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A MULTISCALE APPROACH TO UNDERSTANDING SNAKE USE OF CONSERVATION BUFFER STRIPS IN AN AGRICULTURAL LANDSCAPE

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***Abstract*.—In regions of the United States that are predominately devoted to agricultural production, most grassland habitat remains as linear strips, including areas along roads and within conservation buffer strips. While land management agencies in the United States promote conservation buffer strips as beneficial to wildlife populations, we know little about snake use of these habitats, especially in relation to multiscale factors. Our poor understanding of these relationships hinders effective design and management of these habitats to conserve biodiversity. We evaluated the influence of buffer design, management, and surrounding landscape characteristics on snake occurrence in grassed waterways in southeastern Iowa. We documented snakes at nearly 80% of the grassed waterways and captured 119 individual snakes of five species; one of which, the Smooth Green Snake (*Lioclonorophis vernalis*), is listed as a species of conservation concern in Iowa. We used a multiple logistic regression and an information theoretic approach to determine the most parsimonious local and landscape variable models that best explained snake species occurrence. The "local" waterway design variable, width, occurred in the best local variable models for three of the five species and was positively associated with snake presence for all three species. Landscape variable models also helped explain snake presence; individual species responded differently to the various landscape metrics. Insights gained from this study may provide opportunities for improving the conservation value of buffer strips to snakes in these fragmented landscapes.**

Key Words.—agricultural matrix; buffer strips; conservation; grassed waterways; Iowa; landscape metrics; snakes

INTRODUCTION

In many part of the United States, and particularly in the Midwestern U.S. (hereafter, Midwest), intense agricultural production and urbanization have substantially reduced and fragmented native ecosystems (e.g., Samson and Knopf 1994, Radeloff et al. 2005), resulting in heightened environmental concerns related to soil erosion, pesticide and nutrient runoff (e.g., Matson et al. 1997, Turner and Rabalais 2003), and loss of biological diversity (e.g., Herkert 1994, Kolozsvary and Swihart 1999, Fahrig 2003, Cushman 2006). For example, with the loss of over 99% of the native Tallgrass Prairie in North America (Samson and Knopf 1994), wildlife are restricted to using non-native habitats such as pastures, hayfields, Conservation Reserve Program (CRP) fields, and linear strip-cover habitats (Frawley and Best 1991; Warner 1994; Best et al. 1995, 1997; Bollinger 1995). Since the 1950's, the intensification of rowcrop agriculture in the Midwest has caused the consistent decline of the larger areas of non-native grasslands, such as hayfields and pasture (Dinsmore 1981; Warner 1994). Consequently, many grassland wildlife species have declined or disappeared from this region (Bowles 1981; Christiansen 1981; Dinsmore 1981).

The Conservation Reserve Program, enacted in 1985 as part of the Food Security Act and managed through the U.S. Department of Agriculture (USDA), was designed to address the environmental degradation associated with agricultural practices (Ribaudo et al. 2001). Program participants withdraw erodible land from production and receive annual payments for maintaining permanent vegetative cover. The CRP program has resulted in the conversion of previously cultivated agricultural land to perennial grassland habitat (Ribaudo et al. 2001; Egbert et al. 2002; Lovell and Sullivan 2006) with related environmental benefits including decreased soil erosion, improved water quality, and enhanced wildlife habitat (McCoy et al. 1999; Weber et al. 2002; Lovell and Sullivan 2006). However, in areas of the Midwest with extensive rowcrop production, linear grassland habitats (Fig. 1), such as roadsides, field borders, fencerows, and conservation buffers (e.g., filter strips, grassed waterways), constitute a significant amount of the grassland habitat available to wildlife (Warner 1994). In 1997, the USDA introduced the National Conservation Buffer Initiative to encourage landowners to add over 3.2 x 10^6 km of conservation buffers to the landscape (Natural Resources Conservation Service [NRCS] 2000) by 2002, through various landowner incentive programs, including continuous enrollment CRP (United States Congress 1996). While falling short of this original goal (Schnepf 2005), the acreage of conservation buffers is increasing. For example, from 2005 to 2009, the acreage of CRP buffers increased from 711 to 817 x 10^3 ha (1.75 to 2.01 x 10^6 ac; Farm Service Agency

FIGURE 1. A grassed waterway positioned in an agricultural field in southeastern Iowa. (Photographed by Tricia Knoot)

2009. Conservation Reserve Program: Annual Summary and Enrollment Statistics-FY 2009. Available from http://www.fsa.usda.gov/Internet/FSA_File/fyannual2009.pdf [Accessed 29 March 2011]).

The intensification and expansion of human land use in the U.S. and across the globe has reduced native wildlife habitat, with smaller and often fragmented "islands" of suitable habitat remaining (e.g., Saunders et al. 1991, Samson and Knopf 1994, Radeloff et al. 2005). As emphasized and supported by the theory of island biogeography (MacArthur and Wilson 1967), a theory that has been debated and expanded upon over the last several decades (Lomolino 2000), the size and configuration of remaining habitat affects wildlife population density as well as species richness (Andrén 1994). Consequently, the continued increase in grassland conservation buffers offers potential benefits for biological diversity through increased habitat heterogeneity at multiple scales (Benton et al. 2003), reduced habitat fragmentation, and increased connectivity among habitat patches (Lovell and Sullivan 2006). However, studies targeting the influence of landscape characteristics on wildlife use of grassland conservation buffers are few, which hinder effectively planning, design, and management of these habitats. Also, most research on wildlife use of linear grasslands focused on the abundance, distribution, and reproductive success of birds (e.g., Bryan and Best 1991; Warner 1994; Henningsen and Best 2005), with limited information on the benefits of conservation buffers to other wildlife species, such as snakes.

Reptiles have seen consistent population declines throughout the world, which are attributed to a variety of factors, including land use patterns, such as habitat loss and degradation (Gibbons et al. 2000). In Iowa, 10 of the 27 snake species found in the state are imperiled (State of Iowa 2002) and greater than 90% of the original land cover has been converted to agriculture and urban areas (Farrar 1981). Thus, an understanding of the use of conservation buffers strips by snakes can inform targeted habitat conservation and restoration efforts, while contributing to our overall understanding of snake use of linear habitats in agricultural landscapes. However, conservation planning requires attention to local and landscape features that can impact habitat use by snakes. Knowledge gained from studies of the spatial ecology of snakes in other types of habitats, such as Tallgrass Prairie (Cagle 2008), early successional habitat (Kjoss and Litvaitis 2001), wetlands (Roe et al. 2004; Attum et al. 2008), and riparian corridors (Roth 2005), highlights the need for further understanding of multiscale effects on snake use of grassland habitat in an agricultural context. Furthermore, snakes have been documented occupying linear (edge) habitat (Durner and Gates 1993; Blouin-Demers and Weatherhead 2001; Carfagno and Weatherhead 2006), suggesting the potential importance of grassland buffers to snake distribution patterns in an agricultural landscape

Our research focused on grassed waterways, a linear grassland habitat and conservation buffer practice included in the USDA conservation buffer initiative. Grassed waterways (Fig. 1) are constructed in rowcrop fields where water runoff is greatest and are primarily designed to reduce soil loss and nutrient runoff, but also can be managed to enhance the value of these habitats to wildlife (Bryan and Best 1991). For example, the NRCS

(2001) recommends that landowners minimize disturbance in these habitats by delaying mowing until after August 1. Landowners can construct waterways that differ in width and length depending on-site conditions and personal objectives; however, the NRCS (2001) recommends that landowners maximize waterway width if wildlife habitat is a priority. These recommendations are largely based upon research that focused on improving habitat and nesting success for grassland birds (Bryan and Best 1991), with unknown applicability to other grassland associated wildlife. Grassed waterways provide an opportunity to evaluate the influence of both local- and landscape-level variables on snake use of a habitat embedded in an agricultural landscape. Given that there are no known studies of snake use of conservation buffer strips, our study was exploratory in nature and therefore we addressed two main objectives; first to characterize the snake community in grassed waterways, and second to evaluate the influence of local and landscape factors on snake species occurrence.

MATERIALS AND METHODS

***Study site.*—**We selected grassed waterways in Washington County, in the Southern Iowa Drift Plain (Prior 1991). Washington County contained the second highest acreage of grassed waterways enrolled in the CRP in the state and had a range of habitats such as rowcrop fields, CRP fields, pastures, hayfields, and woodlands (Prior 1991), allowing for an evaluation of the importance of landscape features on snake occurrence. We chose 31 grassed waterways for our study; 63% were surrounded by Corn (*Zea mays*) and the remaining sites were embedded in Soybean (*Glycine max*) rowcrop fields. Grassed waterways were primarily planted to cool-season grasses and had been established for at least two years. The predominant grasses in the waterways were Smooth Brome (*Bromus inermis*) and fescue (*Festuca* spp.). Other common plants included Reed Canary Grass (*Phalaris arundinacea*), Western Wheatgrass (*Pascopyrum smithii*), Giant Ragweed (*Ambrosia trifida*), Alfalfa (*Medicago sativa*), goldenrod (*Solidago* spp.), and clover (*Trifolium* spp.). We selected grassed waterways that were > 400 m apart to lessen the likelihood of overlapping use by snakes. In April 2003, in each waterway, we set up one transect that was the same width as the waterway and ranged in length from 150–200 m ($\bar{x}$ = 191.9 m, SE = 3.4).

***Local variable measurements.*—**We measured the grassed waterway width at 50 m intervals along each transect to calculate mean waterway width. Vegetation measurements were taken within each waterway in mid-May and late-July 2003, and averaged over both sampling periods for use in data analysis. For sampling purposes, we divided each transect into two equal-length segments and then measured the vegetation at two randomly selected sites within each segment. At each site, we estimated the canopy coverage, on an overlapping basis of grasses, forbs, and plant litter within a 20 x 50 cm quadrat (Daubenmire 1959). We measured the vertical density of the vegetation using a Robel Pole marked at 10 cm intervals (Robel et al. 1970). To estimate vertical density, visual obstruction measurements were taken from the four cardinal directions at a height of 1 m and a distance of 4 m from the pole.

Different tillage practices in rowcrop fields can result in variable crop residue coverage that can affect wildlife use (Castrale 1985). Because grassed waterways are surrounded by rowcrop fields, we evaluated the influence of crop residue in the adjoining fields on snake species occurrence in the waterways. Once in mid-May, at each site, we recorded the type of crop residue (Corn or Soybean) and measured the amount of residue in the crop field surrounding the waterway. For each grassed waterway, we used a 20 x 50 cm quadrat (Castrale 1985) to measure crop residue coverage at five different sites, taken at 50 m intervals along the waterway and located 5 m into the crop field from the edge of the waterway. We sampled alternate sides of each waterway for successive measurements. Two coverage estimates were recorded at each site; one was centered over a crop row and the other was placed between rows. We then averaged measurements over all sites for each waterway.

***Landscape variable measurements.*—**We purchased 2001 USDA Farm Service Agency aerial photographs of the study sites and converted these to digital images using the Image Analyst extension in the ArcView (Environmental Systems Research Institute, Redlands, California, USA) geographic information system (GIS). Each map feature was digitized, assigned to a habitat category and ground-truthed in the summer of 2003 (Fig. 2). We chose to measure landscape variables up to a distance that would reasonably encompass the area within the range of typical seasonal snake movement. For example, Fitch (1999) recorded that the average movement from hibernacula to summer ranges for male Eastern Garter Snakes (*Thamnophis sirtalis*), the second most abundant species recorded in our study (Table 3), was about 750 m, whereas female average movement was 480 m. Therefore, using ArcView, we created an 800 m buffer, as measured from the midline of each transect, to determine the proportion of each habitat type and the nearest distance to such habitat within each buffer. Two compositional (% coverage) and three configuration (nearest distance to habitat) metrics were used in subsequent analyses. The two compositional metrics were the percentage coverage of herbaceous habitat (%HERB) and the percentage coverage of

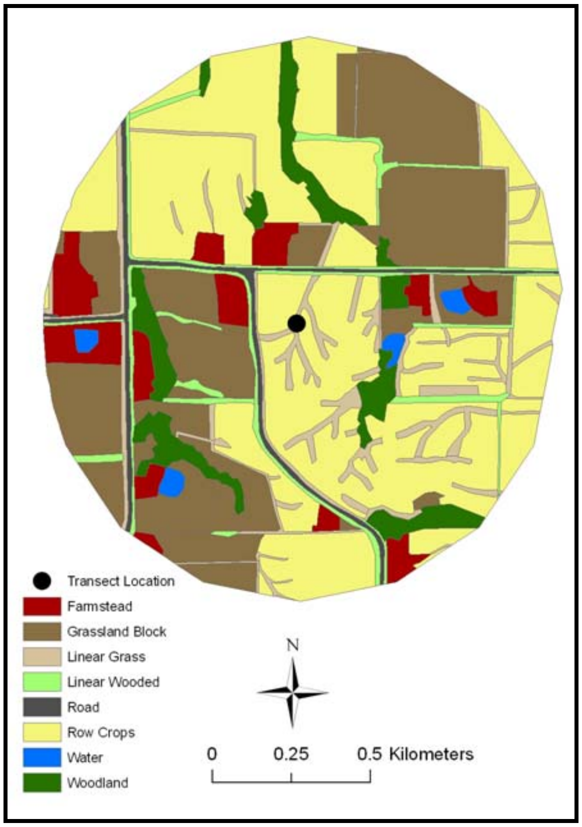

FIGURE 2. Habitat categories within an 800 m buffer zone surrounding one study site transect within a grassed waterway in southeast Iowa. Each map feature was hand-digitized from orthorectified aerial photographs and was ground-truthed in 2003. Habitat categories were further refined and consolidated for analysis.

wooded habitat (%WOOD). The three landscape configuration metrics were: (1) the nearest distance to herbaceous block habitat (DHERB) [> 30 m wide habitat]; (2) the nearest distance to wooded habitat (DWOOD); and (3) the nearest distance to a farmstead (DFARM). The nearest distance to herbaceous strip cover [< 30 m wide habitat] was not included in the calculation of the DHERB variable because all grassed waterways were directly connected to an herbaceous strip cover, most often a roadside. These five variables should adequately define the different habitat (wooded vs. herbaceous) used by snakes (Vogt 1981; Fitch 1999; Keller and Heske 2000). We considered farmsteads to be an important component of the agricultural landscape because snakes use building foundations and old wells as hibernacula (Vogt 1981; Stanford et al. 2010).

Snake surveys.—To determine the relative abundance and species composition of the snake community in the grassed waterways, we used artificial shelters and mark-recapture methods (Fitch 1987). We constructed artificial shelters of 0.64 cm (0.25-inch) thick sheets of oriented strand board (OSB), cut to 0.9 x 0.9 m sections. Boards were placed in the grassed waterways in mid-April 2003 to allow them to weather before we began snake surveys. We placed five shelters in each waterway at 50 m intervals; however, four boards were placed in each of the five waterways < 200 m long. Each shelter was placed a random distance from the centerline of the transect, alternating sides of the centerline for each successive shelter. From 12 May through 1 August 2003, two observers surveyed each transect weekly for snakes. We surveyed each of the 150 artificial shelters 12 times for a total of 1800 shelter surveys. Most farmers scheduled mowing of the grassed waterways in early August, requiring that we complete the research by this time.

When we captured a snake, we clipped a unique pattern of scales for mark-recapture information (Fitch 1987). We captured five individuals in vegetation near shelters; these snakes were assigned to the nearest shelter and included in subsequent totals. Herein, snake abundance is expressed as the number of snakes/100 shelter surveys. We considered a snake species present at a site if it was observed at least once in any of the surveys.

Data analysis.—We calculated means and standard errors for snake abundance, local characteristic measurements, and landscape variable measurements. Local and landscape variables were transformed as needed to meet the assumptions of normality and homogeneity of variance; all landscape variables and the vegetation density measurements were natural log transformed and plant litter and crop residue were square root transformed. Untransformed means and standard errors are reported for ease of interpretation. We compared the coverage of crop residue in the two crop types by using Student's t-tests. Statistical significance was set at an alpha level of ≤ 0.05.

We used multiple logistic regression (Hosmer and Lemeshow 1989) and an information theoretic approach (Burnham and Anderson 2002) to determine the most parsimonious local and landscape variable models that best explained snake occurrence. We were also interested in whether landscape models explained species presence as well as, or better than, the local models. To maintain simplicity and explanatory power of our models, we reduced our set of variables to four local (waterway width, crop residue coverage, vegetation vertical density, litter coverage) and four landscape (herbaceous habitat coverage; nearest distance to herbaceous block cover, wooded habitat, and farmstead) variables. Two of the local variables, waterway width and crop residue coverage, were chosen *a priori* to address possible waterway design and management considerations. Because snakes may choose habitat based on structural features (Reinert 1993), we expected

TABLE 1. Local characteristics measured on or adjacent to 31 grassed waterways in southeast Iowa.

Local variables	Variable code	$\bar{x}$	SE	Range
Width (m)	Width	12.6	0.8	6.2–24.6
Crop residue (%)	Resid	33.6	3.7	5.5–83.8
Vertical density (dm)	Vdens	3.5	0.2	1.9–6.7
Grass cover (%)	GrasC	65.2	2.3	34.8–91.8
Forb cover (%)	ForbC	7.5	1.5	0.0–27.9
Litter cover (%)	LittC	91.1	1.9	57.3–98.0

that vegetation density might affect snake use of grassed waterways. Plant litter cover may also influence snake occurrence in grassed waterways. For example, snakes have been reported concealed under plant litter or cover objects during periods of inactivity (Fitch and Shirer 1971; Plummer and Mills 2000). The four chosen local variables were not strongly correlated ($r < |0.4|$). To select from the five landscape variables measured, we addressed potential multicollinearity problems. Variables were considered to be strongly correlated if Pearson correlation coefficients were $\geq |0.7|$. Wooded habitat coverage and distance to wooded habitat were strongly correlated ($r = -0.72$, $P < 0.001$), so we eliminated wooded habitat coverage because it was most correlated with other variables.

All combinations of local variables and all combinations of landscape variables were used to create local and landscape candidate models, respectively. We adopted this exploratory approach, because all combinations of our reduced set of local and landscape variables represent the diverse habitat affinities of the suite of species we recorded. To compare the candidate models, we first calculated Akaike's Information Criterion values (corrected for small sample size [$\mathrm{AIC_c}$]) for each model. Smaller $\mathrm{AIC_c}$ values indicated greater support for the model (Burnham and Anderson 2002). Compared to the best model, other candidate models were considered to be competitive if $\Delta\mathrm{AIC_c} < 2$ (Burnham and Anderson 2002). We addressed model selection uncertainty by first determining the Akaike weight (w_i), calculated using the $\Delta\mathrm{AIC_c}$ for each model. We then calculated the relative importance of each variable by summing over weights for models in which the variables occurred (Burnham and Anderson 2002). Akaike weights and importance values can range from 0 to 1.

For each species, the all-variable local and landscape (global) models were evaluated for model fit by calculating the Hosmer-Lemeshow goodness-of-fit statistic, $\hat{C}$ (Hosmer and Lemeshow 1989). A corresponding P-value was calculated from the approximated chi-square distribution of $\hat{C}$ (Hosmer and Lemeshow 1989). Small P-values (≤ 0.05) indicate a poor fit of the model to the data possibly because of either overdispersion in the data (sampling variance > theoretical variance) or inadequate model structure (Burnham and Anderson 2002). As a measure of predictive power, we reported the "Max-rescaled R-square" (Max R^2) statistic (Proc logistic; SAS Institute, Cary, North Carolina, USA), adapted from the generalized R^2 (Allison 1999). We reported models if they explained the variability in the data better than an intercept-only model.

RESULTS

Local and landscape characteristics.—Grassed waterway widths spanned a range of approximately 20 m (Table 1). The coverage of crop residue varied among fields surrounding the waterways. In general, residue coverage in fields planted to Corn the preceding year ($\bar{x}$ = 35.6%, SE = 5.4) was not significantly different (t = 0.64, df = 29, P = 0.53) from that in fields planted to Soybeans ($\bar{x}$ = 31.6%, SE = 5.3). Therefore, residue type was not included in further analyses. As expected, grass was the predominant vegetation type in the waterways. In general, forb cover was low (on average < 8%), and litter cover was consistently high (waterway averages ranged between 57–98%; Table 1). Herbaceous block cover composed nearly three times more of the total landscape coverage than wooded habitat (Table 2). The average distances from the grassed waterways to herbaceous block cover, wooded habitat, and farmsteads were similar, although the individual distances ranged widely.

TABLE 2. Landscape compositional and configuration metrics measured within an 800 m buffer of each of the 31 grassed waterways in southeast Iowa.

Landscape variables	Variable code	$\bar{x}$	SE	Range
Composition (% coverage)				
Herbaceous	%herb	16.1	2.0	4.3–45.3
Wooded	%wood	5.7	1.0	0.3–18.6
Configuration (distance to nearest feature [m])				
Herbaceous block cover	dherb	227.6	30.0	47.0–691.8
Wooded habitat	dwood	206.0	29.0	23.2–700.6
Farmstead	dfarm	179.0	24.5	27.6–698.1

TABLE 3. Frequency of occurrence and relative abundance (snakes / 100 shelter surveys) of snakes captured in the 31 grassed waterways in southeast Iowa, 12 May through 1 August 2003.

Snake species	Frequency of occurrence (%)	Total individuals	Abundance $\bar{x}$	Abundance SE
Brown Snake (*Storeria dekayi)*	58.1	52	2.92	0.71
Eastern Garter Snake (*Thamnophis sirtalis*)	32.3	34	1.85	0.94
Plains garter Snake *(Thamnophis radix)*	19.4	15	0.81	0.45
Smooth Green Snake *(Lioclonorophis vernalis)*	22.6	9	0.51	0.19
Fox Snake *(Elaphe vulpine)*	22.6	8	0.44	0.16
Total snakes[a]	77.4	119	6.59	1.36

[a] Includes all individuals captured; one garter snake was identified to genus and was only included in the total snake count.

Snake presence and abundance.—We found 119 individual snakes of five species in the grassed waterways (Table 3). Snakes were documented at 24 of the 31 sites. Capture frequency declined substantially by the last week in June; 70% of the captures occurred from mid-May through mid-June. The Brown Snake (*Storeria dekayi*) was the most abundant species and was encountered most frequently (Table 3). We recorded two species of garter snakes (*Thamnophis* spp.); they occurred at 48% of the sites. The Smooth Green Snake (*Lioclonorophis vernalis;* Fig. 3), a species of conservation concern in Iowa, and Fox Snake (*Elaphe vulpina*) were both less abundant than Brown Snakes and garter snakes but were recorded at nearly a quarter of the sites (Table 3).

Local and landscape effects.—Local variables explained the presence of four of the five snake species recorded in the grassed waterways (Table 4); the chosen local variables did not explain Fox Snake presence any better than the intercept-only model and therefore the local model was not included in Table 4. The predictive power of the local models varied among species; Max R^2 values ranged from 0.13 to 0.53. The relative importance of the individual local variables and direction of the relationships (Table 4) explaining snake occurrence differed among species. Of the variables in the best models, waterway width occurred most frequently and was positively associated with the presence of three snake species. Plant litter coverage occurred in the best models of two snake species; litter cover positively influenced Smooth Green Snake occurrence but was negatively related to Eastern Garter Snake occurrence. The variable, crop residue coverage, appeared in the best local model for only the Plains Garter Snake (*Thamnophis radix*) and was negatively associated with the occurrence of this species.

FIGURE 3. *Lioclonorophis vernalis,* caught under cover board at a study site in southeastern Iowa. Photographed by Tricia Knoot.

Landscape variables explained the presence of three of the five snake species (Table 4); the landscape variable models did not explain the presence of the Eastern Garter Snake or Smooth Green Snake any better than an intercept-only model and therefore were not included in Table 4. Predictive power of the landscape variable models varied among species, with the highest predictive power for the Fox Snake (Max R^2 = 0.33). The variables, herbaceous habitat coverage and distance to wooded habitat, occurred in the best landscape models for two of the three species; distance to herbaceous block cover was included in the best model for only one species. The occurrence of Brown Snakes was positively influenced by the coverage of herbaceous habitat in the landscape. Fox Snake occurrence was negatively associated with herbaceous habitat coverage, but interestingly, this species was more frequently encountered in grassed waterways closer to herbaceous block cover. Fox Snakes also occurred more frequently in waterways closer to wooded habitat. In contrast, the Plains Garter Snake was encountered less frequently in grassed waterways nearer to wooded habitat.

Overall, we found that including only locally measured variables in our analysis would not have explained the occurrence of the various species which occupied grassed waterways. For example, the selected

TABLE 4. Best models (i.e., models with lowest Akaike Information Criterion corrected for small sample sizes [AIC_c]) that explained snake species occurrence in 31 grassed waterways in southeast Iowa. Sign in parentheses indicates direction of the relationship.

Snake species	Model type	Best model[a]	AIC_c	R^{2b}	w_i^c
Brown Snake (*Storeria dekayi*)	Local	Width[d] (+)	43.32	0.13	0.21
	Landscape	%herb[d] (+)	39.34	0.28	0.33
Eastern Garter Snake (*Thamnophis sirtalis*)	Local	Width (+), LittC[d] (-)	30.98	0.53	0.49
Plains Garter Snake *(Thamnophis radix)*	Local	Width (+), Resid[d] (-)	31.70	0.26	0.24
	Landscape	Dwood[d] (+)	32.49	0.12	0.26
Smooth Green Snake *(Lioclonorophis vernalis)*	Local	LittC (+)	34.61	0.14	0.20
Fox Snake *(Elaphe vulpine)*	Landscape	Dwood (-), Dherb[d] (-), %herb (-)	35.01	0.33	0.14

[a] Best models listed for species where variables explain species occurrence better than an intercept-only model.

[b] R^2 represents the Max-rescaled R^2 used in logistic regression as a measure of predictive power (Allison 1999).

[c] Akaike weight (w_i) for best model.

[d] Model variables: width = waterway width; LittC = plant litter coverage; Resid = crop residue coverage in surrounding agricultural field; %herb = % coverage of herbaceous habitat in the surrounding landscape; Dwood = distance to wooded habitat; Dherb = distance to herbaceous block cover.

landscape variables helped to explain Fox Snake occurrence, whereas the locally measured variables did not contribute to our understanding of the presence of this species in grassed waterways. In addition, for species in which both local and landscape models explained occurrence, the relative explanatory strength between the scales differed. For example, the best landscape variable model for Brown Snakes fit the data substantially better than the local variable model ($\Delta AIC_c = 3.98$). For the Plains Garter Snake, local and landscape models were comparable in their fit to the data ($\Delta AIC_c = 0.79$). Hosmer-Lemeshow goodness-of-fit statistics indicated a good fit to the data for all local and landscape global models ($P > 0.18$).

DISCUSSION

Throughout many regions of the United States, vast areas of native ecosystems have been altered and transformed into agricultural lands. Although agriculture provides abundant goods and services to society, the negative environmental consequences of industrial agriculture, including the loss of native biodiversity, is of great concern (Matson et al. 1997; Vitousek et al. 1997; Tscharntke et al. 2005). Consequently, the addition of perennial vegetation, such as conservation buffers, into these relatively simplified landscapes has been proposed as a mechanism for enhancing the ecosystem services that agricultural landscapes can provide (Schulte et al. 2006). In this study, we found that grassed waterways, a conservation buffer practice, may provide valuable perennial grassland habitat for snake species in Iowa, a midwestern state in which most of the native grassland has been converted to rowcrop fields. The design and management of grassed waterways is mostly determined by the main objectives of reducing soil erosion and improving water quality (NRCS 1999). However, managers are also encouraged to address wildlife needs by maximizing waterway width, increasing vegetation heterogeneity, and limiting habitat disturbance (NRCS 2001), but landscape context is rarely considered when designing grassed waterways. Our study results further our understanding of multiscale factors that influence the occurrence of snakes, a poorly understood taxon in agroecosystems.

The five snake species recorded in grassed waterways are all thought to have once occurred throughout most of Iowa (Christiansen and Bailey 1990). Some of these species, when considering their life-history traits and habitat associations, have been negatively impacted by the rowcrop-dominated landscape. With intensification of agriculture in Iowa, the Fox Snake and two garter snake species' populations have remained relatively stable (Christiansen 1981), suggesting that, at this point in time, they may have adapted well. In contrast, the two small-bodied snakes that occurred in the waterways have not fared as well in Iowa. Brown Snake populations have declined (Christiansen 1981), and the Smooth Green Snake is listed as a species of special concern in Iowa (State of Iowa 2002). The Brown Snake may have declined because of the loss of native grassland and wooded habitat (Christiansen 1981); < 0.10% of Iowa native grasslands remains and woodlands have declined by nearly 80% since European settlement (Smith 1981; Thomson and Hertel 1981). Although populations of the Brown Snake may be lower than previous levels, they are thought to be quite common in Iowa (LeClere 2001) and they were the most abundant and frequently encountered species in our study. Furthermore, despite their secretive habits, if suitable cover is available, Brown Snakes can be found in suburban areas (Tennant 2003), suggesting their adaptability to a human-dominated landscape. In contrast, the Smooth Green Snake is a species that has been greatly impacted by landscape alteration and habitat loss in much of its eastern and central range of North America (Tennant 2003). In Iowa, Christiansen and Bailey (1990) reported that the Smooth Green Snake could be limited to fewer than 10 scattered populations. The Smooth Green Snake is most often associated with grasslands and is an insectivore; thus, the decline in native grasslands, intensification of agricultural practices, and use of insecticides all may have contributed to the decline of this species (Christiansen and Bailey 1990; Tennant 2003). The presence of the Smooth Green Snake in grassed waterways suggests that the replacement of areas that are not currently in perennial grassland cover with grassed waterways may be of conservation value to this species.

The local and landscape variables that we measured helped to explain snake occurrence in grassed waterways and provided a more thorough understanding of various aspects of grassed waterway planning (i.e., placement within the agricultural landscape), design (i.e., buffer width), and management (i.e., vegetation characteristics) that may be manipulated to influence snake occurrence in Midwestern agroecosystems. For example, the frequency of occurrence of the Brown Snake, Eastern Garter Snake, and Plains Garter Snake was positively influenced by waterway width, possibly reflecting area sensitivity (i.e., occurring less frequently in smaller patches) of these species. The abundance and species richness of snakes have been reported to increase with patch size (Robinson et al. 1992; Kjoss and Litvaitis 2001); although, Burbrink et al. (1998) found that species richness was not associated with the width of riparian habitat. Our findings suggest that maximizing waterway width may increase the occurrence of some snake species in this type of conservation buffer. The amount of litter cover in grassed waterways and crop residue coverage in the surrounding fields also influenced snake species occurrence. Snakes can be more vulnerable to predators in habitats with less cover (Shine and Fitzgerald 1996); thus, we expected that a greater amount of litter cover in grassed waterways and greater crop residue coverage in surrounding fields may afford snakes greater protection from predators. As expected, Smooth Green Snakes occurred more frequently in waterways with greater plant litter cover, but the opposite was true for the Eastern Garter Snake. Also, Plains Garter Snake occurrence was negatively associated with crop residue coverage in surrounding fields. Thus, our findings suggest that waterway width and vegetation management within and adjacent to these buffers may be altered to influence snake occurrence; however, managers should recognize that species can respond differently to habitat modifications.

Our evaluation of the influence of landscape composition and configuration provides a more thorough understanding of snake occurrence in grassed waterways. The variables in the best landscape models were, in general, consistent with habitat associations reported for these species. For example, we encountered the Plains Garter Snake most often in grassed waterways farther from wooded habitat; a finding that is consistent with the observation that Plains Garter Snakes are more often found in open habitats (LeClere 2001; Tennant 2003). The placement of a grassed waterway in an agricultural field is primarily determined by topographic conditions. However, managers could influence snake occurrence by additionally making a priority the placement of waterways in specific fields according to the composition and configuration of habitat in the surrounding landscape.

Throughout the U.S. there is an opportunity to add grassland habitat, in the form of grassland conservation buffers, to agricultural landscapes. Most wildlife research of conservation buffers has focused on within buffer modifications that can enhance habitat for birds and other species of conservation concern, such as butterflies (Reeder et al. 2005). Our research suggests that buffers can also contribute to snake conservation efforts and with knowledge of local buffer attributes and landscape features, managers can more effectively plan, design, and manage these habitats for snake species of interest.

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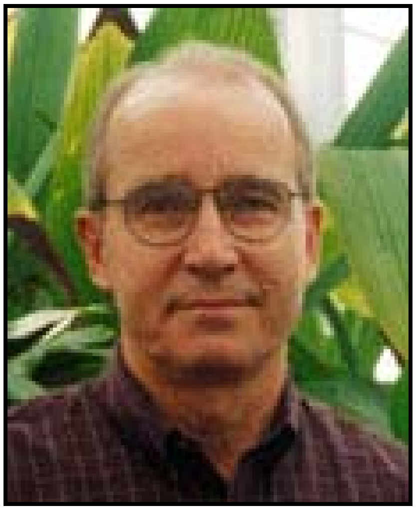

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