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ARCHITECTURAL AND LANDSCAPE RISK FACTORS ASSOCIATED WITH BIRD–GLASS COLLISIONS IN AN URBAN ENVIRONMENT

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ABSTRACT.—We studied building characteristics and landscape context to predict risk of migratory birds being killed by colliding with sheet glass on Manhattan Island, New York City, New York, USA. Trained volunteers monitored 73 discrete building facades daily from the Upper East Side to the southern tip of the Island during autumn 2006 and spring 2007 bird migratory periods using a consistent and scientifically valid search protocol. We recorded 475 bird strikes in autumn 2006 and 74 in spring 2007 of which 82 and 85%, respectively, were fatal. Most building and context variables exerted moderate influence on risk of death by colliding with glass. We recommend a suite of building characteristics that building designers can use to reduce risk of collisions by minimizing the proportion of glass to other building materials in new construction. We suggest that reduction of reflective panes may offer increased protection for birds. Several context variables can reduce risk of death at glass by reducing ground cover, including changes in height of vegetation, and eliminating shrubs and trees from areas in front of buildings. We estimated 1.3 bird fatalities per ha per year; this rate extrapolates to ~34 million annual glass victims in urban areas of North America north of Mexico during the fall and spring migratory periods. Clear and reflective sheet glass poses a universal hazard for birds, specifically for passage migrants in New York City, but also representative and comparable to growing urban areas worldwide. *Received 21 May 2008. Accepted 14 August 2008.*

Growing evidence supports the interpretation that, except for habitat destruction, collisions with clear and reflective sheet glass cause the deaths of more birds than any other human-related avian mortality factor (Klem 1989, 1990b, 2006; Erickson et al. 2001; Manville 2005, 2008). The deaths of 1 billion birds annually from collisions with glass in the United States (U.S.) alone is likely conservative; the worldwide toll is expected to be in the billions (Klem 1990b, 2006; Dunn 1993). Comparable estimates of annual U.S. bird deaths based on extrapolations from other human-related sources include: 120 million from hunting, 60 million from vehicular collisions, 400,000 at wind turbines, and potentially hundreds of millions by domesticated cats (AOU 1975; Banks 1979; Klem 1990b, 1991, 2006; Coleman et al. 1997; Erickson et al. 2001; Manville 2005, 2008). Birds generally act as if sheet glass and plastic in the form of windows and noise barriers are invisible to them. Lethal casualties result from head trauma after birds leave a perch from as little as 1 m away in an attempt to reach habitat seen through or reflected in clear and tinted panes (Klem 1990a, Klem et al. 2004, Veltri and Klem 2005). There is no window size, building structure, time of day, season of year, or set of weather conditions during which birds elude the lethal hazards of glass in urban, suburban, or rural environments (Klem 1989).

We assessed multiple risk factors associated with migratory bird deaths at glass in an urban landscape where increased strike rates have been previously recorded at windows reflecting nearby vegetation (Gelb and Delacretaz 2006). We identified characteristics of building design and landscape context that may explain collision rate at a site, and tested the hypothesis these variables influence the risk of window strikes by migratory birds. Our results are highly relevant to conservationists and regulatory agencies interested in identifying buildings that pose a potential lethal hazard to migrants on passage, and to architects, landscape planners, and other building professionals willing to incorporate these find-

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gs into their designs of human-built struc- res and environments to protect birds.

METHODS

We and 30 trained volunteers affiliated with ew York City Audubon collected data for is study by monitoring 73 discrete sites (i.e., ilding façades) from the Upper East Side to e southern tip of Manhattan Island, New ork City, New York, USA. Each site was nsidered an independent sampling unit. It nsisted of one surface of an entire building a section of a building having a similar ucture, and intercepted birds flying in a di- ction different from those intercepted by her façades of the building. Each sampling it (i.e., façade) possessed a uniform appear- ce to the human eye and consisted of the me composition of glass and non-glass ucture, and associated vegetation. All Up- r East Side sites ($n = 7$) were selected for dy at the Metropolitan Museum of Art. All uthern sites ($n = 18$) were within the World nancial Center. We selected 48 sites from wer midtown (from 20th to 30th streets and m the Hudson River to the East River) to nitor bird–glass strikes within a uniform an area. Lower midtown sites were select- to ensure as uniform distribution as possi- of sampling units and these included com- ations of no vegetation, 1–50% vegetation, -100% vegetation, no glass, 1–50% glass, 51–100% glass. Tape and wheel rules re used to measure distances and heights. stance of vegetation was measured from e of façade to closest branch, leaf, or blade grass. Height of trees was measured using ght of adjacent building. One of us (ND) imated the percentage of vegetation and ss by eye while facing the middle of each from the street curb to reduce any observ- related variation in measurement error.

Each of nine combinations of categorical tures was identified and systematically rep- ented in the lower midtown area. The lower town location was also identified as char- ristic of the greater New York City urban a, having sites with structural characteris- that included residential and commercial dings at heights of four stories or less. We the relatively uniform structure of the er midtown area and the number of re- ed mortalities discovered during the fall and spring migratory periods to estimate annual glass mortalities per area of urban habitat. All sites in all locations were grouped into four carcass and injured-bird search routes. A strike was recorded when a volunteer found a dead or injured bird in front of a glass or an opaque wall at the base of a façade with the search area extending to the gutter of the street. Added attention was given to inspecting bushes and planters when they were present. This methodology provided a conservative estimate of strike frequency, as it did not account for removal of carcasses by scavengers and street sweepers, injured birds that died outside the search area, or post-strike movements of survivors. Routes were walked slowly from 0700 to 1000 hrs, when previous monitoring revealed glass collision victims were found most often. Search routes were completed within 0.5 to 2 hrs. Dead birds were salvaged and donated to authorized researchers (with appropriate State and Federal scientific collection permits) for additional study, and injured birds were taken to local animal care centers for treatment.

We monitored each building façade daily for 58 days (i.e., 9 Sep–5 Nov) in autumn 2006 and 56 days (i.e., 2 Apr–27 May) in spring 2007 to detect window strikes resulting in bird injury or mortality. We divided variables considered to be potential predictors of strike events into two groups: (1) building design and (2) landscape context (Table 1). Building design variables consisted of construction features. Context variables characterized the area immediately in front of a façade. We measured variables defining each façade, and our sample size for the analysis was the number of façades. We measured nocturnal light levels between 0200 and 0500 hrs using a Mannix digital light meter, model DLM-1337.

We used Cox proportional hazards regression (Cox 1972, Riggs and Pollock 1992, SPSS 2006) to test for associations between variables in each group and the probability that a façade would experience a glass strike. Cox proportional hazards regression is applicable to any situation in which the response variable is the time to a discrete event. We screened variables for multicollinearity prior to analysis. We included the covariate with the strongest association with glass strikes for

TABLE 1. Variables measured at building façades in New York City, New York, USA.

Variable	Variable type	Data code	Definition	n
Building design				
Building height	Categorical	1	1–4 stories	18
		2	5–10 stories	29
		3	>10 stories	26
Glass type	Categorical	1	None	11
		2	Reflective	32
		3	Transparent	26
		4	Reflective and transparent	4
Glass-non-glass ratio	Categorical	1	0	11
		2	1–50%	19
		3	51–100%	43
Night lighting 5	Continuous	variable	Illumination (lux) 5 m from façade	65
Night lighting 10	Continuous	variable	Illumination (lux) 10 m from façade	65
Size	Continuous	variable	Length of façade (m)	73
Vegetation reflected in glass	Categorical	1	None	25
		2	1–50%	26
		3	51–100%	22
Landscape context				
Access	Categorical	1	Public	69
		2	Private	4
Facing area	Categorical	1	Open (>18 m)	38
		2	Restricted (≤18 m)	35
Facing habitat	Categorical	1	Vegetated ground cover at base of façade	28
		2	Non-vegetated ground cover at base of façade	45
Ground cover distance	Continuous	variable	Distance from façade to nearest ground cover (m)	73
Ground cover height	Continuous	variable	Height of ground cover (m)	73
Location	Categorical	1	Upper east side	7
		2	Lower midtown	48
		3	Southern	18
Shrub distance	Continuous	variable	Distance from façade to nearest shrubs (m)	73
Shrub height	Continuous	variable	Height of shrubs (m)	73
Tree distance	Continuous	variable	Distance from façade to nearest trees (m)	73
Tree height	Continuous	variable	Height of trees (m)	73

each pair of variables with $r < -0.5$ or >0.5 in further analyses and eliminated the other collinear variables. Cases (i.e., façades) in which no strike event occurred during the study were included in the analysis as censored observations. We arcsine transformed variables measured as proportions (% glass, % vegetation reflected) to normalize their distributions (Zar 1999). We derived separate models for each group using forward and backward stepping algorithms based on likelihood ratios (SPSS 2006). We used Akaike's Information Criterion (AIC), corrected for small sample sizes (AIC_c) to select final models, and model averaging with re-scaled parameter estimates to derive risk ratios in cases where >1 model had a $\Delta\text{AIC}_c \leq 2.0$ (Burnham and Anderson 2002).

We retained variables in proportional hazards models that had P values for their coefficients ≤ 0.15 and calculated risk ratios for those variables. We accepted a 15% level of significance because we believed it was sufficient to indicate the importance of variables in affecting the probability of glass strikes (Johnson 1999). Risk ratios estimate change in the relative risk of an event for an incremental change in the magnitude of a predictor

riable (Riggs and Pollock 1992). The risk
io for a given variable represents the inde-
ndent contribution to risk of an event made
a covariate, regardless of the dimensions
the variable. Risk ratios are useful for es-
ating the contribution to risk of continuous
d categorical variables, and we included
th types of variable in our analysis. We
asured continuous variables on differing
ales (i.e., some were proportions whereas
ers were linear measures in meters), and
ndardized risk ratios for these variables for
10% change in magnitude to allow direct
mparisons among variables. We considered
variable to be a significant predictor of win-
w strikes if the 90% confidence interval for
e risk ratio did not include 1.0. Risk ratios
0.5 or >2.0 generally indicate large effects
covariates on risk of an event.

Risk ratios represent the independent con-
bution of each covariate to risk of an event,
d we used relative influence (RI) values
e., sum of log-transformed risk ratios) to
mpare the influence of the groups of vari-
les on risk (Farmer et al. 2006). We calcu-
ed an RI for model averaged estimates of
fect size to minimize the influence of co-
riates occurring only in a single model for
given variable group.

RESULTS

We recorded 475 and 74 glass strikes in au-
mn 2006 and spring 2007, respectively. Of
ese, 390 (82%) in autumn and 62 (85%) in
ring were fatal. The number of strikes re-
rded at sites with no glass was 7 (1.5%) in
tumn and 2 (2.7%) in spring. There were 50
d 25 known species casualties in autumn
006 and spring 2007, respectively. The 10
ecies recorded most often as strike victims
n decreasing frequency) were: Dark-eyed
nco (*Junco hyemalis*), White-throated Spar-
w (*Zonotrichia albicollis*), Ruby-crowned
inglet (*Regulus calendula*), Golden-crowned
inglet (*R. satrapa*), Hermit Thrush (*Catha-*
us guttatus), Common Yellowthroat (*Geoth-*
pis trichas), Northern Parula (*Parula amer-*
ana), Blackpoll Warbler (*Dendroica striata*),
venbird (*Seiurus aurocapilla*), and Swain-
n's Thrush (*Catharus ustulatus*) for autumn
006, and Ovenbird, Black-and-white Warbler
niotilta varia), Rock Pigeon (*Columba liv-*
), Common Yellowthroat, Northern Waterthrush (*Seiurus noveboracensis*), Canada Warbler (*Wilsonia canadensis*), White-throated Sparrow, Ruby-crowned Kinglet, Gray Catbird (*Dumetella carolinensis*), and Blackburnian Warbler (*Dendroica fusca*) for spring 2007.

Window strikes occurred at 41 of 73 (56%) façades in autumn 2006 and 20 of 73 (27%) façades in spring 2007. Mean time to a window strike from the beginning of the study was 37.4 days (SE = 2.6) overall, and 21.4 days (SE = 2.6) within the subset of façades at which strikes occurred in autumn 2006. Mean time to a window strike was 52.0 days (SE = 2.1) overall, and 28.3 days (SE = 4.1) within the subset of façades at which strikes occurred in spring 2007. Overall, context variables (RI = 2.6 autumn, 4.8 spring) exerted a slightly stronger influence on risk of window strikes than building variables (RI = 1.9 autumn, 0.4 spring).

Building Variables.—Five building variables were included in proportional hazards models after screening for multicollinearity and eliminating variables with no significant association with the risk of glass strikes. Model selection using AIC_c suggested that two autumn models (i.e., façade size, % glass, and glass type vs. glass type and % glass) were nearly equally likely given the data (Table 2). Significant model averaged estimates of effect size were found for the proportion of the façade that was window glass (i.e., % glass) with a 10% increase in this variable causing a 19% increase in risk (Table 3). The autumn model averaged risk ratio for reflective glass type was large (219% increase in risk), but not significant. The 90% confidence interval for reflective glass type nearly excluded 1.0, indicating there was an increase in risk, but our parameter estimate was imprecise.

Three models had $\Delta AIC_c \leq 2.0$ (Table 2), and were used in the calculation of model averaged parameter estimates for spring. The proportion of the façade that was window glass (% glass) was a significant predictor of risk with a 10% increase in this variable causing a 32% increase in risk of a window strike (Table 3). Façade size and night lighting each appeared to exert weak influences on risk. No building variables were found that significantly reduced the risk of window strikes.

Context Variables.—Eight context variables

TABLE 2. Model selection for building variables. Models indicated by bold type are equally likely based on AIC_c values.

Model	AIC_c	ΔAIC_c	*w*	χ^2	Model *P*
Autumn					
FS[a], GP[b], GT[c], NL[d]	307.16	2.71	0.132	26.46	0.000
FS, GP, GT	305.16	0.71	0.358	26.43	0.000
GP, GT	304.45	0	0.510	24.68	0.000
Spring					
GP, GT, NL, FS	162.73	3.78	0.068	12.28	0.056
GP, GT, FS	160.90	1.96	0.169	11.22	0.011
GP, FS	159.68	0.73	0.313	10.42	0.005
GP	158.95	0	0.450	9.37	0.002

[a] Façade size.
[b] Percent glass.
[c] Glass type.
[d] Night lighting 5.

were included in proportional hazards models (Table 4). Model selection using AIC_c suggested two autumn models (i.e., facing area, distance to ground cover, ground cover height, location, and tree height vs. facing area, ground cover height, location, and tree height) were likely given the data (Table 4). Model averaged estimates of effect size from the two models indicated that facing area, height of ground cover, and tree height significantly influenced risk of window strikes. Restricted facing areas (e.g., a short distance to the nearest building in front of a façade) reduced risk of window strikes 69%, whereas 10% increases in the height of ground cover and tree height increased risk of a strike by 13 and 30%, respectively (Table 5). Location and distance to ground cover exerted non-significant influences on risk of a glass strike.

Two models had $\Delta AIC_c \leq 2.0$ for spring (Table 4) and were used in calculation of model averaged parameter estimates. Restricted facing areas strongly (549%) increased risk of spring window strikes and a 10% increase in tree height moderately (22%) increased risk. Distance from façades to tree cover and height of ground cover affected the risk of window strikes non-significantly (Table 5).

We recorded 284 lethal strikes (1.1 fatalities/ha) within the 266-ha generalized urban lower midtown sampling location during autumn 2006. We recorded 47 lethal strikes (0.2 fatalities/ha) for the same area during spring 2007. We estimated 1.3 fatalities/ha of urban

TABLE 3. Model averaged estimates of effect size derived from Cox proportional hazards regression on building variables.

Covariate	β[a]	SE	RR[b]	90% CI	Predictor of risk
Autumn					
Façade size	0.003	0.004	1.08	0.92–1.26	NS[c]
Glass percent	0.019	0.009	1.19	1.04–1.36	Significant
Glass type (none)	−0.160	0.662	0.85	0.29–2.53	NS
Glass type (reflective)	1.160	0.738	3.19	0.95–10.74	NS
Glass type (transparent)	0.322	0.783	1.38	0.38–5.00	NS
Spring					
Façade size	0.004	0.052	1.11	0.13–7.76	NS
Glass percent	0.030	0.007	1.32	1.19–1.44	Significant
Night lighting 5	0.002	0.019	1.04	0.45–2.25	NS

[a] Regression coefficients indicate strength and direction of relations between hazard functions and covariates. All regression coefficients retained in the model are reported.
[b] We standardized risk ratios (RR) and 90% confidence intervals (CI) of the continuous covariates (façade size, percent glass) for a 10% increase.
[c] Non-significant at $\alpha = 0.10$.

E 4. Model selection for context variables. Models indicated by bold type are equally likely based on ues.

Model	AIC$_c$	Δ AIC$_c$	w	χ^2	Model P
D^{b}, GH^{c}, LO^{d}, SD^{e}, SH^{f}, TD^{g}, TH^{h}	298.03	9.26	0.006	43.770	0.000
D, GH, LO, SD, TD, TH	295.53	6.75	0.022	43.732	0.000
D, GH, LO, TD, TH	293.08	4.31	0.076	43.172	0.000
D, GH, LO, TH	290.75	1.98	0.243	43.096	0.000
H, LO, TH	288.77	0	0.653	43.070	0.000
D, GH, LO, SD, SH, TD, TH	159.53	9.79	0.004	27.80	0.001
D, GH, SD, SH, TD, TH	157.28	7.54	0.011	27.23	0.000
D, GH, SD, TD, TH	154.87	5.13	0.038	27.21	0.000
D, GH, TD, TH	152.52	2.78	0.121	26.15	0.000
H, TD, TH	150.47	0.73	0.338	25.05	0.000
D, TH	149.74	0	0.488	23.56	0.000

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nually after combining these measures tion for autumn and spring.

DISCUSSION

t building and context variables exerted ate influences on risk of glass strikes. oportion of windows reflecting vegeta- e., % vegetation) was measured in the ut we did not include it in the proportional hazards regressions, because it integrates building (i.e., % glass and glass type) and context (i.e., facing area, type, distance, and height of vegetation) variables, which made it difficult to interpret. It proved to be a significant predictor of glass strikes (RR_{10} = 1.26, 90% CI = 1.14–1.39) when we included percent of reflected vegetation in an exploratory model. We interpret these findings as an

E 5. Model averaged estimates of effect size derived from Cox proportional hazards regression on variables.

Covariate	β^{a}	SE	RR^{b}	90% CI	Predictor of risk
l					
g area	−1.177	0.493	0.31	0.14–0.69	Significant
nd cover distance	0.005	0.025	1.02	0.89–1.14	NS^{c}
nd cover height	2.433	1.352	1.13	1.01–1.26	Significant
tion (lower midtown)	−0.698	0.587	0.50	0.19–1.30	NS
tion (southern Manhattan)	0.339	0.611	1.40	0.51–3.83	NS
height	0.097	0.030	1.30	1.14–1.48	Significant
g area	1.857	0.650	6.49	2.23–18.89	Significant
nd cover height	1.979	1.464	1.10	0.98–1.25	NS
distance	−0.055	0.036	0.70	0.48–1.03	NS
height	0.076	0.028	1.22	1.08–1.39	Significant

sion coefficients indicate strength and direction of relations between hazard functions and covariates. All regression coefficients retained in the reported.

ndardized risk ratios (RR) and 90% confidence intervals (CI) of the continuous covariates (ground cover distance, ground cover height, tree a 10% increase.

ignificant at $\alpha = 0.10$.

indication that building designers can reduce the risk of bird–glass strikes by reducing the proportion of glass to other building materials in any new construction. The type of glass affected the autumn model significantly, although no individual category of glass had a significant effect. The high-magnitude risk ratios for reflective glass suggest this type of glass strongly increases risk of strikes. However, confidence intervals with 1.0 near the lower confidence limits coupled with the large risk ratios are an indication the analysis lacked power to accurately estimate effect size for this variable.

Context variables had a slightly stronger relative influence than building variables, and the analysis indicates that several context variables under the control of builders can be manipulated to reduce the risk of glass strikes. We found that increasing the height of ground cover and tree cover adjacent to new and existing buildings increases the risk of strikes by 13 and 30%, respectively, for each 10% increase in height. Our risk ratios are scaled for any 10% change in a covariate indicating that 10% reductions of the heights of these types of cover will reduce the risk of strikes by the same amount. This supports a previous study documenting increased strikes at glass with reflected vegetation (Gelb and Delacretaz 2006). Eliminating vegetative ground cover from areas adjacent to buildings may also reduce risk, although the effect was non-significant in our analysis. Large reductions in risk (69%) in autumn can be achieved by restricting the area in front of façades, primarily by placing buildings close together. However, the large (549%) increase in risk associated with this context variable in spring contradicts this finding. This also suggests that migrating birds may behave differently in Manhattan in spring versus autumn, which would complicate efforts to manage strike risk using this context variable. Previous studies suggest that spacing between buildings may be of limited value since a lethal collision can occur when a bird strikes a glass surface after leaving a perch from as little as 1 m distant (Klem 1990b, Klem et al. 2004, Veltri and Klem 2005). The non-significant effect of location (indicating that lower midtown locations strongly reduced risk) in autumn regressions suggests that having tall buildings in the surrounding area increases risk of window strikes, presumably by restricting the availability of flight paths for birds.

Quantitative analyses of both building and context variables associated with the glass hazard for birds provide further support for recently published suggestions informing architects and other building industry professionals about how to mitigate or eliminate avian mortality at glass (Brown and Caputo 2007, City of Toronto Green Development Standard 2007). Our results confirm that sheet glass consisting of small windows to entire walls of buildings is a lethal hazard for birds. Searching for and monitoring potential hazardous sites will identify problem urban areas. Minimizing the use of large expanses of glass and nearby vegetation in the vicinity of clear and reflective panes will mitigate bird–glass collisions, and prevent injury and death to birds on passage during migratory periods. In this context, it is important to note that even variables that entered models non-significantly (i.e., confidence interval overlapping 1.0) exert some influence on risk of strikes, either directly or by conditioning the effect of significant predictors. Design changes by a builder on any or all of the variables identified (Tables 3, 5) will affect the risk of strikes; however, the strongest effect will be realized by altering the significant predictors.

Our systematic sampling of lower midtown provided an opportunity to estimate annual avian mortality at glass in a relatively uniform urban environment, typical of urban areas without skyscrapers, including single-story or two-story residences. The species recorded as collision casualties in the lower midtown study area are representative of the same or similar species on passage over a broad front and expected to occur in similar urban environments throughout the continent (Lincoln and Peterson 1935, Able 1999). Using this sample and urban area data from Statistics Canada (2001) and U.S. Bureau of Census (2002), the annual bird kill at glass during migratory periods alone in the urban environment is estimated to be 5,676 for Manhattan, 3,163,633 for Canada, 31,159,228 for the United States, and 34,322,861 for North America north of Mexico. These estimates are likely conservative since they exclude buildings above four stories where large annual

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t of Interior (2002) list of Spe-
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y (2007) WatchList recorded
lties: American Woodcock
r), Yellow-bellied Sapsucker
rius), Wood Thrush (*Hylo-*
a), Chestnut-sided Warbler
sylvanica), Canada Warbler,
Oriole (*Icterus galbula*). The
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ntribution to Conservation Science

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ABSTRACT.–
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TION OF NORTHERN BOBWHITES WITH SURFACE TER IN THE SEMI-ARID TEXAS PANHANDLE

LER,[1,2,5] ALEXANDRA B. FELIX,[3,4] AND FRED S. GUTHERY[1]

e assessed association of Northern Bobwhites (*Colinus virginianus*) with surface water (nat-
the semi-arid Texas Panhandle during May–September 2001–2003. The difference between
ances of nest locations (n = 33) and random points to nearest surface water was −107.8 m
L = −142.7 to −72.9) indicating that nest locations were closer to water than expected by
birds appeared to associate with surface water during summer (May–Aug) based on dif-
cation distances of 83 bobwhites (1,408 locations) and random-point distances to nearest
SE = −62.4 ± 17.0 m, 95% CL = −96.4 to −28.4). Our results provide evidence that
ciate with surface water in the semi-arid Texas Panhandle. *Received 22 February 2008.*
2008.

of surface water to Northern
us virginianus) survival and
ecially in arid and semi-arid
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est sites within walking dis-
if they did not, the brood
ve. Vorhies (1928:449) re-
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Lehmann (1953) speculated
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to increase humidity at nest
returned. Science has yet to
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rds (Kentish Plovers [*Char-
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troversy over surface-water
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centered around decades-old
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Northern Bobwhites have been observed drinking water when available (Prasad and Guthery 1986), and have reportedly congregated in large numbers at a water source (468 bobwhites in 2 hrs at a single water hole; Lehmann 1984:87). Free-standing water may not be necessary, however, for bobwhite populations to persist (Stoddard 1931:500–503, Guthery 2000:40–44). The importance of surface water to bobwhites may depend on low availability of preformed water (Hernández et al. 2007) during relatively high environmental temperatures (Prasad and Guthery 1986). However, preformed water may not be limiting even during periods of drought (Guthery and Koerth 1992), and bobwhites also obtain water through metabolic processes (Guthery 2002). Scientific evidence would seem to quell the debate about the physiological needs of bobwhites, but behavioral responses to water availability, perhaps unrelated to physiology, may exist.

The spatial distribution of forage and predators within an animal's environment can influence the animal's spatial distribution (Stephens and Krebs 1986:161–168); sites of resource supplementation have often influenced movements of wildlife species, such as bobwhites congregating near supplemental feeders during winter (Guthery et al. 2004). This behavioral response may be described as a site-association effect and can have important ecological implications, including changes in resource use and availability, and potential changes in cause-specific mortality rates through species distributional changes (e.g., higher hunter or predator effort near resource

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