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Abstract: Wildlife damage to crops is a widespread concern among agricultural producers and wildlife professionals. In the United States, raccoon (*Procyon lotor*) damage to field corn (*Zea maize*) has become a serious concern, as raccoon depredation to corn has increased significantly in recent years. However, little information is available to suggest the underlying factors responsible for recent increases in raccoon depredation on agricultural crops because there is a limited understanding of the ecological factors influencing wildlife damage to crops at local scales. During 2004, we initiated a study to elucidate the ecological factors influencing depredation to field corn by raccoons, and, in particular, to determine the relationship between local raccoon abundance and raccoon damage to corn. We used mark-recapture techniques to trap raccoons in 14 forest patches in northern Indiana and estimated raccoon abundance for each patch using the Huggins closed capture maximum likelihood approach in Program MARK™. All cornfields adjacent to the trapped forest patches were surveyed for raccoon damage to obtain patch-specific estimates of crop damage for each patch. We used the best subsets regression moderated by r^2 and Akaike's information criterion (AIC$_c$), as well as stepwise multiple linear regression to model the influence of raccoon abundance, raccoon sex and age ratios, and landscape characteristics (e.g., forest patch size, isolation) on the amount of damage incurred to cornfields by raccoons. Both best subsets and stepwise regression produced an optimal model that included raccoon abundance and the proportion of forest patch edge bordered by corn as important predictors of raccoon damage to corn. Both raccoon abundance and the proportion of forest patch edge bordered by corn were positively related to the amount of raccoon damage to corn. The results of our study support the supposition that recent increases in raccoon abundance throughout much of the midwestern United States likely have contributed to the concomitant increases in damage to agricultural crops observed in this region. Although current management regimes for raccoons appear to be ineffective at regulating raccoon populations at the landscape level, our results suggest that sustained localized management of raccoon populations may decrease the amount of damage incurred to cornfields at local scales.

Key words: corn, crop damage, human–wildlife conflicts, Indiana, mark-recapture, *Procyon lotor*, Program MARK, raccoon, wildlife damage management

Wildlife damage to agricultural crops is a serious concern affecting much of the world today (e.g., Nyhus et al. 2000, O'Connell-Rodwell et al. 2000, Singleton et al. 2005). In the United States alone, annual economic losses caused by wildlife currently exceed $22 billion, with wildlife damage to agricultural crops comprising a substantial portion of these losses (Conover 1998, 2002). Although wildlife-caused losses represent only an estimated 1% of the total value of agricultural production in the United States, data from agricultural and wildlife professionals indicate that wildlife damage to field crops has increased significantly in the last few decades (Wywialowski 1994, 1997). Although little information is available to suggest the underlying ecological factors responsible for the observed increases in wildlife damage, fluctuations in the abundance of wildlife populations undoubtedly are a

critical factor contributing to annual variation in crop damage. For example, crop damage is positively related to white-tailed deer (*Odocoileus virginianus*) density (Flyger and Thoerig 1962, Hartman 1972, Vecellio et al. 1994, Braun 1996).

Although a number of species have been linked to crop depredation in the United States, crop damage by deer and raccoons (*Procyon lotor*) is the most recognized and widespread (Conover and Decker 1991, Wywialowski 1997, Conover 1998, 2002). While white-tailed deer often are considered to be the species primarily responsible for depredation to field corn (*Zea maize*; Craven and Hygnstrom 1994, Conover 1998), damage to corn by raccoons also can be extensive (Conover 1998, Humberg et al. 2007). For example, in northern Indiana 87% of 73,000 corn plants were damaged by wildlife, recorded in 100 fields over 2 growing seasons. The damage

was attributed to raccoons (Humberg et al. 2007). Differences among studies in estimates of the quantity of crop damage, as well as in the species identified as being responsible for crop damage, likely reflect differences in landscape characteristics and abundance of wildlife populations among agricultural regions.

Damage to corn by raccoons is a serious concern among agricultural producers in the United States (second only to deer), with 25% of producers reporting raccoon damage to crops (Conover 1998, 2002). Corn is the preferred food item of raccoons in agricultural landscapes, and, when available, it can comprise >50% of their diet (Giles 1939, Rivest and Bergeron 1981, Kaufmann 1982). Thus, landscapes supporting elevated raccoon populations likely incur substantial damage to corn, particularly during years when the availability of alternative food sources (e.g., mast) is limited. Throughout much of the midwestern United States, raccoon populations have dramatically increased over the past 15 years (Gehrt et al. 2002, Plowman 2003). Responding positively to changing land-use practices, raccoons have reached their highest abundances in urban and agricultural environments (Pedlar 1994, Prange et al. 2003). From 1957 to 1987, the percentage of wildlife agencies reporting damage to crops by raccoons increased from 10% to 94% (McDowell and Pillsbury 1959, Conover and Decker 1991). The widespread increases in reports of raccoon damage to crops likely are tied to recent increases in raccoon abundance; however, no information is available to suggest how closely localized increases in raccoon abundance correspond to increases in crop damage at small spatial scales.

In areas of sparse forest, the distribution and density of wildlife populations often varies directly with the abundance of woody cover (Bayne and Hobson 2000, Virgós 2002, Pardini et al. 2005, Beasley et al. 2007a); thus, studies identifying forested habitat as an important factor influencing crop damage often imply that increased animal abundance is the underlying mechanism governing the amount of damage sustained by crops. Previous research has identified landscape components associated with forested habitats as being critical factors influencing the amount of wildlife damage to crops at both local and landscape scales

Raccoon damage to field corn.

(Garrison and Lewis 1987, Braun 1996, Naughton-Treves 1998, Retamosa 2006, Linkie et al. 2007). For example, in a fragmented region of Indiana, Retamosa (2006) observed a positive relationship between the amount of forested area within the landscape and the rate of damage incurred to corn and soybean crops by wildlife at a coarse spatial scale, while fine-scale analyses revealed that mean forest patch size and amount of forest edge significantly influence depredation levels locally. However, few studies have attempted to directly quantify the relationship between animal abundance and depredation to crops (Flyger and Thoerig 1962, Hartman 1972, Vecellio et al. 1994, Braun 1996, Siex and Struhsaker 1999), and no studies have explored this relationship for raccoons. Moreover, there is no a priori reason to suspect that the relationship between raccoon abundance and raccoon damage to crops is linear, as depredation levels may vary as a function of sex or age for raccoons, and there may be a threshold population size at which additional damage becomes negligible (due to the availability of partially consumed ears on the ground).

Given the substantive damage that is sustained by crops from raccoons each year, elucidation of the relationship between raccoon abundance and raccoon depredation to crops is critical. Without an understanding of this relationship, management strategies that seek to address human–wildlife conflicts involving crop depredation by raccoons through manipulation of raccoon abundance cannot

be appropriately implemented. In particular, a clear understanding of this relationship is critical at fine spatial scales. Given the congruent relationship between raccoon harvest and pelt price, and current low value of pelts, successful management of raccoon populations is most likely to occur at local scales (Gehrt et al. 2002, Plowman 2007). In our study, we examined the influence of local landscape characteristics and raccoon population parameters on the extent of damage to field corn by raccoons. Our objective was to quantify the relationship between raccoon abundance and raccoon damage to field corn at small spatial scales, as well as to model variance in raccoon damage to field corn in response to raccoon abundance, forest patch size, forest patch isolation, proportion of woodlot edge bordered by corn, and raccoon sex and age ratios.

Study area

Our 1,165-km² study area was located in the Upper Wabash River Basin (UWB) in northcentral Indiana, USA (Moore and Swihart 2005), comprising portions of Grant, Huntington, Miami, and Wabash counties. We chose this study area because the landscape of the UWB was representative of fragmented agricultural landscapes throughout the midwestern United States, and we had extensive data on the movement behavior of raccoons and crop depredation patterns of wildlife in this region (Beasley et al. 2007*a*, *b*; DeVault et al. 2007; Humberg et al. 2007). The topography within the UWB was flat, with gently rolling areas near 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. 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-hickory-maple [*Quercus-Carya-Acer*]) in the UWB were highly fragmented. Across 35 of the 23-km² landscapes analyzed within the UWB

by Moore and Swihart (2005), 75% of the forest patches were <5 ha, 50% were <2 ha, and only 1% of patches were >100ha.

Methods

We conducted trapping from March 28 through May 25, 2004, in 14 forest patches distributed throughout the study area. Forest patches were selected based on their size and degree of isolation in an effort to reflect the observed distribution of these variables in the study area. We captured raccoons using box live traps (Tomahawk Live Trap Co., Tomahawk, Wis.) baited with commercial cat food. Traps were placed in a grid (50-m spacing) within forest patches and pre-baited for 1 night. Following the pre-baiting period, traps were opened and maintained for 10 consecutive nights. The total number of traps per grid varied with forest patch size, and a maximum of 30 traps were placed in any single forest patch. We immobilized captured raccoons with an intramuscular injection of Telazol at a rate of 5mg/kg of estimated body mass (Gehrt et al. 2001). All captured raccoons were ear-tagged (Monel #3, National Band and Tag Company, Newport, Ky.), weighed to the nearest 0.1 kg, sexed, and aged (tooth-wear technique; Grau et al. 1970). Raccoons were classified as juveniles (<1 year), yearlings (1–2 years), or adults (>2 years); however, due to low sample sizes, juveniles and yearlings were combined for all analyses. Following their recovery, captured individuals were processed and released at the capture site. For all recaptured raccoons, we recorded the ear tag number and released them without immobilization. All trapping and handling methods conformed to Purdue University Animal Care and Use Committee policies under Protocol 01-079.

For each woodlot, we estimated female-to-male sex ratios and yearling- (yearlings and juveniles) to-adult age ratios. To compute raccoon abundance estimates, we used the Huggins closed capture-recapture modeling procedure (Huggins 1989, 1991) in Program MARK (White and Burnham 1999). We chose the Huggins modeling procedure to be run with the closed models maximum likelihood estimator because the Huggins approach allows the incorporation of covariates (e.g., sex, age) into models. The Huggins estimator

Female raccoon with young.

includes parameters for initial capture (p) and recapture (c) probabilities, but differs from other estimators in that N is a derived parameter from the number of unique animals captured and p (Finley et al. 2005). The exclusion of population estimates from the likelihood function allows initial efforts to be centered on obtaining parsimonious estimates of p and c for the combined data set, which then can be used to generate more accurate estimates of N for subsets of the data (e.g., forest patches; White 2005).

Many of the smaller forest patches where we trapped provided little information about the detection probabilities of individuals within each patch (i.e., too few individuals per patch). To overcome problems associated with low numbers of individuals per patch, we modeled the combined data from 13 of the woodlots to obtain parsimonious models of the p and c parameters for the combined data set, but obtained woodlot specific estimates of N by treating each woodlot as a disparate attribute group in MARK (Finley et al. 2005, White 2005). Both sex and age of raccoons were considered in the models as covariates. We used a bias-corrected version of Akaike's information criterion (AIC$_c$; Burnham and Anderson 2002) to rank models, with the best model having the lowest AIC$_c$ value. One forest patch was trapped for 4 days due to logistical constraints. This patch was not modeled in combination with the other 13 patches, as MARK requires equal lengths of capture histories among attribute groups. Therefore, we estimated the population size for this patch disparately, using the model selected from the combined patch analysis.

We surveyed all cornfields (23) adjoining the 14 forest patches for damage by raccoons (including those cornfields across roads when woodlots abutted roads). Raccoons primarily damage corn ears between the milk and mature stages of development (MacGowan et al. 2006, Humberg et al. 2007); thus, fields were surveyed in mid-September (13th) after crops had matured to ensure that most of the total damage that would occur throughout the growing season would be observed. To ensure that damage only by raccoons was counted, 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 wildlife species responsible for damage. Additionally, all technicians had previously participated in a crop depredation study conducted in the same landscape, and, therefore, they had extensive experience identifying and distinguishing wildlife crop damage (see Humberg et al. 2007).

In each cornfield adjacent to forest patches trapped for raccoons, sampling crews (2 individuals) walked 5 m apart starting 5 m into the field and walked the entire length of the field (except when fields extended beyond the length of the forest patch). In situations where cornfields extended beyond the edge of forest patches where raccoon traps were set, we extended sampling transects for those fields 25 m beyond the forested edge, regardless of the size of the field. The count of all corn plants (both those standing and those on the ground) that were damaged by raccoons were recorded and each plant was marked clearly with paint to avoid double counting. We were able to accurately observe damage within 5-m of each transect; therefore, we assumed that all raccoon damage between the field edge and 20 m into each field was recorded. Over 85% of raccoon damage to corn recorded in a contemporaneous crop depredation study in the same landscape occurred within 20 m of forested edges (Beasley, unpublished data; DeVault et al. 2007); therefore, we assumed that the 20-m sampling design sufficiently represented the magnitude of damage sustained in each field. To standardize damage estimates across forest

patches by area, we divided the combined total number of plants damaged from all fields surrounding a forest patch by the total area sampled for that patch.

To define landscape characteristics associated with each forest patch, we used a geographic information system (GIS) developed from 1998 U.S. Geological Survey digital orthophotos of 1-m resolution. Habitat types were delineated as forest (closed-canopy forests, including deciduous and evergreen); shrubland (ranging from scattered trees in an open matrix to open-canopy forests); corridors (habitat with trees >3 m in height and <30 m in width spanning some distance between 2 larger habitats); grassland (open areas not allocated to agriculture); agriculture (all types of crops, excluding tree plantations); water (open, nonlinear water bodies, rivers, and streams >3 m wide); and developed (cities, farmhouses delineated by the mowing line, and animal-holding facilities).

The proportion of each forest patch's total edge that occurs adjacent to corn likely influences the amount of damage incurred to the cornfields surrounding that patch. Cornfields adjacent to patches with a low percentage of edge in corn likely are damaged disproportionately more than cornfields adjacent to forest patches that are completely surrounded by corn because of the limited availability of alternative food resources. Therefore, the crop types of all fields surrounding forest patches sampled for raccoons were incorporated into the GIS to determine the proportion of each patch surrounded by corn. We used ArcGIS 9.0 (Environmental Systems Research Institute, Redlands, Calif. 2004) to measure the total crop edge sampled during damage surveys, the proportion of edge bordered by corn for each trapped forest patch, and the overall size of trapped patches. We calculated an index of isolation for each forest patch using patch-based metrics in FRAGSTATS 3.3 (McGarigal et al. 2002). Metric calculations for each patch were based on a 1-km search radius with an 8-neighbor rule (for patch delineation). A 1-km search radius was selected because it encompassed an area (314 ha) >1.5 times the largest home range observed for raccoons in our study area (191 ha; Beasley et al. 2007b).

Using general linear models, we evaluated the amount of damage incurred to cornfields

by raccoons as a function of habitat and demographic variables. Explanatory variables tested included (1) forest patch size, (2) forest patch isolation, (3) the proportion of woodlot edge bordered by corn, (4) raccoon abundance, (5) female-to-male sex ratio, and (6) yearling-to-adult age ratio. We used best subsets regression moderated by r^2 and Akaike's information criteria corrected for small sample size (AIC_c), as well as stepwise linear regression to identify the most parsimonious model(s) that accurately predicted the response variable (Burnham and Anderson 2002). Stepwise regression builds models by selecting subsets of explanatory variables that best explain the variance in the response variable. Explanatory variables were selected for inclusion and subsequent retention into the model at α = 0.15. We examined correlations among each of the explanatory variables using Pearson's correlation coefficients. Those variables selected for inclusion in the final model were further explored (including interactions) using analysis of covariance (ANCOVA) to elucidate any patterns in crop damage across varying levels of the explanatory variables.

To elucidate the nature of the relationship between raccoon abundance and crop damage, we explored the fit of both linear and nonlinear (i.e., quadratic and cubic) regression models. We evaluated the fit of higher-order terms relative to the linear model by incorporating the cubic and quadratic terms into our linear model to examine their contribution to the model. All statistical analyses were performed using SAS, version 9.1 (SAS Institute, Cary, N. C.).

To evaluate local economic losses to cornfields relative to variance in raccoon abundance and forest patch size, we used the damage estimates (plants/m²) observed in our study to simulate damage to 4 hypothetical forest patches that we created based on the range of forest patch sizes observed in our study area, assuming that each patch was completely surrounded by corn. These simulated forest patches represented the mean (7.3 ha), as well as the quartiles of the range of the distribution of forest patch sizes in our study area (i.e., 61 ha, 121 ha, and 182 ha). We assigned a perimeter length to each hypothetical forest patch based on the mean and quartiles of forest patch perimeter lengths in our study area using ArcGIS 9.0 (Environmental Systems

Research Institute, Redlands, Calif. 2004). The amount of damage incurred to each patch relative to variance in raccoon abundance was estimated by multiplying the amount of area within a 20-m buffer surrounding the patch by damage rates (plants/m²) derived from our regression model equation. Based on average planting rate observed in our study area, we estimated the density of corn stalks to be 6.7 corn plants per m². From this estimate, we derived economic losses for each patch using a yield of 395 bushels per ha at an estimated cost of $2.49 per bushel (Hurt 2006).

Results

We captured 120 individual raccoons (64 males and 56 females) and recorded 224 total captures (including recaptures) over 2,461 trap nights. The overall recapture rate of raccoons was 47%, although recapture rates varied substantially among patches (range: 0–73%). The number of raccoons captured per forest patch was highly variable, as well, ranging from 2 to 22 ($\bar{x}$ = 8.6, SD = 6.3). Within forest patches, female-to-male sex ratios ranged from 0 to 1.4 females per male ($\bar{x}$ = 0.9, SD = 0.7), and

yearling to adult age ratios ranged from 0 to 1.4 yearlings per adult ($\bar{x}$ = 0.4, SD = 0.5).

We computed 19 models in Program MARK, with the top 4 models deviating ≤2 AIC_c units from one another (Table 1). Models 1, 2, and 4 supported the inclusion of the individual covariates sex or age; however, we generated population size estimates for each woodlot with the {p(t) = c(t)} model, where t reflected differences in trapping occasion, as this model contained the fewest parameters among the top 4 models and differed by <1 AIC_c unit from the highest ranking model. Based on this model, the average number of raccoons per woodlot was 10.8 (range = 2–27, SE = 1.5).

In 23 cornfields that surrounded the 14 trapped patches, we recorded 16,749 corn plants damaged by raccoons. The number of plants damaged per woodlot was highly variable, ranging from 10 to 4,859 ($\bar{x}$ = 1,196, SD = 1,570); however, 13 woodlots had <4,000 plants damaged, and 10 woodlots had <1,000 plants damaged. Damage estimates per unit area (total damage per field divided by the area sampled) ranged from 0.004 to 0.27 ($\bar{x}$ = 0.09, SE = 0.03) plants damaged per m². The proportion

Table 1. Model selection results of the 19 models constructed in Program MARK to estimate raccoon abundance for 13 forest patches in northern Indiana, 2004.

Model[1]	AIC_c	ΔAIC_c	AIC_c weights	Model likelihood	No. of parameters	Deviance
{p(t+sex) = c(t+sex)}	1073.528	0.0	0.2776	1.0	11	1051.302
{p(t) = c(t+sex)}	1074.178	0.65	0.2005	0.7224	11	1051.952
{p(t) = c(t)}	1074.25	0.72	0.19351	0.6971	10	1054.062
{p(t+sex+age) = c(t+sex+age)}	1075.537	2.01	0.10169	0.3663	12	1051.269
{p(t+sex) = c(t)}	1075.609	2.08	0.09809	0.3534	11	1053.383
{p(t+age)c(t+age)}	1076.144	2.62	0.07504	0.2703	11	1053.918
{p(.+sex) = c(.+sex)}	1079.137	5.61	0.0168	0.0605	3	1073.117
{p(.) = c(.+sex)}	1079.842	6.31	0.01181	0.0425	3	1073.821
{p(.) = c(.)}	1080.054	6.53	0.01063	0.0383	2	1076.043
{p(.+age) = c(.+age)}	1081.71	8.18	0.00464	0.0167	3	1075.69
{p(.) = c(.+age)}	1082.061	8.53	0.00389	0.014	3	1076.041
{p(.+age) = c(.)}	1083.091	9.56	0.00233	0.0084	4	1075.057
{p(.+sex) = c(.)}	1083.355	9.83	0.00204	0.0073	4	1075.321
{p(t)c(t+sex)}	1086.416	12.89	0.00044	0.0016	19	1047.761
{p(t)c(t)}	1086.451	12.92	0.00043	0.0015	18	1049.861
{p(t+sex)c(t+sex)}	1087.736	14.21	0.00023	0.0008	20	1047.011
{p(t)c(t+age)}	1088.516	14.99	0.00015	0.0005	19	1049.861
{p(t+sex+age)c(t+sex+age)}	1089.726	16.2	0.00008	0.0003	21	1046.928
{p(t+age)=c(t+age)}	1090.363	16.83	0.00006	0.0002	20	1049.638

[1]Model notation: p = initial capture probability; c = recapture probability; t = time-specific detection probability, by trapping occasion; sex = raccoon's sex; age = raccoon's age (yearling or adult)
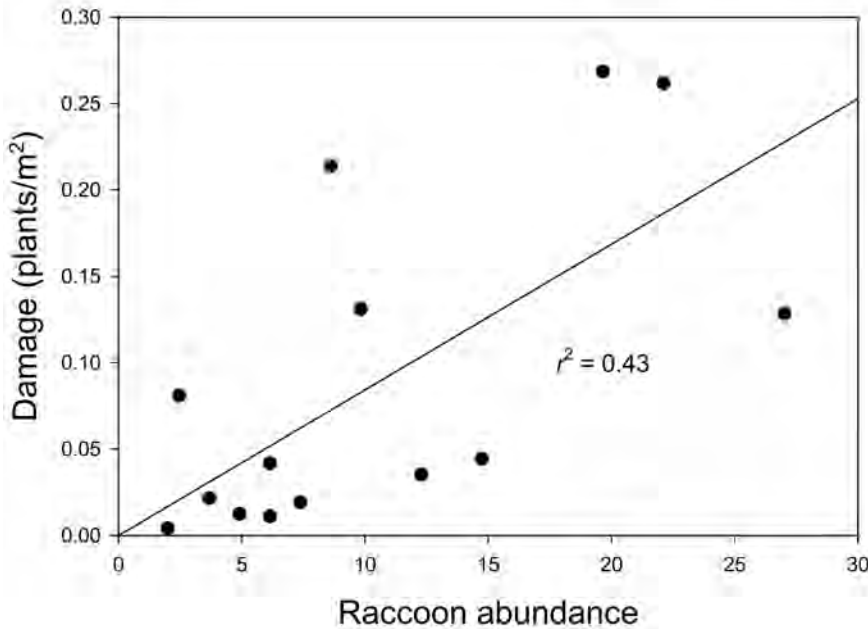
FIGURE 1. Relationship between raccoon abundance and the amount of damage incurred to adjacent cornfields by raccoons for 14 forest patches in northern Indiana, 2004. Crop damage is represented as the number of damaged plants per unit of area sampled.

of woodlot edge bordered by corn ranged from 0.10 to 1.0 ($\bar{x}$ = 0.56, SE = 0.08). Forest patch size, corrected for the effective area trapped, ranged from 0.5 to 16.3 ha ($\bar{x}$ = 6.5, SD = 4.9).

Pearson's correlation tests indicated that raccoon abundance and sex ratio were significantly correlated (*P* = 0.02). Our primary objective was to elucidate the influence of raccoon abundance on the extent of crop damage. Therefore, we excluded raccoon sex as a variable from our model. However, given the significant correlation between female-to-male sex ratio and raccoon abundance, we further explored the association among these variables, which revealed a strong positive relationship (r^2 = 0.36).

Stepwise regression and best subsets regression both selected the same "best model," identifying raccoon abundance and the proportion of forest edge bordered by corn as important predictors of raccoon damage to field corn (*F* = 6.73, *P* = 0.012, r^2 = 0.55; Table 2). However, only raccoon abundance was significant at the α = 0.05 level (*t* = 3.48, *P* = 0.005). Individually, both raccoon abundance (r^2 = 0.43; Figure 1) and the proportion of

forest edge bordered by corn (r^2 = 0.06) were positively related to the amount of damage incurred to field corn by raccoons. Although the proportion of forest edge bordered by corn was not significant in the final model at the α = 0.05 level (*t* = 1.70, *P* = 0.12), the inclusion of this variable increased the overall model r^2 from 0.43

TABLE 2. Model selection results of the best 1, 2, 3, 4, and 5 variable models in comparison with the null model, ranked by r^2 and Akaike's information criteria corrected for small sample size, predicting the amount of raccoon depredation to field corn in northern Indiana, 2004.

r^2	AIC_c	ΔAIC_c	Variable
0.55	-70.03	0.00	abundance, edge
0.43	-69.94	0.86	abundance
0.56	-66.65	3.38	abundance, age, edge
0.57	-62.22	7.81	abundance, isolation, age, edge
0.58	-56.78	13.25	abundance, size, isolation, age, edge
0.00	12.95	82.98	null model

Note: Abundance = raccoon abundance; edge = proportion of woodlot edge bordered by corn; isolation = degree of woodlot isolation; age = raccoon yearling to adult age ratio; size = size of woodlot.
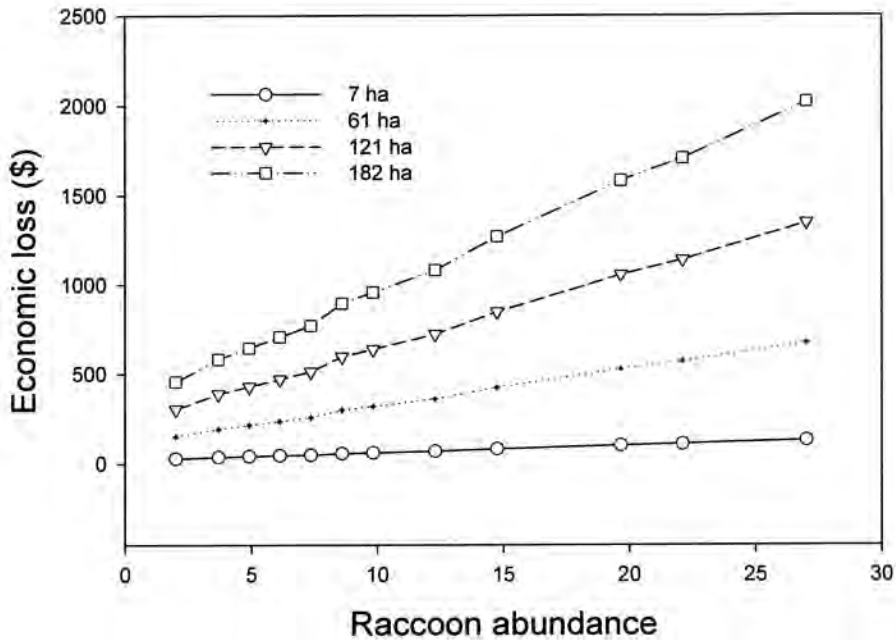
FIGURE 2. Predicted relationship between raccoon abundance and economic losses to corn crops as a function of forest patch size across 4 hypothetical forest patches. Economic loss was estimated using a yield of 395 bushels/ha at $2.49/bushel. Forest patch sizes represent the mean, as well as the quartiles of the range of the distribution of patch sizes in our study area, Indiana, USA.

(with only raccoon abundance included in the model) to 0.55.

Given the substantial contribution of corn edge in model predictability, we used ANCOVA to explore the relationship between raccoon abundance and crop damage across varying proportions of corn edge. We assigned 3 categories to proportions of corn edge: (1) 0–0.33, (2) 0.34–0.66, and (3) 0.67–1.0. We left raccoon abundance as a continuous covariate in the model. The relationship between raccoon abundance and raccoon damage to corn did not differ across levels of corn edge ($F = 0.47$, $P = 0.67$) or as a function of the interaction between corn edge and abundance ($F = 0.78$, $P = 0.49$).

We explored both linear and nonlinear models to explain the relationship between raccoon abundance and raccoon damage to corn. While models, including higher-order terms (i.e., quadratic, cubic), improved the r^2 relative to the linear model, these terms were not significant in the model ($P > 0.05$); thus, we felt the linear model produced the best fit to our data.

Among our hypothetical forest patches, monetary losses varied as a direct function of raccoon abundance for all patch sizes and crop yields (Figure 2). However, economic losses also varied substantially among forest patch sizes, with larger patches sustaining greater losses than smaller patches. For example, within the range of abundance estimates observed in this study, losses exceeded $1,000 for our 2 largest forest patches (121 ha and 182 ha), while for the smallest forest patch (7.3 ha) losses did not exceed $200 at any yield.

Discussion

Raccoon abundance clearly was identified as an important predictor of the amount of damage incurred to cornfields by raccoons. Given the importance of corn to raccoons in agricultural landscapes (Rivest and Bergeron 1981, Kaufmann 1982), it is not surprising that raccoon abundance alone predicted a substantial portion of the variance in crop damage among patches and that raccoon abundance was positively and linearly related to the amount of raccoon damage to corn. However, in more heavily forested landscapes, the relationship between raccoon abundance and crop damage may differ or be less pronounced because of the increased availability of alternative food resources.

Of the models we evaluated, by far the one

that included both raccoon abundance and the proportion of forest edge bordered by corn explained the most variance in the amount of crop damage incurred by raccoons. When available, agricultural crops or foods associated with crops (e.g., insects) serve as the primary food resources for raccoons in agricultural landscapes (Rivest and Bergeron 1981). Given the positive relationship we observed between raccoon damage and the amount of edge bordered by corn, elevated levels of depredation in fields adjacent to woodlots predominantly surrounded by corn likely reflected a lack of alternative food resources (e.g., insects in soybean fields) proximal to that patch.

Across forest patches, the proportion of female raccoons within a patch was positively related to the overall abundance of raccoons in that patch. Female raccoons, due to parturition and rearing, are more constrained in terms of their resource needs than are males. Thus, forest patches containing elevated proportions of females likely contain higher quantities of critical resources and subsequently can support larger raccoon populations than can patches containing a limited availability of resources. The substantial demographic variance observed in sex and age ratios of raccoons among forest patches suggests that resource availability likely differed considerably among patches in our study area.

Recent research has suggested that economic losses to crops by raccoons can be substantial (Conover 1998, 2002; Humberg et al. 2007). Among our hypothetical forest patches, monetary losses varied as a direct function of raccoon abundance for all patch sizes. Despite minimal predicted economic losses (<$200) within cornfields adjacent to forest patches of the average size observed in our study area, even at the highest abundance of raccoons we observed (n = 27), estimated economic losses sustained to crop fields adjacent to larger forest patches rapidly exceeded the reported tolerance levels of landowners (McNew 2004). Agricultural landscapes in other regions contain much larger forest fragments than did those surveyed for damage in our study area. Thus, the substantive, damage-related monetary losses predicted for fields adjacent to large simulated forest patches (>60 ha) suggests that the economic impact of raccoons in agricultural landscapes containing large forest patches likely is substantial, particularly if those patches support abundant raccoon populations. However, it is important to note that for the largest simulated patch in our study, losses probably were overestimated, as large forest patches rarely are completely surrounded by corn, and these patches likely contain high quantities of alternative food resources.

Our results provide support for the hypothesis that recent increases in raccoon abundance throughout much of the midwestern United States have contributed to the increased levels of crop damage observed in this region. Further increases in raccoon abundance likely will significantly increase the extent of damage incurred to field corn unless additional management for this species is implemented. Harvest is now one of the primary causes of raccoon mortality throughout much of their range (Kaufmann 1982, Sanderson 1987, Gehrt 2003). However, due to the current low value of raccoon pelts, landscape level management for this species through commercial trapping is unlikely to reduce raccoon depredation to corn. Fortunately, our models suggest that even small reductions in raccoon numbers in forest patches harboring large populations of raccoons could substantially reduce the economic losses incurred to crops locally. Thus, targeted management of raccoon populations (i.e., direct removal) potentially could be highly effective in reducing the extent of damage to field corn at local scales, giving individual landowners who are experiencing excessive crop damage the ability to reduce damage levels through a maintained raccoon harvest regime (Rosatte et al. 2007).

Acknowledgments

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