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Abstract:
Management programs aimed at reducing wildlife damage to row crops rely on information concerning the spatial nature of wildlife damage at local and landscape scales. In this study we explored spatial patterns of wildlife damage within individual corn and soybean fields by describing relationships between specific locations where wildlife damage was recorded and distances from such locations to various habitat types that presumably influenced animal abundance and movements in our study area. Using stratified random sampling, we conducted depredation surveys of 100 corn fields and 60 soybean fields from May through October both in 2003 and 2004 and recorded the specific global positioning satellite (GPS) coordinates of wildlife damage to individual corn and soybean plants. We then generated random point locations in the same fields using a geographic information system (GIS) and evaluated whether damage point locations and random point locations differed with respect to distances to the nearest patches of forest, developed area, or grassland and shrubland habitats. For both crop types, damage point locations were significantly closer to forest patches than were random point locations, but farther from developed areas than random point locations. Logistic regression analyses further indicated that distance to forest influenced the probability of wildlife damage within fields, although pseudo r^2 values of the best models were low (0.15). Our results clearly indicated that field portions that were nearest to forested habitats were more likely to suffer wildlife damage than field portions farther from forested habitats. We suggest that targeted removals of depredating species, concentrated along crop-forest interfaces, may be an effective, cost-effective means of reducing corn and soybean damage in areas where wildlife damage is especially problematic.

Key words: agriculture, corn, depredation, human–wildlife conflicts, Indiana, Midwest, raccoon, soybean, white-tailed deer, wildlife damage management

Many agricultural producers complain of excessive and intolerable wildlife damage to their crops (Brown et al. 1978, Brown and Decker 1979, Conover 1998), and several wildlife species, especially white-tailed deer (*Odocoileus virginianus*) and raccoons (*Procyon lotor*) that regularly cause damage to field crops, are abundant or increasing in much of the Midwest. For example, damage caused by white-tailed deer to corn (Sperow 1985, Vecellio et al. 1994, Wywialowski 1996, Tzilkowski et al. 2002, Humberg et al. 2007) and soybeans (de Calesta and Schwendeman 1978, Tanner and Dimmick 1984, Humberg et al. 2007) has been well-documented. Furthermore, corn can constitute up to 65% of the diet of raccoons during the late summer and fall (Rivest and Bergeron 1981), and significant damage to corn caused

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by raccoons has been documented (Humberg et al. 2007).

Exclusion (i.e., fencing) is an effective tool to minimize damage caused by deer (Craven and Hygnstrom 1994) and raccoons (Boggess 1994). However, exclusion is not a cost-effective means of reducing damage to large expanses of low-value crops, such as corn and soybeans (Conover 2002). Instead, wildlife damage in corn and soybean fields might be managed more effectively via regulated hunting, targeted removal of depredating species, or by altering the configuration and composition of landscape elements in agricultural areas (Van Vuren and Smallwood 1996, Beasley 2005, Retamosa 2006). To better implement and understand the effectiveness of such management strategies, detailed information is needed on the spatial nature of wildlife damage at local and landscape scales.

Previously, we described general patterns of crop depredation by wildlife in northern Indiana (Humberg et al. 2007) and found that raccoons and white-tailed deer were primarily responsible for damage to corn, whereas white-tailed deer and woodchucks (*Marmota monax*) caused most damage to soybeans. We also noted temporal differences in patterns of depredation between raccoons and white-tailed deer (Humberg et al. 2007). In the same study area, Retamosa et al. (in press) demonstrated that severity of wildlife damage within corn and soybean fields was related to the composition and configuration of habitat elements surrounding fields at a landscape scale. Specifically, Retamosa et al., (in press) found that landscape parameters associated with forest cover (i.e., percentage of forest cover, mean forest patch size, amount of wooded edge) were good predictors of wildlife damage to corn and soybeans on a field-level basis. We also determined that the severity of raccoon damage to corn is positively correlated with raccoon abundance in adjacent woodlots (J. C. Beasley, unpublished data). Thus, the timing and extent of wildlife damage to field crops in the Midwest appears to be influenced by local and landscape-level processes. However, we believe that a more thorough understanding of crop damage by wildlife can be gained by evaluating spatial aspects of depredation at a finer scale.

Here, we extend our previous work on wildlife damage in corn and soybean fields to explore the spatial patterns of crop damage within fields. To that end, we describe relationships between specific locations where wildlife damage was recorded within fields and the distances from such locations to various habitat types that influence animal abundance and movements in our study area.

Study area

Our 1,165-km^2 study area is located in the Upper Wabash River Basin (UWB) in northcentral Indiana, USA, encompassing portions of Grant, Huntington, Miami, and Wabash counties. The topography within the UWB is flat, with gently rolling areas along river drainages at an average elevation of 243 m above sea level. Approximately 96% of the land area within the UWB was privately owned, 71% of which was in agricultural use. The primary agricultural crops in the UWB were corn and soybeans with small interspersed fields of hay and small grains. Only 13% of the UWB was forested, compared to an average of 19% statewide (Moore and Swihart 2005). All contiguous forest tracts within the study area were confined to major drainages where frequent flooding or locally steep topography made the land unsuitable for crop production. The remaining native forests (predominantly oak [*Quercus*], hickory [*Carya*], and maple [*Acer*]) in the UWB were highly-fragmented. Of the 35 23-km^2 study areas within the UWB landscape analyzed by Moore and Swihart (2005), 75% of the forest patches were <5 ha, 50% were <2 ha, and only 1% of patches were >100 ha.

Methods

A Geographic Information System (GIS) was constructed to categorize land cover and classify individual agricultural fields by size and crop type (Retamosa et al., in press). For the present study, land cover was categorized as agricultural, forest, grassland-shrubland, developed area (usually a homestead), and other. A sample of fields representing the distribution of field sizes in the study area was assigned to 1 of 3 categories: <12 ha, 12–24 ha, or >24 ha, and were systematically surveyed from planting to harvest for evidence of wildlife damage to crops. We surveyed 82 fields (53 corn fields; 29 soybean

Raccoons are major wildlife consumers of field corn in northern Indiana. (*Photo by James Beasley*)

fields) in 2003 and 78 fields (47; 31) in 2004 for evidence of wildlife damage to crops. Surveyed corn fields averaged 21.3 ha (SD = 18.9) in size; soybean fields averaged 24.3 ha (SD = 19.2). Most fields were rectangular, although some fields had curvilinear borders adjacent to woodlots, roads, drainage ditches, and grassed waterways.

After plant emergence, we established edge and interior transects in each field using hand-held Global Positioning Satellite (GPS) receivers and survey flags. All transects ran parallel with the fields' row plantings, and transects continued through the end cross-rows to the ends of the fields. Two edge transects were established randomly from 1–15 m of the edges of each field, following curvatures of field edges. Interior field transects (two for < 12 ha, four for 12–24 ha, and six for > 24 ha fields) were spaced equidistantly within the remainder of each field surveyed. Most fields had 4 definable edges, of which only the 2 edges that ran parallel to the entire field row were surveyed (e.g., north-south orientation, east-west orientation). Some irregularly shaped fields had more than 4 edges. For fields with > 4 edges, we surveyed the 2 major edges that ran parallel to entire field planting orientation and any other edge of the same orientation that was greater than one-quarter the length of the field in the direction being surveyed. Wildlife biologists (Indiana Department of Natural Resources and Purdue University Wildlife Extension), who were experienced in assessing various types of crop damage, trained our technicians on techniques to determine the specific wildlife species responsible for crop damage and on the developmental stages of corn and soybean plants.

Technicians walked field transects and surveyed each field approximately once per month from the time of plant emergence until harvest. Survey crews of 2 technicians each walked along transects and documented all plants that exhibited any sign of wildlife-caused damage visible from transects. For corn, and, to a lesser extent, soybeans, transect widths decreased as the plants grew and visually obstructed adjacent rows. The mean distance from transects to damage points was 1.6 m (SD = 2.19) during the vegetative stage of corn growth and 0.6 m (1.0) during the reproductive stage. For soybeans, mean distances from transects to damage points during vegetative and reproductive growth stages were 0.93 (1.43) and 0.43 (1.30), respectively. At each plant damage location, crews recorded the number of plants damaged, wildlife species responsible, amount of leaf area damaged, percentage of seed damage, height of damage, growth stage of plant at the time of damage, and remaining yield (estimated percentage of yield remaining on each damaged plant). At locations where ≤20 plants were damaged, we collected data for each damaged plant; in areas where >20 plants were damaged, we collected data on 20 randomly-selected damaged plants. All documented damage was marked clearly with paint to avoid recounting during subsequent surveys. In addition to collecting plant damage characteristics, we recorded Universal Transverse Mercator (UTM) coordinates using hand-held GPS units at the epicenter of each location where we collected damage information (i. e., damage location). For the present study, we considered each damage location as an equal, independent observation, regardless of the number of plants damaged at that location.

We used the Animal Movement extension (Hooge and Eichenlaub 1997) in ArcView 3.3 (Environmental Systems Research Institute, Inc.) to generate 2,156 random point locations along transects among all the sampled fields within the GIS, matching the total number of locations where wildlife damage was recorded in all fields surveyed. Random point locations were distributed among fields based on the number of transects sampled in each field (a surrogate of field size). We pooled all point locations and used the type of point location (random or damage) as the dependent variable in subsequent analyses.

Ultimately, our goal was to describe which portions of fields (e.g., interior or edge) were most susceptible to wildlife damage and how adjacent habitat type influenced the severity of damage. Ostensibly, the most straightforward approach would have been to evaluate distances between point locations and field edges of various types (e.g., agricultural, wooded, grassland-shrubland, or developed areas). However, we were unable to use simple distances from point locations to field edges in our analyses because true field edges often were ambiguous. Our criteria for marking field boundaries included field ownership, crop type planted, and planting date; therefore, our demarcation of fields likely did not mirror the perception of habitat boundaries to raccoons, white-tailed deer, and other wildlife that damage crops. Instead, we evaluated distances from point locations (damage and random) to the nearest edges of habitat types (as defined by the GIS) that we hypothesized would influence animal movement and abundance (i.e., forest, grassland-shrubland, and developed areas) without regard to field boundaries. As such, any agricultural fields located adjacent to each other were treated as a single field in the analyses.

Distances from each damage location and random point to the nearest forest, grassland-shrubland, and developed area were measured within the GIS using ArcView 3.3. Because the data were not normally distributed, we used nonparametric Mann-Whitney *U* tests to examine differences in rankings of distances between damage point locations and random point locations to each of the predictor variables (distance to nearest patch of forest, distance to nearest grassland-shrubland, and distance to nearest developed area) within each crop type. We conducted binary logistic regression analyses (Norušis 1999) to further examine relationships between point location type (damage or random) and the 3 continuous predictor variables. We evaluated all possible models using the 3 predictor variables with the Akaike Information Criterion (AIC; Akaike 1973). AIC values are useful for identifying the most parsimonious models that accurately predict the response variable (Burnham and Anderson 2002). We used SPSS version 10.0 (SPSS 1999) for all statistical analyses.

Results

We documented a total of 582,515 depredation events (any damage caused by wildlife to a single plant) at 2,156 locations over the 2 growing seasons. We recorded wildlife damage in 149 of 160 fields surveyed; there was no detectable wildlife damage in 5 corn fields and 6 soybean fields. Overall, soybean fields (509,415 damaged plants) were damaged more frequently than corn fields (73,100 damaged plants), despite a greater sampling effort in corn (n = 100) than in soybean fields (n = 60). During the 2 growing seasons we surveyed, white-tailed deer (61%) and woodchucks (38%) were most often responsible for damage to soybean plants; whereas raccoons (87%) and white-tailed deer (10%) were responsible for most damage to corn. (See Humberg et al. 2007 for a more detailed description of wildlife damage to surveyed fields.)

In corn and soybean fields, damage point locations were closer to forest patches than random point locations (U = 641,317.0, P <0.001 for corn; U = 183,995.5, P < 0.001 for soybeans; Table 1; Figure 1). However, the opposite trend emerged for distance to nearest developed area, where random point locations were closer to developed areas than damage point locations (U = 922,668.5, P = 0.016 for corn; U = 254,269.0, P < 0.001 for soybeans; Table 1). There was no difference between point location types for distance to grassland-shrubland habitats in corn fields, although for soybeans the difference was significant (U = 266,035.5, P = 0.035), with nonrandom points being slightly farther from grassland-shrubland habitats than were actual damage locations (Table 1).

Logistic regression analyses further indicated that the distance to the forest influenced the probability of wildlife damage (Table 2). For corn and soybeans, the 2 best models (as indicated by AIC values) both included distance to forest as a predictor variable (Table 2). Distance to developed areas was included in 1 of the 2 best models for corn and both of the top 2 models for soybeans. The best models for both corn and soybeans consistently had Nagelkerke (pseudo) r^2 values of 0.15, and correctly classified 65–67% of point locations.

TABLE 1. Mean distances (± SE) in meters from point locations to nearest patches of forest (D Forest), developed area (D Developed) and grassland-shrubland (D Grass). Statistical significance between point location types (damage or random) for the 3 distance measurements are indicated separately for each field type (* = $P < 0.05$; ** = $P < 0.01$). Although means are presented, Mann-Whitney *U* tests were used to evaluate statistical significance. Data were gathered in 160 corn and soybean fields in northern Indiana in 2003 and 2004.

	Point type	*n*	D Forest	D Developed	D Grass
Corn	Damage	1480	**122.57 ± 3.49	*234.98 ± 4.16	79.30 ± 1.91
	Random	1316	**204.75 ± 4.50	*218.91 ± 4.15	78.87 ± 1.97
Soybean	Damage	676	**144.88 ± 5.99	**219.90 ± 5.25	*67.26 ± 2.66
	Random	840	**241.60 ± 6.42	**197.86 ± 4.80	*71.03 ± 2.28

Discussion

Our results clearly indicated that the probability of wildlife depredation within corn and soybean fields varied spatially. The distance from locations within fields to forested and developed habitats, and by extension, to varying abundances of wildlife that damage crops, contributed to the probability of wildlife damage. Certainly, factors other than distance to various habitat types influence the probability of wildlife damage within fields, including availability and variety of alternative food sources for wildlife, extant management programs, and landscape-level habitat features (e.g., juxtaposition of surrounding habitats). The importance of other factors was made evident by the low pseudo r^2 values (0.15) of the logistic models. Even so, our results strongly suggested that field portions nearest to forested habitats in particular were more likely to suffer wildlife damage than field portions farther from forested habitats. Undoubtedly, the presence and configuration of woodlots in agricultural landscapes are important predictors of wildlife damage to corn and soybeans (Braun 1996, Dijak and Thompson 2000, Henner et al. 2004, Beasley 2005, Retamosa et al. in press).

The importance of forested habitats in agricultural landscapes for wildlife that damage crops (e.g., white-tailed deer and raccoons) is unquestionable. However, in agricultural landscapes many nongame species (e.g., passerine birds, bats, small mammals, reptiles, amphibians) also rely heavily on small forested habitats for food, cover, and breeding areas (e.g., Kolozsvary and Swihart 1999, Rosenblatt et al. 1999, Menzel et al. 2005). As such, we do not advocate removal of woodlots or components of woodlots, such as snags and woody debris, to alleviate crop damage in heavily agricultural areas. Instead, we suggest that targeted removals of depredating species, concentrated along crop–forest interfaces, may be an effective, cost-effective means of reducing damage. Crop damage is directly related to deer density (Conover 1989, Vecellio et al. 1994, Braun 1996) and raccoon density (J. C. Beasley, unpublished data); therefore, management strategies that include decreasing densities of such species in woodlots adjacent to corn and soybean fields should help reduce crop damage, at least temporarily (Yoder 2002). Future studies aimed at evaluating temporal aspects of population

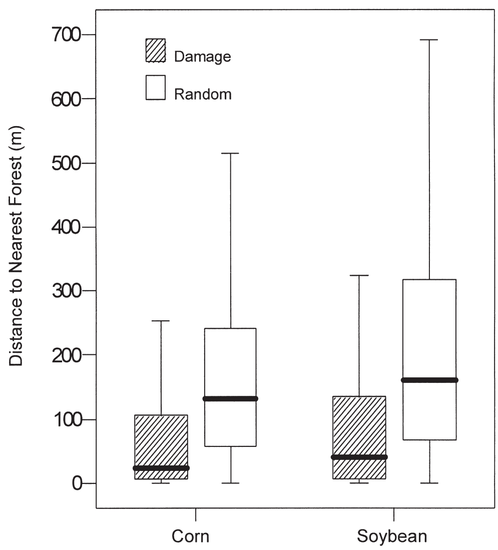

FIGURE 1. Locations of wildlife damage in corn and soybean fields usually were found nearer to forested habitats than were random points. Plots depict the median (thick horizontal line), interquartile range (box), and outliers (vertical bars).

Table 2. Binary logistic regression models predicting point location type (damage or random) in 160 corn and soybean fields in northern Indiana in 2003 and 2004. The models reported here were the best models for each crop type as indicated by Akaike Information Criterion (AIC) values, selected from all possible models using 3 predictor variables (distance to nearest forest patch [D Forest], distance to nearest developed area [D Developed], and distance to nearest grassland-shrubland [D Grass]). All models reported here were significant at $P < 0.001$ as evaluated by the model χ^2. All models other than those reported here had ΔAIC values > 2.00.

Corn model	ΔAIC	% correct[a]	Nagelkerke r^2	Variable	Coefficient	SE
1	0.00	64.6	0.146	Intercept	0.764	0.055
				D Forest	-0.006	0.001
2	0.81	64.8	0.147	Intercept	0.697	0.082
Soybean model	**ΔAIC**	**% correct**	**Nagelkerke r^2**	**Variable**	**Coefficient**	**SE**
1	0.00	67.0	0.145	Intercept	0.082	0.105
				D Forest	-0.004	0.001
				D Develed	0.002	0.001
2	1.23	67.2	0.145	Intercept	0.125	0.116
				D Forest	-0.004	0.001
				D Develed	0.002	0.001
				D Grass	-0.001	0.001

[a] Percentage of point locations correctly classified as damage or random by the logistic model.

reductions and movements among landscape elements in agricultural landscapes should prove beneficial.

Our model results were very similar for both corn and soybean fields. The best logistic models (as indicated by AIC values) included distance to forest and distance to developed areas as predictor variables, and all had pseudo r^2 values of 0.15. Retamosa et al. (in press) likewise found that many of the same local and landscape variables were important in predicting damage to both corn and soybeans on a field-level basis. Even though in our study area raccoons were primarily responsible for damage to corn and white-tailed deer were primarily responsible for damage to soybeans (Humberg et al. 2007), both species are considered edge species (Wishart 1984, Craven and Hygnstrom 1994, Dijak and Thompson 2000, Kuehl and Clark 2002) and have similar habitat requirements. Thus, certain habitat conditions at a variety of spatial scales appear to influence the severity corn and soybean damage similarly (Retamosa et al., in press).

Most wildlife damage issues can be managed effectively with an integrated program that may consist of fear-provoking stimuli, habitat alterations, and lethal reductions of wildlife populations (Conover 2002); protecting Midwestern row crops from wildlife depredation is no exception. Ultimately, protecting corn and soybean crops may be accomplished most effectively by manipulating landscape elements (Landis et al. 2000, Retamosa et al., in press). However, we also suggest that targeted removals of raccoons and white-tailed deer may help alleviate crop damage in areas where depredation by these species is particularly problematic.

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