transmitters were recovered from 2 sandpipers that were tagged in 2003 and recaptured on the study area in May 2004. Both sandpipers had carried the radio and harness for a full year during migratory movements from Kansas to wintering latitudes in South

America. Neither bird showed any evidence of feather or skin abrasion caused by prolonged transmitter attachment.

Daily probability of survival. Eight sandpipers dropped the transmitter within 24 hours of attachment and were excluded from the analyses of daily survival. In total, 124 ($n = 53$ males, $n = 71$ females) adult (AHY) upland sandpipers were included in the analyses of daily survival. Four mortality events were observed in 2002 and 2003 combined; no radio-marked birds were killed during the 2004 field season. Mortality events occurred at 3, 8, 29 and 39 days after radio attachment, and included $n = 1$ bird in the glue/clip treatment (male) and $n = 3$ birds in the harness treatment (2 females, 1 male). One individual was trampled at a nest site by bison, one individual was discovered cached in the nest of an eastern woodrat (*Neotoma floridana*), and cause of death for the remaining two birds was not determined. Models with a constant rate of daily survival (S_c) and a sex difference (S_{sex}) were an equally parsimonious fit to the data ($\Delta AIC \leq 2$, Table 1). Model-averaged parameters indicated that the daily and period survival rates of males and females were similar (Table 3). In both the radio retention analysis and the daily survival analysis, varying the inflation factor (\hat{c}) from 1 to 6 had no effect on model rankings. Thus, our results would be robust to substantial amounts of overdispersion.

Discussion

This study is the first comprehensive application of radio-telemetry technology to upland sandpipers, and the first to adapt the nest survival model of Program Mark for estimation of the probabilities of radio retention and daily survival. Our major results were two-fold: leg-harnesses yielded substantially higher rates of radio retention than

glue methods, and daily survival rates of upland sandpipers were high during the stationary breeding period. Robust estimates of radio retention rates and daily survival rates are scarce in the wildlife literature, making direct comparisons to results of previous studies difficult.

This is the first study to report retention rates for the leg harness method of radio attachment with free-living shorebirds. Comparative data are available for songbirds only. Doerr and Doerr (2002) and Woolnough et al. (2004) had difficulty estimating harness life/survival because most birds retained transmitters for the entire duration of the study, or until the transmitter battery died (Table 4). Estimation of daily retention rates allows estimation of projected harness life. Our estimate of 1290 days may be optimistic because our monitoring was limited to the stationary summer breeding period. Actual duration of harness retention may be shorter if the rate of wear or decay in harness materials increases over time. Nonetheless, at least two birds retained radios for at least 1 year.

Although radio retention rates for our harness method were considerably higher than methods using glue, attachment with glue might be useful under some circumstances. If the goals of a study are to gather detailed information needed for home range size estimates, to investigate resource selection information, or to track individuals for long seasonal periods then the harness method is the best method. However, if the goal of a study is to quickly locate nest sites or to track individuals for short periods of migration, then a gluing technique may be more cost effective.

The best rate and duration of radio retention among our glue techniques was obtained by clipping feathers on the back before attaching the radio with glue ($\hat{S} =$

0.9801, $\hat{E} = 50$ days; Table 2). Several studies have reported retention rates for radios attached with glue to shorebirds and passerines (Table 4). Warnock and Warnock (1993), Johnson et al. (1997) and Rohweder (1999) found that a glue/clip method yielded retention rates of 49, 30 and 31 days, respectively. Our results indicate that cyanoacrylate glue is a viable alternative to the marine epoxy used by Warnock and Warnock (1993).

In a captive study with European starlings, Woolnough et al. (2004) found that a glue/pluck method resulted in low radio retention rates of attachment after the first 5 days (Table 4). Our retention rate for the glue/plucking attachment method was 6 days (table 2), which is consistent with the 5 day period of radio attachment reported by Woolnough et al. (2004).

In conclusion, the nest survival model of Program MARK provides researchers with flexible options for analysis of known fate data. Here, we applied this model to evaluation of transmitter attachment techniques and daily survival of individuals. The main advantages of this model are that the exact date of transmitter loss or mortality is not necessary, daily rates are not assumed to be constant over time and the potential for determining the biological factors that can be attributed to different survival rates is greater because of the ability to add covariates to each individual record. The added advantage of allowing covariates would allow researchers to build models that assess impacts of different biological factors on radio retention or daily survival (Dinsmore et al. 2002). In the future, comparative analyses of radio retention should use the nest survival model to evaluate different attachment techniques in other species of wildlife.

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Table 1. Model results for the radio retention analysis and the daily survival analysis.

Analysis	Model	Deviance	K^a	AICc^b	Δ AICc	w_i^c
Retention	S_{trt}	219.8	4	227.8	0	1.00
	$S_{\text{trt}+t}$	173.3	81	339.4	111.6	0.00
	S_c	346.6	1	348.6	120.8	0.00
	S_t	295.6	78	455.4	227.6	0.00
	$S_{\text{trt}*t}$	148.3	312	837.1	609.4	0.00
Survival	S_c	61.7	1	63.7	0	0.73
	S_{sex}	61.7	2	65.7	2.0	0.27
	S_t	31.6	79	193.5	129.9	0.00
	$S_{\text{sex}+t}$	108.6	80	272.7	209.0	0.00
	$S_{\text{sex}*t}$	68.5	158	400.6	336.9	0.00

^a Number of parameters

^b Akaike's Information Criterion for small sample sizes

^c Akaike weight of model

Table 2. Estimates of daily retention rate (\hat{S}) and duration of radio retention (\hat{E} , days) for the 4 attachment techniques.

Treatment	<i>n</i>	\hat{S}	SE	95% CI	\hat{E}	SE	95% CI
Harness	85	0.9992	0.0005	0.9969, 0.9998	1290	0.1332	323, 5160
Glue/clip	11	0.9801	0.0099	0.9480, 0.9925	50	0.2166	19, 133
Glue/none	25	0.9627	0.0085	0.9421, 0.9762	26	0.2095	17, 41
Glue/pluck	20	0.8628	0.0338	0.7824, 0.9167	7	0.2952	4, 11

Table 3. Daily survival rate (\hat{S}) and period survival (\hat{B}) for the 90-day breeding season.

Sex	<i>n</i>	\hat{S}	SE	95% CI	\hat{B}	SE	95% CI
Female	71	0.9988	0.0008	0.9949, 0.9997	0.9006	0.0008	0.6582, 0.9742
Male	53	0.9987	0.0009	0.9954, 0.9997	0.8911	0.0009	0.6309, 0.9716

Table 4. Estimates of average duration of radio retention (\hat{E} , range or 95%CI) for glue (G) and harness (H) attachment techniques. We restricted our summary to studies of small-bodied species of birds (< 200 g), where radio-marked individuals were fully-grown and monitored under field conditions.

Group	Species	Attachment method	\hat{E} (days)	<i>n</i>	Source	
Shorebird	Upland sandpiper	G	clip	50 (19-133)	11	This study
	<i>Bartramia longicauda</i>		none	26 (17-41)	25	
			pluck	7 (4-11)	20	
	Dunlin	G	clip	>49	33	Warnock and Warnock 1993
	<i>Calidris alpine</i>					
	Western sandpiper	G	clip	>49	63	Warnock and Warnock 1993
	<i>Calidris mauri</i>					
	Piping plover	G	none	54 (36-68)	49	Drake et al. 2001
	<i>Charadrius melodus</i>					
	Eurasian golden-plover	G	clip/gauze	20 (2-48)	13	Whittingham 1996
<i>Pluvialis apricaria</i>						
Green sandpiper	G	none/gauze	>17 (3-35)	5	Smith et al. 1999	
<i>Tringa ochropus</i>						
Landbird	Shorebirds	G	clip	31 (19-55)	11	Rohweder 1999
	10 spp.		clip/gauze	29 (15-49)	15	
			none/gauze	19 (11-23)	5	
	Northern cardinal	G	clip/gauze	5 (2-14)	16	Johnson et al. 1991
	<i>Cardinalis cardinalis</i>					
	Blue jay	G	clip/gauze	20 (1-36)	24	Johnson et al. 1991
<i>Cyanocitta cristata</i>						

	Kirtland's Warbler <i>Dendroica kirtlandii</i>	G	clip/gauze	10 (3-25)	7	Sykes et al. 1990
	Barn swallow <i>Hirundo rustica</i>	G	pluck	2 (1-4)	5	Brigham 1989
	Wood thrush <i>Hylocichla mustelina</i>	G	pluck/gauze	> 40	46	Winker et al. 1990
	Brown-headed cowbird <i>Molothrus ater</i>	G	clip/gauze	12 (3-24)	60	Raim 1978
	Noisy friarbird <i>Philemon corniculatus</i>	G	clip	7 (2-12)	4	Ford et al. 2000
	Honeyeaters <i>Phylidonyris</i> spp.	G	clip/gauze	5 (1-23)	23	O'Connor et al. 1987
	Red-cockaded woodpecker <i>Picoides borealis</i>	G	clip/gauze	10 (5-14)	3	Nesbitt et al. 1978
	Brown thrasher <i>Toxostoma rufum</i>	G	clip/gauze	16 (5-32)	15	Johnson et al. 1991
	American robin <i>Turdus migratorius</i>	G	clip/gauze	19 (2-49)	59	Johnson et al. 1991
Shorebird	Upland sandpiper <i>Bartramia longicauda</i>	H	leg loop	1290 (323-5160)	85	This study
	American woodcock <i>Scolopax minor</i>	H	wing loop	>31	256	Krementz et al. 1994
	American woodcock <i>Scolopax minor</i>	H	wing loop	>26	25	Krementz and Berdeen 1997
Landbird	Brown treecreeper <i>Climacteris picumnus</i>	H	leg loop	149 (28-280)	13	Doerr and Doerr 2002

Wood thrush <i>Hylocichla mustelina</i>	H	leg loop	270-630	148	Powell et al. 1998
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^a G= glue, H = harness, clip = feathers were prepared by clipping ~2 mm, gauze = gauze pad glued to radio or bird, none = no preparation, pluck = radios glued to bare skin after feathers were plucked.

Figure 1. A) Side view of unassembled transmitter and B) top view of assembled transmitter used in this study. Radios were 2.5 cm x 1.2 cm x 0.6 cm with a 20 cm whip antenna. The lateral tubes for harness material were 2 mm in diameter.

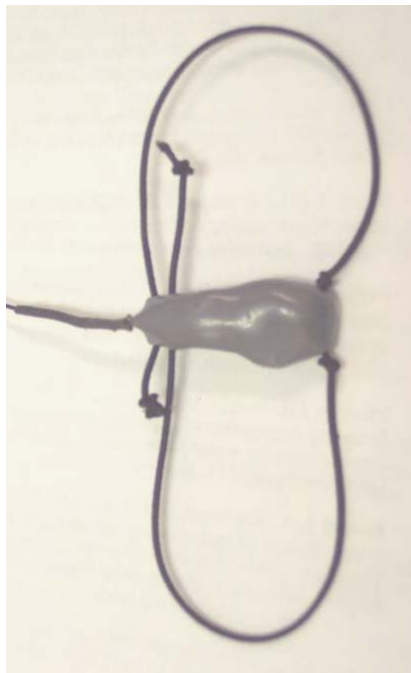
A.



Tubes at the back

Tube at the front

B.



Appendix 1. Input file for radio retention analysis in Program Mark. Note: an “*n*” of two indicates that more than one bird had that capture history, but due to space constraints only one band number appears in the “ID” column.

ID	k	l	m	f	n	ID	k	l	m	f	n
nest survival group=1 (glue/clip)						nest survival group=4 (harness)					
/*28393*/	18	21	21	0	1	/*28406*/	24	30	30	0	1
/*28389*/	17	23	23	0	1	/*28405*/	24	30	31	1	1
/*28448*/	44	50	50	0	1	/*28412*/	28	31	37	1	1
/*28473*/	53	60	64	1	1	/*28411*/	28	37	38	1	1
/*28449*/	45	55	62	1	1	/*28401*/	24	30	37	1	1
/*28416*/	30	46	49	1	1	/*28413*/	29	29	44	1	1
/*28388*/	30	49	49	0	1	/*28396*/	21	36	43	1	1
/*28391*/	17	44	44	0	1	/*28400*/	23	43	49	1	1
/*28392*/	18	31	50	1	1	nest survival group=2 (glue/none)					
/*28415*/	29	64	64	0	1	/*28360*/	1	1	2	1	2
/*28417*/	31	72	72	0	1	/*28380*/	10	11	11	0	1
nest survival group=2 (glue/none)						/*28383*/	10	10	14	1	1
/*28360*/	1	1	2	1	2	/*28368*/	7	7	13	1	1
/*28380*/	10	11	11	0	1	/*28372*/	8	8	14	1	1
/*28383*/	10	10	14	1	1	/*28369*/	7	11	16	1	1
/*28368*/	7	7	13	1	1	/*28373*/	8	15	18	1	1
/*28372*/	8	8	14	1	1	/*28376*/	9	13	19	1	1
/*28369*/	7	11	16	1	1	/*28366*/	4	17	17	0	1
/*28373*/	8	15	18	1	1	/*28374*/	9	21	23	1	1
/*28376*/	9	13	19	1	1	/*28363*/	2	7	17	1	1
/*28366*/	4	17	17	0	1	/*28370*/	7	20	23	1	1
/*28374*/	9	21	23	1	1	/*28367*/	4	14	21	1	1
/*28363*/	2	7	17	1	1	/*28382*/	10	28	28	0	1
/*28370*/	7	20	23	1	1	/*28361*/	1	2	24	1	1
/*28367*/	4	14	21	1	1	/*28381*/	10	22	33	1	1
/*28382*/	10	28	28	0	1	/*28384*/	10	38	38	0	1
/*28361*/	1	2	24	1	1	/*28385*/	11	11	53	1	1
/*28381*/	10	22	33	1	1	/*28364*/	3	49	58	1	1
/*28384*/	10	38	38	0	1	/*28371*/	8	60	64	1	1
/*28385*/	11	11	53	1	1	/*28378*/	9	64	66	1	1
/*28364*/	3	49	58	1	1	/*28375*/	9	66	66	0	1
/*28371*/	8	60	64	1	1	/*28365*/	3	78	78	0	1
/*28378*/	9	64	66	1	1	/*28379*/	9	31	35	1	1
/*28375*/	9	66	66	0	1	nest survival group=3 (glue/pluck)					
/*28365*/	3	78	78	0	1	/*28402*/	24	24	25	1	1
/*28379*/	9	31	35	1	1	/*28449*/	67	67	70	1	1
nest survival group=3 (glue/pluck)						/*28404*/	24	24	28	1	1
/*28402*/	24	24	25	1	1	/*28383*/	30	31	34	1	1
/*28449*/	67	67	70	1	1	/*28407*/	25	28	30	1	1
/*28404*/	24	24	28	1	1	/*28407*/	29	31	34	1	1
/*28383*/	30	31	34	1	1	/*28398*/	23	24	29	1	2
/*28407*/	25	28	30	1	1	/*28406*/	24	30	30	0	1
/*28407*/	29	31	34	1	1	/*28405*/	24	30	31	1	1
/*28398*/	23	24	29	1	2	/*28412*/	28	31	37	1	1
/*28406*/	24	30	30	0	1	/*28411*/	28	37	38	1	1
/*28405*/	24	30	31	1	1	/*28401*/	24	30	37	1	1
/*28412*/	28	31	37	1	1	/*28413*/	29	29	44	1	1
/*28411*/	28	37	38	1	1	/*28396*/	21	36	43	1	1
/*28401*/	24	30	37	1	1	/*28400*/	23	43	49	1	1
/*28413*/	29	29	44	1	1	nest survival group=4 (harness)					
/*28396*/	21	36	43	1	1	/*28520*/	10	11	11	0	1
/*28400*/	23	43	49	1	1	/*28661*/	59	60	60	0	1
nest survival group=4 (harness)						/*28510*/	8	10	11	1	1
/*28520*/	10	11	11	0	1	/*28711*/	16	19	19	0	1
/*28661*/	59	60	60	0	1	/*28550*/	16	20	20	0	1
/*28510*/	8	10	11	1	1	/*28713*/	16	22	22	0	1
/*28711*/	16	19	19	0	1	/*28429*/	17	23	23	0	1
/*28550*/	16	20	20	0	1	/*28726*/	19	25	25	0	1
/*28713*/	16	22	22	0	1	/*28730*/	20	28	28	0	1
/*28429*/	17	23	23	0	1	/*28566*/	21	29	29	0	1
/*28726*/	19	25	25	0	1	/*28547*/	16	26	26	0	1
/*28730*/	20	28	28	0	1	/*28705*/	13	24	24	0	1
/*28566*/	21	29	29	0	1	/*28722*/	19	30	30	0	1
/*28547*/	16	26	26	0	1	/*28498*/	12	24	24	0	1
/*28705*/	13	24	24	0	1	/*28700*/	13	25	25	0	1
/*28722*/	19	30	30	0	1	/*28411*/	18	30	30	0	1
/*28498*/	12	24	24	0	1	/*28563*/	20	32	32	0	1
/*28700*/	13	25	25	0	1	/*28567*/	22	34	34	0	1
/*28411*/	18	30	30	0	1	/*28549*/	16	29	29	0	1
/*28563*/	20	32	32	0	1	/*28718*/	18	31	31	0	1
/*28567*/	22	34	34	0	1	/*28735*/	21	34	34	0	2
/*28549*/	16	29	29	0	1	/*28639*/	55	70	70	0	1
/*28718*/	18	31	31	0	1	/*28691*/	10	26	26	0	1
/*28735*/	21	34	34	0	2	/*28530*/	14	30	30	0	1
/*28639*/	55	70	70	0	1	/*28502*/	14	31	31	0	1
/*28691*/	10	26	26	0	1	/*28551*/	17	34	34	0	1
/*28530*/	14	30	30	0	1	/*28556*/	19	36	36	0	1
/*28502*/	14	31	31	0	1	/*28351*/	10	31	31	0	1
/*28551*/	17	34	34	0	1	/*28736*/	24	45	45	0	1
/*28556*/	19	36	36	0	1	/*28767*/	47	69	69	0	1
/*28351*/	10	31	31	0	1	/*28733*/	21	44	44	0	1
/*28736*/	24	45	45	0	1	/*28741*/	29	52	52	0	1
/*28767*/	47	69	69	0	1	/*28525*/	10	34	34	0	2
/*28733*/	21	44	44	0	1	/*28699*/	13	40	40	0	1
/*28741*/	29	52	52	0	1	/*28615*/	50	79	79	0	1
/*28525*/	10	34	34	0	2	/*28569*/	22	53	53	0	1
/*28699*/	13	40	40	0	1						
/*28615*/	50	79	79	0	1						
/*28569*/	22	53	53	0	1						

ID	<i>k</i>	<i>l</i>	<i>m</i>	<i>f</i>	<i>n</i>
/*28527*/	13	45	45	0	2
/*28725*/	20	52	52	0	1
/*28571*/	23	56	56	0	1
/*28376*/	14	48	48	0	1
/*28553*/	18	52	52	0	1
/*28562*/	20	54	54	0	1
/*28538*/	15	50	50	0	1
/*28369*/	13	49	49	0	1
/*28715*/	16	52	52	0	1
/*28734*/	21	57	57	0	1
/*28724*/	19	56	56	0	1
/*28717*/	18	56	56	0	2
/*28720*/	19	57	57	0	1
/*28516*/	9	48	48	0	1
/*28531*/	14	53	53	0	1
/*28554*/	19	58	58	0	1
/*28732*/	20	59	59	0	1
/*28508*/	8	47	48	1	1
/*28432*/	14	55	55	0	1
/*28580*/	34	76	76	0	1
/*28565*/	21	64	64	0	1
/*28570*/	22	65	65	0	1
/*28698*/	20	64	64	0	1
/*28710*/	15	60	60	0	1
/*28737*/	24	70	70	0	1
/*28703*/	13	62	62	0	1
/*28370*/	10	60	60	0	1
/*28386*/	13	64	64	0	2
/*28716*/	16	70	70	0	1
/*28503*/	13	68	68	0	1
/*28709*/	15	70	70	0	1
/*28568*/	22	78	78	0	1
/*28558*/	19	76	76	0	1
/*28564*/	21	78	78	0	1
/*28560*/	20	78	78	0	1
/*28492*/	11	70	70	0	1
/*28537*/	15	74	74	0	2
/*28552*/	17	76	76	0	1
/*28543*/	16	78	78	0	1
/*28534*/	15	78	78	0	1
/*28513*/	9	78	78	0	1

Appendix 2. Input file for survival analysis in Program Mark. Note: an “*n*” of 2 indicates that more than one bird had that capture history, but due to space constraints only one band number appears in the “ID” column.

ID	k	l	m	f	n	ID	k	l	m	f	n
nest survival group=1 (males)											
/*28393*/	18	21	22	1	1	/*28386*/	13	64	64	0	1
/*28448*/	44	50	50	0	1	/*28693*/	13	64	64	0	1
/*28473*/	53	60	60	0	1	/*28716*/	16	70	70	0	1
/*28449*/	45	55	55	0	1	/*28503*/	13	68	68	0	1
/*28416*/	30	46	46	0	1	/*28564*/	21	78	78	0	1
/*28392*/	18	31	31	0	1	/*28560*/	20	78	78	0	1
/*28415*/	29	64	64	0	1	/*28492*/	11	70	70	0	1
/*28417*/	31	72	72	0	1	/*28537*/	15	74	74	0	2
/*28380*/	10	11	11	0	1	/*28534*/	15	78	78	0	1
/*28373*/	8	15	15	0	1	nest survival group=2 (females)					
/*28366*/	4	17	17	0	1	/*28389*/	17	23	23	0	1
/*28370*/	7	20	20	0	1	/*28388*/	30	49	49	0	1
/*28367*/	4	14	14	0	1	/*28391*/	17	44	44	0	1
/*28381*/	10	22	33	0	1	/*28369*/	7	11	11	0	1
/*28378*/	9	64	64	0	1	/*28376*/	9	13	13	0	1
/*28375*/	9	66	66	0	1	/*28374*/	9	21	21	0	1
/*28379*/	9	31	31	0	1	/*28363*/	2	7	7	0	1
/*28383*/	30	31	34	0	1	/*28382*/	10	28	28	0	1
/*28407*/	25	28	28	0	1	/*28361*/	1	2	24	0	1
/*28406*/	24	30	30	0	1	/*28384*/	10	38	38	0	1
/*28427*/	35	38	38	0	1	/*28364*/	3	49	49	0	1
/*28661*/	59	60	60	0	1	/*28371*/	8	60	60	0	1
/*28429*/	17	23	23	0	1	/*28365*/	3	78	78	0	1
/*28730*/	20	28	28	0	1	/*28398*/	23	24	24	0	1
/*28547*/	16	26	26	0	1	/*28397*/	23	24	24	0	1
/*28498*/	12	24	24	0	1	/*28405*/	24	30	30	0	1
/*28639*/	55	70	70	0	1	/*28412*/	28	31	31	0	1
/*28530*/	14	30	30	0	1	/*28376*/	42	49	49	0	1
/*28502*/	14	31	31	0	1	/*28411*/	28	37	37	0	1
/*28767*/	47	69	69	0	1	/*28401*/	24	30	30	0	1
/*28699*/	13	40	40	0	1	/*28396*/	21	36	36	0	1
/*28615*/	50	79	80	1	1	/*28400*/	23	43	43	0	1
/*28569*/	22	53	53	0	1	/*28520*/	10	11	11	0	1
/*28725*/	20	52	52	0	1	/*28510*/	8	10	10	0	1
/*28571*/	23	56	56	0	1	/*28711*/	16	19	19	0	1
/*28554*/	19	58	58	0	1	/*28550*/	16	20	20	0	1
/*28580*/	34	76	76	0	1	/*28713*/	16	22	22	0	1
/*28565*/	21	64	64	0	1	/*28726*/	19	25	25	0	1
/*28570*/	22	65	65	0	1	/*28566*/	21	29	30	1	1
/*28698*/	20	64	64	0	1	/*28705*/	13	24	24	0	1
/*28710*/	15	60	60	0	1	/*28722*/	19	30	30	0	1
/*28737*/	24	70	70	0	1	/*28700*/	13	25	25	0	1
/*28703*/	13	62	62	0	1	/*28411*/	18	30	30	0	1
/*28370*/	10	60	60	0	1	/*28563*/	20	32	32	0	1
						/*28567*/	22	34	34	0	1

ID	<i>k</i>	<i>l</i>	<i>m</i>	<i>f</i>	<i>n</i>
/*28549*/	16	29	29	0	1
/*28718*/	18	31	31	0	1
/*28735*/	21	34	34	0	1
/*28729*/	21	34	34	0	1
/*28691*/	10	26	26	0	1
/*28551*/	17	34	34	0	1
/*28556*/	19	36	36	0	1
/*28351*/	10	31	31	0	1
/*28736*/	24	45	45	0	1
/*28733*/	21	44	44	0	1
/*28741*/	29	52	52	0	1
/*28525*/	10	34	34	0	2
/*28527*/	13	45	45	0	1
/*28701*/	13	45	45	0	1
/*28376*/	14	48	48	0	1
/*28553*/	18	52	52	0	1
/*28562*/	20	54	54	0	1
/*28538*/	15	50	50	0	1
/*28369*/	13	49	49	0	1
/*28715*/	16	52	52	0	1
/*28734*/	21	57	57	0	1
/*28724*/	19	56	56	0	1
/*28717*/	18	56	56	0	1
/*28719*/	18	56	56	0	1
/*28720*/	19	57	57	0	1
/*28516*/	9	48	48	0	1
/*28531*/	14	53	53	0	1
/*28732*/	20	59	59	0	1
/*28508*/	8	47	48	1	1
/*28432*/	14	55	55	0	1
/*28709*/	15	70	70	0	1
/*28568*/	22	78	78	0	1
/*28558*/	19	76	76	0	1
/*28552*/	17	76	76	0	1
/*28543*/	16	78	78	0	1
/*28513*/	9	78	78	0	1

Chapter 2

Resource Selection and Range Requirements of Upland Sandpipers at an Experimentally Managed Prairie Landscape

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Abstract: The native grasslands of central North America are highly fragmented, and most remaining tracts are intensively managed for grazing. Loss of tallgrass prairie and changing land management practices have caused many grassland birds that rely on these areas for breeding to decline in population numbers. The upland sandpiper breeds exclusively in the grasslands of the U.S. and Canada and has been recognized as an indicator of tallgrass prairie health. We used radio telemetry to gather information on area use and resource selection for upland sandpipers at Konza Prairie Biological Station in Northeast Kansas. Konza Prairie, located in the Flint Hills of Kansas, is divided into 60 different experimental units that receive combinations of prescribed burning and grazing treatments that have been managed for 20 years. This unique landscape allowed us to investigate specific tallgrass management strategies, and their impact on the range and habitat requirements of a bird that relies on the prairie for breeding. We found that upland sandpipers have large home ranges during the breeding season (male: $\bar{X} = 199.0$ ha \pm 40.5 SE, $n = 21$, female: $\bar{X} = 247.7$ ha \pm 51.7 SE, $n = 23$). Males provided most care to young post hatching and had home ranges that were twice as large during brood-rearing ($\bar{X} = 200.8$ ha \pm 69.1 SE, $n = 9$) than during the nesting period, ($\bar{X} = 67.02$ ha \pm 11.84 SE, $n = 14$, $\chi^2_1 = 5.14$, $P = 0.023$). Upland sandpipers selected home range sites comprised of areas that had been burned the same spring ($n = 44$, $\chi^2_3 = 31.65$, $P <$

0.001), but did not show preference for certain habitat types within their home range ($\chi^2_3 = 1.49, P = 0.685$). We also found that upland sandpiper were using sites with higher percentages of bare ground, herbaceous and short woody vegetation, and low amounts of vegetative litter. Management strategies for the upland sandpiper should seek to preserve large contiguous tracts of tallgrass prairie that receive a heterogeneous mix of burning and grazing intensities.

Introduction

Grasslands were once the largest biome in North America but because of over-grazing, fragmentation and conversion to row crops and non-native grasses, as much as 99% of the original grasslands have been lost (Samson and Knopf 1994). Habitat loss and fragmentation, in addition to changes in land management practices, have led to marked declines in population numbers of grassland birds (Samson and Knopf 1994, Vickery and Herkert 2001, Brennan and Kuvlesky 2005).

Within the grassland biome, tallgrass prairies have suffered the greatest loss. For example, in Iowa the amount of historic tallgrass prairie is thought to have been over 12 million hectares and as of 1994 there was only a little over 12 thousand hectares remaining (Samson and Knopf 1994). Kansas has a relatively high percentage of tallgrass prairie remaining (27.4%) when compared to other Midwestern states (Samson and Knopf 1994). Most remaining tallgrass prairie is located within the Flint Hills ecoregion of eastern Kansas (Samson and Knopf 1994, Robbins et al. 2002).

Although Kansas has a large amount of contiguous tallgrass prairie remaining, these grasslands are not unaffected by human activities or alteration. The majority of the remaining tallgrass prairie in Kansas is impacted by cattle grazing and prescribed burning

administered by private landowners (Knapp et al. 1999). There are three main grazing management practices applied to the Flint Hills region: year-round, season-long and early intensive. Year-round grazing consist of cow-calf operations and usually burns conducted every 2-3 years. Season-long grazing consists of steer grazing from May to mid-October and annually burned. Early intensive grazing includes burning tallgrass prairie annually and stocking steers at high densities from May to mid-July. Over the past 25 years, there has been a diversification in the range land management from a majority of the grazing practices being year-round to a mix of all three types. Increasing the amount of tallgrass prairie burned annually and grazing intensity can cause a shift to a more homogenous landscape (Collins 1992, Hartnett et al. 1996, Knapp et al. 1999, Collins 2000), and may be a factor contributing to declines in grassland bird species.

To best manage the remaining tracts of tallgrass prairie, Vickery and Herkert (2001) suggested gathering baseline information on management strategies and the resulting habitat structure selected by breeding grassland birds. Management decisions based on partial or incomplete data can cause management practices to be ineffective or detrimental to grassland bird populations (Murphy 2003, Dinsmore et al. 2003).

The upland sandpiper (*Bartramia longicauda*) is a long distant migrant that breeds exclusively in the grasslands of the United States and Canada (Houston and Bowen 2001). This species is sensitive to habitat fragmentation but has been observed using a variety of grassland habitats subjected to many different grazing and burning practices (Dechant et al. 1999, Houston and Bowen 2001). These 2 attributes make the upland sandpiper a candidate to be considered an indicator species of healthy grasslands. For example, Kantrud and Kologiski (1983) consider the upland sandpiper to be an

indicator species for native prairies in the Dakota region, along with Baird's Sparrow (*Ammodramus bairdii*) and Sprague's Pipit (*Anthus spragueii*).

Previous studies have found that upland sandpipers feed in short vegetation, nest in taller vegetation and use vegetation of various heights to raise broods, with no apparent selection or avoidance of grazed areas (Dechant et al. 1999, Houston et al. 2001). In Kansas, upland sandpipers were more abundant in annually burned grazed and ungrazed grasslands than conservation reserve program (CRP) lands (Zimmerman 1993, Klute et al. 1997).

Many studies have found that upland sandpipers are sensitive to habitat fragmentation (Dechant et al. 1999, Winter and Faaborg 1999). The area requirements of the upland sandpiper have been most commonly delineated through correlations of patch size and abundance. In most instances, upland sandpipers are not encountered on patches of grasslands less than 30 ha in size (Dechant et al. 1999, Johnson and Igl 2001). Home range or territory size of unmarked birds has been estimated to be between 8 ha (Wiens 1969) and 85 ha (Ailes and Toepfer 1977).

Although many different studies have investigated upland sandpipers and their habitat associations, all of the current resource selection and habitat use information for upland sandpipers relies entirely on observations of foraging or nesting birds. Habitat association studies that rely on physical observations of individuals, especially cryptically-colored birds, may be biased in their conclusions (Wagner 1981, Balph and Balph 1983). Rather than collecting data on all habitats used, past studies may only have been collecting data on the subset habitats that permit visual detections of upland sandpipers.

In order to fully understand the resource requirements of the upland sandpiper, it is imperative to collect unbiased data. Radio telemetry is a powerful tool that allows researchers to collect unbiased data that do not require visual confirmation of an animal location (Millspaugh and Marzluff 2001, McDonald and McDonald 2002). Major advances have been made in the technology of radio telemetry equipment, including development of tiny radio transmitters that are small enough to attach to small to medium sized birds and have enough battery power to last an entire breeding season (Millspaugh and Marzluff 2001) and improved attachment techniques (Sanzenbacher et al. 2000).

Ailes and Toepfer (1977) attached radio transmitters to 2 individuals in a mated pair of upland sandpipers during the nest incubation period. From this limited sample, they determined that the home range sizes were 8.5 ha and 85.6 ha for the male and female respectively. In order to make generalizations about the home range size and area requirements of the upland sandpiper a larger sample size and a sound study design is required.

We used radio telemetry to study upland sandpipers at the Konza Prairie Biological Station (hereafter, Konza Prairie) in northeast Kansas. Konza Prairie consists of 60 experimental watershed units (average size = 60 ha) that have been subjected to different fire and grazing treatments since 1980 (Knapp et al. 1998; 1999). The mosaic of different experimental units permits use of a different approach towards describing resource use of upland sandpipers. Rather than focusing on resources being used by sandpipers in the experimental landscape, we were able to examine and use practices being applied to the landscape, and the subsequent selection of various fire and grazing treatments by upland sandpipers. Understanding how management decisions affect space

use by species utilizing remaining tracts of tallgrass prairie will provide managers better information regarding land use practices for these areas (Collins 2000, Fuhlendorf and Engle 2004).

The objectives of this study were to use radio telemetry: 1) to quantify area requirements in an experimental landscape that contains a mosaic of different tallgrass prairie habitats created by different combinations of grazing and prescribed fire, and 2) to quantify resource selection based on time since last burn and grazing treatments.

Methods

Study Site

This study was conducted during April to July of 2003 and 2004 at the Konza Prairie Biological Station (hereafter Konza Prairie), a 3,487 ha tallgrass prairie preserve located in the Flint Hills of northeastern Kansas (39° 05'N, 96° 34'W). Konza Prairie is part of the Long-term Ecological Research (LTER) network supported by the National Science Foundation. The field site is effectively an experimental landscape because it is subdivided into 60 experimental units (\bar{X} size = 55.4 ha \pm 44.7 SD, range = 3.4 ha, 226.3 ha) that receive different management applications. Each experimental unit is subjected to a specific combination of 1 of 5 prescribed burning (1, 2, 4, 10, or 20 year burning intervals) and 1 of 3 grazing treatments (grazed by bison *Bison bison*, cattle *Bos taurus* or ungrazed). Each of these different combinations is replicated across the biological station. Most units are burned in April, but a few units are burned at different times of the year or have had a change in fire interval. Experimental units are managed individually and are separated by boundaries that are maintained year round by mowing.

The vegetation of Konza Prairie is predominantly native tallgrass or bluestem prairie, dominated by a matrix of perennial, warm-season C₄ grasses including: big bluestem (*Andropogon gerardii*), little bluestem (*A. scoparius*), Indian grass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*, Towne 2002). A diverse mixture of other less abundant species includes warm-season and cool-season grasses, composites, legumes, and other forbs.

Field Methods

Upland sandpipers were captured at night using spot lights and a long-handled dip net during April and May of 2003 and 2004. Sex was determined by a molecular marker based on the CHD gene (B.K. Sandercock, Kansas State University, unpublished data). Each bird in this study was fitted with a radio transmitter (Model PD-2, ca. 3.8 g, Holohil Systems Ltd., Ontario, Canada) attached with a leg-loop harness (Sanzenbacher et al. 2000).

Upland sandpiper locations were estimated using 2 methods. A vehicle mounted null-peak triangulation system fitted with a digital compass (Sailcomp[®] 103AC, KVH industries, Inc., Middletown, RI 02842) was used to locate each bird twice daily, six days a week for the duration of the breeding season (May to August; Anderka 1987, Cox et al. 2002). In addition to regular triangulation, birds were homed in on and flushed to locate nests and broods. Handheld global positioning receivers (GPS, model III plus, Garmin International Inc., Olathe, KS 66062) were used throughout the study to mark locations of triangulation points and bird sightings.

Program LOCATE II (Nams 1990) was used to determine locations of radio-marked sandpipers for each set of triangulation bearings (n = 2 or 3; Millsbaugh and

Marzluff 2001). All locations (in universal transverse mercator, UTM, coordinates) were then imported into ArcView 3.2 Geographical Information System (Environmental Systems Research Institute, Inc., St. Charles, MO).

In 2004, the accuracy of our telemetry system was assessed by placing transmitters at known locations in the field. First, ArcView was used to randomly select test transmitter sites in experimental units that had been used by upland sandpipers. A GPS unit was then used to navigate to the predetermined random test transmitter site. Once the transmitter had been placed in the field, the actual coordinates of the location using the “average” function was recorded. The location of the transmitter was then estimated using the same triangulation methods described above at least 3 separate times per test transmitter location in order to obtain average coordinates per location. Once the estimated locations were imported into ArcView, the Animal Movement extension was used to calculate distances between estimated and actual transmitter location (Hooge and Eichenlaub 1997, Fearer and Stauffer 2004). The distances for each transmitter location were averaged and then an average was taken across all transmitter locations. The accuracy of our triangulation system was fairly good (mean = 92.5 m \pm 33.0 SE, range = 6.6 m, 291.0 m, n = 150), relative to the average size of the experimental units (60 ha., diameter ~874 m).

Vegetative characteristics of sites used by upland sandpipers were determined by averaging the measurements at 6 points (1 animal use point and 5 random points). ArcView was used to create a buffer of 50 m around each estimated use point. Within this buffer, we used ArcView to randomly select 5 points to correspond with the estimated use point. At each use and randomly selected point a visual obstruction

reading was taken with a Robel pole (Robel et al. 1970) from each cardinal direction, we then averaged those readings and visually estimated the percent ground cover of 5 vegetation categories: grass, forb, bare ground, woody stems < 1m height, and woody stems > 1m height within a 2 m² circle. To improve repeatability, percent cover was classified into 1 of 6 cover categories 0% (0), 1-20% (1), 21-40% (2), 41- 60% (3), 61- 80% (4) and 81- 100% (5).

To compare the vegetation characteristics of used and unused sites, ArcView was used to select random points in experimental units that did not receive any estimated sandpiper locations. The same set of vegetation variables were also collected at non-use points.

Data Analysis

ArcView 3.2 (Environmental Systems Research Institute, Inc., St. Charles, MO) was used for all analyses of spatial data. Geographic Information System (GIS) layers with burn and grazing histories were available for all Konza Prairie experimental units.

Determination of individuals for analysis. To determine the minimum number of points required to accurately estimate home range, we plotted range size versus number of locations. Kernel estimates usually require at least 20 locations but we included individuals with ≥ 15 locations because range size was not related to sampling effort (see Results). In 2003 and 2004, we inadvertently radio marked both members in 5 breeding pairs. To maintain independence, we randomly removed 1 individual from each pair prior to the home range and resource selection analyses (Millspaugh and Marzluff 2001).

Estimation of home range size. We subdivided the breeding season into two periods. Nesting was defined as the period between initial radio attachment and the date

that the first nest hatched or failed. Brood-rearing was defined as the period between nest completion until the bird could no longer be detected on our study site.

Home range size was determined for the nesting period, the brood rearing period and the entire breeding season by using the 95% fixed kernel method within the Animal Movement extension. Analyses were restricted to birds with ≥ 15 locations. The smoothing parameter was determined using the Least Square Cross Validation (LSCV) method (Gitzen and Millspaugh 2003). Bias can occur in home range estimation with species that exhibit a central-place behavior to a nest site or roost site within their home range. To calculate total home range, we removed all animal use points within a 100 m radius (fits accuracy of telemetry system, ~ 95 m) of known nest sites when determining the total home range for each individual (Rosenburg and McKelvey 1999). To calculate home range during the nesting period, we did not remove points because the nesting site is inherent in defining the home range. To calculate home range during the brood-rearing period, there was no clearly defined central tendency area because the precocial young of upland sandpipers are highly mobile and range widely.

We used the chi-square approximation to the non parametric Kruskal-Wallis test (Proc NPAR1WAY, SAS software, Version 8.1, SAS Institute Inc., Cary, NC 27513, USA) to examine sexual and seasonal differences in home range size.

Estimation of resource selection. To quantify tallgrass prairie habitats selected by upland sandpipers, we used a multivariate analysis of variance, compositional analysis, to compare the proportion of management applications used relative to the area available (Aebischer et al. 1993, Millspaugh et al. 2005). Two difficulties with using compositional analysis to study resource selection include: defining what resources are

available to the study species, and defining the boundaries of a study area (Aebischer et al. 1993). We were able to avoid these problems here because Konza Prairie is subjected to discrete management and treatments, and quantification of the proportion of each management application being implemented within the study area was relatively simple.

Because of the error involved in estimating animal locations from triangulation, and the non-random distribution of upland sandpiper locations within their home range we used utilization distributions (UD) to define resource use within home ranges (Millspaugh et al. 2005). A function from Beardah and Baxter (1995) was used to calculate fixed kernel density estimates by using “plug-in” options for bandwidth selection (Wand and Jones 1995, Jones et al. 1996), which provide a grid of raw probability density estimates throughout each animal’s home range. We used a normal kernel for all density estimates (Silverman 1986). To remain consistent with other resource selection studies and to reduce potential bias from the tails of the UD, we considered only the 95% CI of each UD (by volume). We overlaid the UD grid of each radio-marked sandpiper on the habitat patch GIS map within ArcView 3.2 and summed the raw UD values by patch type. For each habitat type, we divided the summed UD value by the total UD value of all patches (0.95) to obtain a UD-weighted estimate of use for each habitat type for each individual animal.

To avoid analytical problems with unused strata, all the different management applications found on Konza prairie were reduced to 4 main strata (also referred to as zero data, Bingham et al. 2004). The 4 management application categories were based on whether the unit had been burned recently in the preceding spring and whether it was grazed by either bison or cattle: BTY_G = burned and grazed; BTY_U = burned and

ungrazed; NB_G = not burned that year and grazed and NB_U = not burned that year and ungrazed. If an individual did not use 1 of these strata we replaced this zero value with 0.0001 (Pendleton et al. 1998).

For each analysis, we conducted a log-ratio transformation $y_i = \ln(x_i/x_j)$ ($i=1, \dots, D, i \neq j$) (where x_i is the proportion of the individual's home range in habitat i , x_j is the proportion of one habitat type, and D equals habitat types) for the used and available data. We subtracted differences in the log transformed availability data from the log transformed use data for each animal (i.e., $d_i = \ln(x_{ui}/x_{uj}) - \ln(x_{ai}/x_{aj})$ where d is a matrix used to test the hypothesis that use equals availability). We tested for overall selection ($d = 0$) by constructing a residual matrix from the log-ratio differences and calculated the Wilks' lambda statistic as:

$$\Lambda = \frac{|R_1|}{|R_2|},$$

where R_1 and R_2 were matrices of mean corrected sums of squares and cross products, respectively. We transformed Λ into $-N \times \ln(\Lambda)$ where N was the number of animals and k was the number of habitat classes. When use differed from availability, we calculated the mean and standard deviation for the log-ratio differences, which were then used to rank each habitat type. We used t -tests to assess difference between ranks and determine where selection differed by habitat pairs (Aebischer et al. 1993, Erickson et al. 2001).

In order to accurately define an appropriate correct study area for the upland sandpipers we created one large "study area" polygon using all the outermost polygon edges from each individual home range. Because the upland sandpiper study area

extended beyond the boundary of Konza Prairie we incorporated the management strategies that occurred on the land adjacent to Konza Prairie. These management strategies are typical of Flint Hills management regimes, which are to burn annually and to graze cattle; this management matches the BTY_G category described above (Robbins et al. 2002).

Vegetative characteristics. We used a multivariate principal components analysis (PCA; Proc PRINCOMP, SAS software, Version 8.1, SAS Institute Inc., Cary, NC 27513) to summarize our 7 correlated vegetation variables (Morrison et al. 1992). The Kaiser criterion (eigenvalue ≥ 1) was used to select the number of factors to retain for use in our analysis of used versus nonuse sites (Kaiser 1960). We used the PC least scores means to compare foraging and nesting sites by sex, and to compare used sites versus unused sites during the brood rearing period.

Results

A total of 220 adult upland sandpipers were captured during 2003 and 2004. Of these captures, 85 sandpipers (45 males, mean mass = 144.53 g \pm 10.11 SD; 40 females, mean mass = 193.33 g \pm 19.53 SD) were radio marked. From this total, we discarded 3 individuals (2 M, 1 F) that were depredated shortly after marking, and 41 individuals with ≤ 15 locations. A total of 2,130 locations for 41 individuals were obtained using radio telemetry to triangulate and relocate upland sandpipers at Konza Prairie. Forty-one individuals were used for home range analysis.

Home Range

There was no significant relationship between number of locations and estimated home range size (Figure 1).

We pooled across years to determine a mean home range size for male and female upland sandpipers (Table 1). The average number of locations for males and females was 34.3 ± 11.7 SD. Male and female home range size was not different during nesting ($\chi^2_1 = 0.43$, $P = 0.512$); or across the entire season ($\chi^2_1 = 0.10$, $P = 0.751$). Females contributed little to brood rearing activities ($n = 3$), therefore we could not compare home range sizes with males during this period. However, the home range of male upland sandpipers was 2 times larger during brood rearing than of nesting ($P = 0.05$, Table 1).

Resource Selection and Vegetation Associations

Compositional analysis. At a landscape scale, upland sandpipers established home range sites nonrandomly on the experimental landscape at Konza Prairie (Figure 2, $\chi^2_3 = 31.65$, $P < 0.001$, $n = 44$). Compositional analysis rankings for selection of home ranges within the study area indicated a preference for recently burned and grazed units (BTY_G), followed by burned and ungrazed units (BTY_U). Thus, the preferences were ranked: BTY_G > BTY_U >> NB_U > NB_G. Upland sandpipers did not show significant preference between the most recently burned categories ($T = 1.89$, $P = 0.07$) or a significant avoidance between the units that had not been burned recently (NB_G, NB_N, $T = -0.60$, $P = 0.55$). However, they did show a significant preference for the most recently burned management units over those units that had not been burned for ≥ 1 year (BTY_G, $T = 5.68$ (NB_G) and 5.89 (NB_U), $P < 0.001$; BTY_U, $T = 5.26$ (NB_G) and 5.27 (NB_U), $P < 0.001$).

At an individual scale, upland sandpipers did not show any deviation from random when selecting management applications within their home range (Figure 3, $\chi^2_3 = 1.49$, $P = 0.685$, $n = 44$).

Vegetation analysis. Vegetation measurements were taken at 293 use (28 individuals, M = 13, F = 15) and 516 nonuse points in 2004. The top 3 principal components (PC) satisfied the requirements of the Kaiser criterion (Table 2), and explained 65% of the cumulative variation in the 7 vegetation variables (Table 2).

PC 1 was a measure of grass cover because it had a high positive loadings for the Robel average, % grass and % litter (Table 3). Similarly, PC 2 was a measure of forb cover because it had high positive loadings for % herbaceous and % woody < 1 m. PC 3 was a measure of woody vegetation because it had high positive loadings for % woody < 1 m and % woody > 1 m.

Sites used by upland sandpipers during the brood rearing period tended to be a mix of shorter vegetation that was open with lower densities of grass, higher bare ground coverage and a mix of forb, woody and grass coverage (Figure 4). Significant differences between least squares means principal scores for sites used versus unused were evident in PC 1 and PC 2 (Figure 5, $n = 373$, PC 1, $F_{(1, 371)} = 65.05$, $P < 0.001$; PC 2, $F_{(1, 371)} = 6.55$, $P = 0.011$). There was no difference in the PC 3 least squares means score between sites used and not used (Figure 5, $n = 373$, $F_{(1, 1)} = 0.18$, $P = 0.675$).

There were no significant differences in the PC least square means score between males and females, measurements taken at the nest site and foraging sites or with an interaction between sex and where the measurement was taken (Table 4).

Discussion

This is one of the first systematic studies to use radio telemetry to examine the range requirements and resource selection for a breeding population of a grassland bird. Our study resulted in 4 major findings: 1) upland sandpipers have large home ranges

(mean > 150 ha) during the breeding season, 2) home range size increases during the brood rearing period, 3) upland sandpipers selected experimental units that had been burned that same spring with no preference or avoidance of grazed areas, and 4) vegetation analysis revealed a difference in the vegetative structure between used and unused sites.

Many studies have commented on the area sensitivity and habitat requirements of the upland sandpiper and other grassland birds (Walk and Warner 1999, Johnson and Igl 2001, Winter and Faaborg 1999). However, few studies have examined the home range or habitat requirements of grassland birds using radio telemetry. Estimates of home range size for other grassland birds include: greater-prairie chicken (*Tympanuchus cupido*, Svedarsky et al. 2003), eastern meadowlark (*Sturnella magna*) and Dickcissel (*Spiza americana*, Wells 2005). Svedarsky et al. (2003) reports that greater prairie chickens have large home ranges and may require more than 1600 ha to sustain a large (> 200) male population. Wells (2005) found that post fledgling Dickcissels and eastern meadowlarks have home ranges that were on average 51 ha and 80 ha respectively. Most studies of grassland birds that delineate home range size or habitat requirements are conducted by observations of species in different habitat patches during the nesting portion of the breeding season. Some of the most commonly recognized area-sensitive birds (Johnson and Igl 2001, Davis 2004) have reported home ranges (e.g. area requirements) that vary from 0.2 ha for the chestnut collared longspur (*Calcarius ornatus*) to 1570 ha for the Northern harrier (*Circus cyaneus*, Dechant et al. 2003a; 2003b) with the most similar home range to upland sandpipers occurring with the Sprague's pipit (*Anthus spragueii*, 190 ha, Dechant et al. 2003c).

Previous observational estimates of upland sandpiper home ranges were from 8 ha to 60 ha and occurred mostly during the nesting period of the breeding season (Wiens 1969, Ailes 1977, Dechant et al. 1999). This range is similar to the estimates presented in this study for the nesting period but this information is only correct for that period. In order to fully understand the area requirements for the entire breeding season it is important that area usage studies also consider the brood rearing period. Although upland sandpipers have a different breeding strategy compared to many grassland songbirds, understanding how area usage changes throughout the breeding season is an important piece of information that is lacking for many of the grassland birds that are considered “area sensitive” and threatened by grassland conversion. The large home ranges exhibited by upland sandpipers are a likely explanation of the area sensitivity exhibited by these birds in other parts of their range.

There are large amounts of data on the nesting habitat requirements of the upland sandpiper (Dechant et al. 1999, Houston and Bowen 2001). We focused our study on the foraging and loafing activities of upland sandpipers by removing all estimated animal locations within 100 m of each bird’s nest before analysis.

Upland sandpipers prefer recently burned areas to areas that have not been burned recently when selecting a home range within a landscape. Although there are differences in the plant communities that inhabit more frequently burned areas as opposed to those less frequently burned (Collins 2000), it is unlikely that the plant community is driving upland sandpiper home range selection. Important correlates are likely to include the abundance of invertebrate prey, the ease of searching for and finding prey and the ability to spot and avoid predators.

Upland sandpipers feed mainly on small invertebrates, especially grasshoppers (Houston and Bowen 2001). Joern (2004) found that on Konza Prairie there is a strong correlation between time since last burn, canopy height, total grass biomass and grasshopper abundance. Grasshopper densities were highest in those sites that had been recently burned (Joern 2004). Joern (2004) also found that as canopy height and total grass biomass increased, grasshopper density decreased. This correlation with a major prey item of the upland sandpiper and the habitat that occurs from the management applications that upland sandpipers prefer, leads us to believe that prey abundance is the major driving factor in resource selection by upland sandpipers.

It is possible that these invertebrates may be most easily located and captured within areas that are more open and allow for easy locomotion along the ground. Upland sandpipers are visual predators that search for food by walking on the ground and have never been observed catching food during flight. The ability to search for food without expending great amounts of energy is imperative.

Recently burned areas may facilitate easy movement, have high prey abundance and may also give this ground dwelling species an advantage when trying to spot predators. The openness of the recently burned areas may also allow for an easier escape from both terrestrial and avian predators. The lack of dense, tall vegetation could allow for quicker flight or ground maneuvers.

The data from the fine scale analysis of the difference between sites used by brood rearing upland sandpipers and those sites not used show that they were using sites that were open with a sparse covering of grass, forbs and woody cover. This compliments the resource selection analysis and allows us to make the same assumptions

about the importance of these areas because of the availability and ease of capturing prey and predator avoidance during the brood rearing portion of the breeding season.

The upland sandpiper is grassland bird that uses large tracts of native prairie and although resource selection analysis indicates that this bird selects home ranges based on the availability of recently burned prairie their home ranges are so large that they encompass a mosaic of different management strategies and prairie habitats. In addition to the habitat composition of their home range they are highly sensitive to habitat fragmentation and conversion to row crops. The upland sandpiper is also a very visible and easily recognizable grassland bird, spending much of their time perched atop fence posts or performing aerial displays with a very distinctive call. These attributes make the upland sandpiper a good candidate for “poster species” status for prairie restoration and management.

Using a grassland bird species that can be easily recognized by the general public may increase the availability of funds and support of restoring and maintaining tallgrass prairie throughout their historical range. Although it is difficult to name the upland sandpiper an “umbrella species” because it does not use resources that are important to other declining grassland birds, it does have qualities that will allow land managers to gain greater public support and interest which could ultimately lead to more funds and more land for the restoration and proper management of large tracts of tallgrass prairie.

Management Implications

The upland sandpiper is listed as a species of conservation concern in at least 13 states and provinces and has been showing declines in many western states (Houston and Bowen 2001). Our results indicate that effective conservation and management of the

upland sandpiper will require the preservation of large (>1000 ha) contiguous pieces of grassland that are subjected to a mosaic of different burn frequencies occurring in blocks of greater than 60 ha. It is imperative that a management plan is set up to ensure that large tracts of land are burned each year to provide adequate foraging and brood rearing habitat. Grazing by large herbivores is an important disturbance within the tallgrass prairie ecosystem (Hartnett et al. 1996, Collins 2000). Fortunately, upland sandpipers readily use habitats that are grazed and may exhibit benefits from this practice.

Because of their affinity for tallgrass prairies that are intact and subjected to varying degrees of disturbances from multiple sources (e.g. burning and grazing), the upland sandpiper can become a poster species of tallgrass prairie restoration and management that could lead to greater amounts of funding and support for conservation of native grasslands.

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Table 1. Home range size (ha) comparison of upland sandpipers during the breeding season. No statistical testing was performed on the brood rearing period for females because of sample size.

Sex	Nesting ^a		Brood rearing ^b		Total ^c		Home range, SE (range)
	n	Locations, SE (range)	Home range, SE (range)	n	Locations, SE (range)	Home range, SE (range)	
F	19	27, 2 (15, 40)	121.3, 35.0 (13.6, 658.4)	2	28, 4 (29, 37)	143.8, 1.3 (142.9, 144.7)	247.7, 51.7 (32.8, 902.9)
M	14	30, 3 (16, 55)	67.0, 11.8 (2.8, 154.7)(A)	9	26, 3 (15, 43)	200.8, 69.1 (21.6, 577.2)(A)	199.0, 40.5 (62.7, 773.9)

^aTook place from the time the radio transmitter was attached until the nest hatched or failed and only includes individuals that had an active nest.

^bTook place from the time of nest completion until the bird was no longer acting broody or when it was no longer detected on the site and only includes birds that had successful nests.

^cThis included the entire time a bird was detected on site regardless of nesting status.

A The brood rearing period is twice as large as the nesting ($\chi^2_1 = 5.14, P = 0.023$).

Table 2. Eigenvalues of the correlation matrix for use and non use points of vegetation measurements taken on Konza Priarie. Bold type indicates Kaiser Criterion satisfaction (Eigenvalue > 1.0).

Factors	Eigenvalue	Difference	Proportion	Cumulative Proportion
PC 1	2.17	0.90	0.31	0.31
PC 2	1.27	0.14	0.18	0.49
PC 3	1.12	0.22	0.16	0.65
PC 4	0.91	0.09	0.13	0.78
PC 5	0.81	0.31	0.12	0.90
PC 6	0.49	0.28	0.07	0.97
PC 7	0.21	0.00	0.03	1.00

Table 3. Eigenvector table for the top three vegetation principal components (PC). Bold face type indicates those loadings (> 0.3) used to define the PC. We used the PC loadings to determine the vegetative structure represented by each PC.

Vegetation Variable	Grass (PC 1)	Herb (PC 2)	Woody (PC 3)
Robel Mean	0.47	0.11	0.42
% Grass	0.56	-0.15	-0.27
% Litter	0.34	-0.26	0.08
% Herbaceous	-0.03	0.72	-0.02
% Woody < 1 m	-0.12	0.34	0.58
% Woody > 1 m	-0.06	-0.42	0.63
% Bare Ground	-0.57	-0.27	-0.06

Table 4. Comparison of least squares means scores for vegetation measurements between 3 different variables.

	<u>PC1</u>			<u>PC2</u>			<u>PC3</u>		
	df ^a	F ^b	P ^c	df ^a	F ^b	P ^c	df ^a	F ^b	P ^c
Sex ^d	1, 206	0.48	0.490	1, 206	0.45	0.503	1, 206	1.62	0.205
Type ^e	1, 206	1.13	0.290	1, 206	0.28	0.597	1, 206	1.15	0.285
Interaction ^f	1, 206	0.26	0.608	1, 206	0.08	0.775	1, 206	0.03	0.854

^a Degrees of freedom

^b F-statistic

^c P-value

^d Male versus Female

^e Foraging versus nesting location

^f An interaction between sex and type (sex*type)

Figure 1. Number of upland sandpiper locations per individual versus the \log_{10} transformed home range size ($n = 52$, $y = 0.003x + 2.06$, $r^2 = 0.011$).

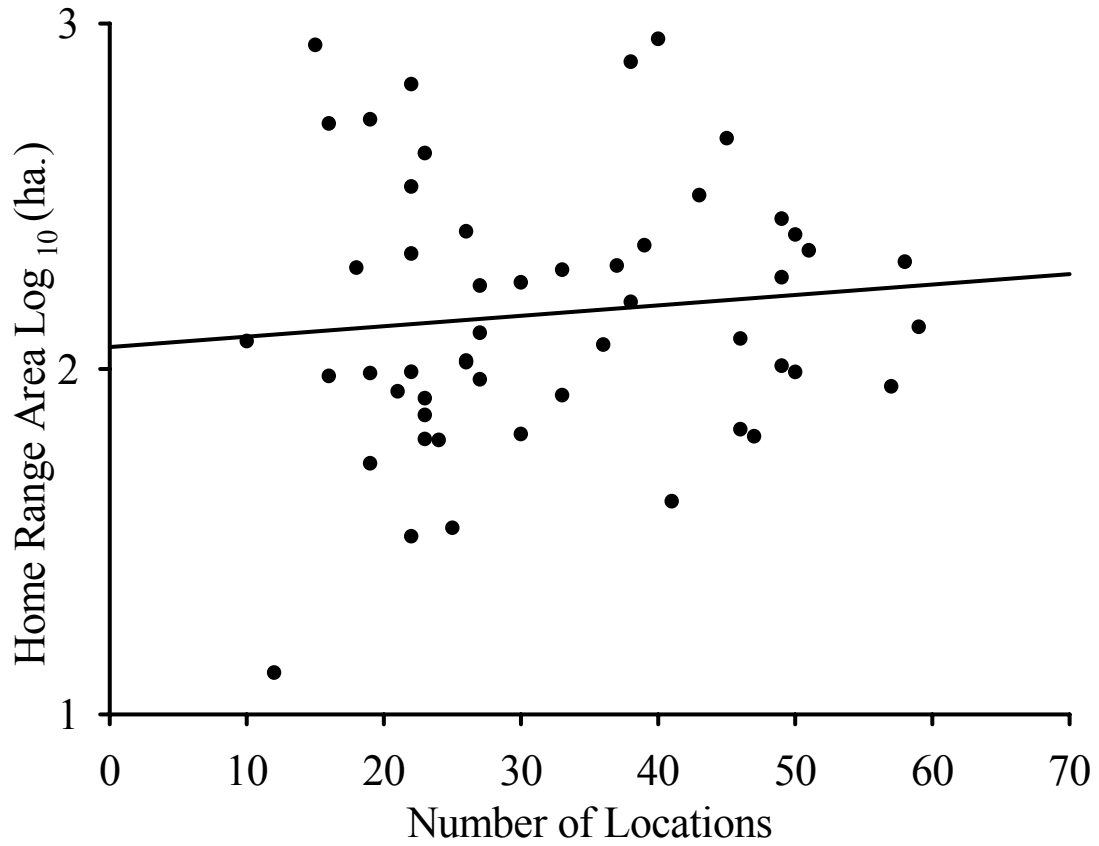
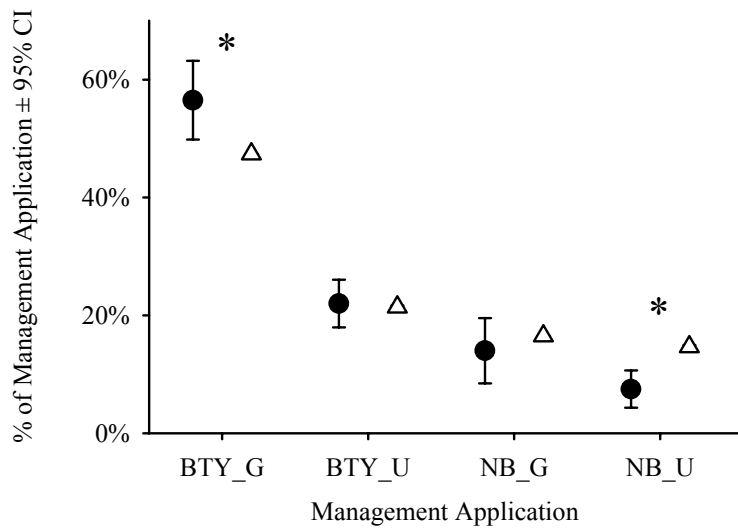


Figure 2. Used and available land management treatments and a box plot of the differences in the log ratio based on compositional analysis for upland sandpipers selection within the study area. BTY_G represents burned that year grazed, BTY_U represents burned that year not grazed, NB_G represents not burned that year grazed and NB_U represents not burned that year ungrazed. On figure A the dark circles represent used applications and hollow triangles represent available applications. Figure B is based on the compositional analysis with the NB_U was used as the comparison baseline (* indicates significant difference).

A)



B)

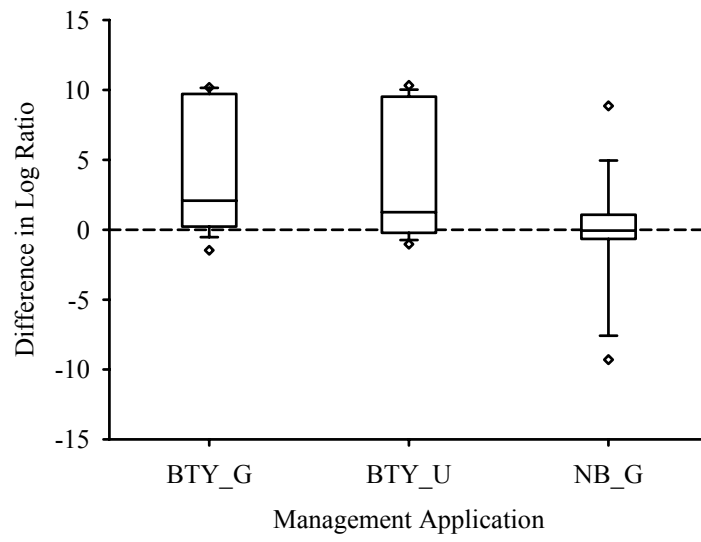
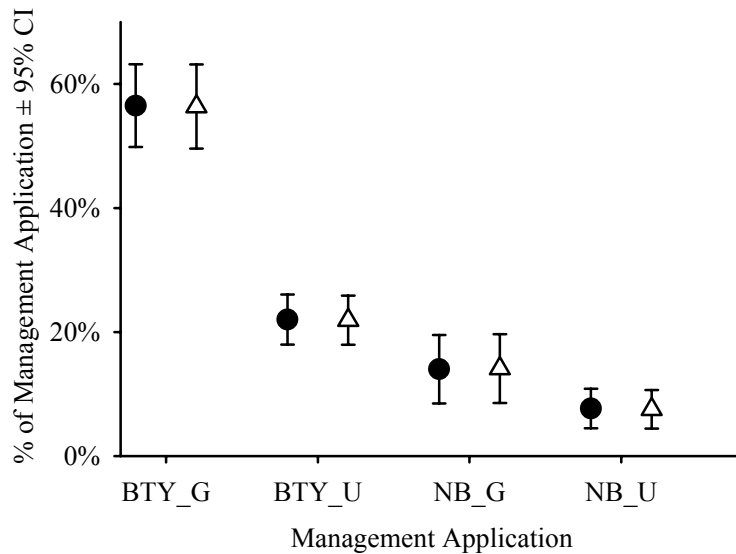


Figure 3. Used and available land management treatments (A) and a box plot of the differences in the log ratio (B) for upland sandpipers selection within their home range. BTY_G represents burned that year grazed, BTY_U represents burned that year not grazed, NB_G represents not burned that year grazed and NB_U represents not burned that year ungrazed. On figure A the dark circles represent used applications and hollow triangles represent available applications. Figure B is based on the compositional analysis with the NB_U was used as the comparison baseline (* indicates significant difference).

A)



B)

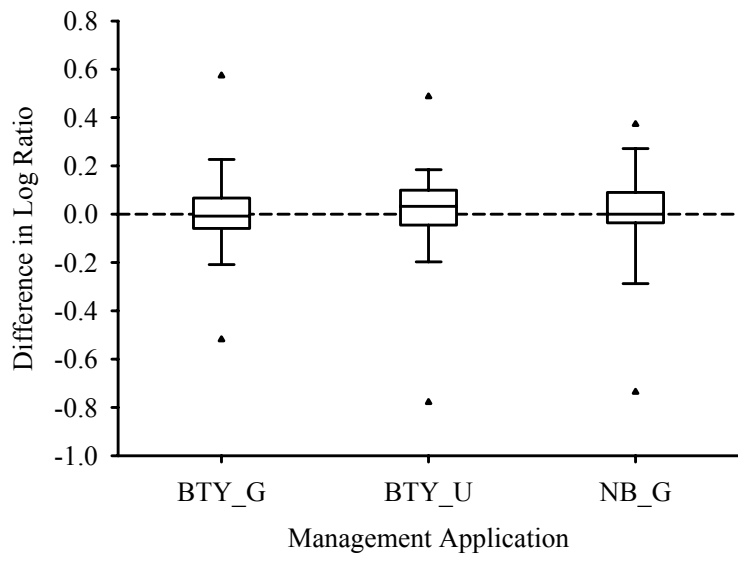


Figure 4. Mean principal component (PC) scores for sandpiper use sites (used, black bars) and random nonuse sites (grey bars) during the brood-rearing period of 2004. See table 3 for PC explanation. (*, significant difference, $P < 0.05$).

