Predicting Raccoon, *Procyon lotor*, Occurrence Through the Use of Microhabitat Variables

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Baldwin, Roger A., Allan E. Houston, Michael L. Kennedy, and Pin Shuo Liu. 2006. Predicting Raccoon, *Procyon lotor*, occurrence through the use of microhabitat variables. Canadian Field-Naturalist 120(2): 225-231.

Recent increases in Raccoon (*Procyon lotor*) abundance have been implicated for decreased nesting success of songbirds and transmission of rabies. Understanding the relationship between occurrence and microhabitat factors should be helpful in managing this species, though our current understanding of this relationship is inadequate. Therefore, we conducted a study in western Tennessee during 2000–2002 to determine this association. Occurrence (capture) data were assessed from results of live trapping at 176 and 112 trap sites during winter and summer, respectively, at three sites. A maximum of 26 habitat variables were measured at each trap location; all grids were combined for statistical analyses to account for varying relationships between occurrence and microhabitat factors across different landscapes. Univariate and stepwise logistic-regression analyses were used to assess associations among microhabitat variables and occurrence. Resulting models were validated through the jackknife procedure. Predictive equations were constructed from logistic-regression models to compute capture probabilities. Univariate analyses yielded numerous significant variables with those representing forest characteristics and proximity to water generally the most significant. Strong concordance was observed between winter and summer seasons for most variables though several differed (number of large hardwood snags, ground dens, and plant food species, distance to potential water and roads). Such temporal variability was expected due to seasonal differences in habitat components and biological needs of Raccoons. Variables included in derived models were similar to those scoring highest in univariate analyses; classification rates for models (winter = 72%; summer = 78%) were among the highest recorded for generalist species. By accounting for landscape attributes and replicating across sites, more accurate and useful models were developed. Such models should provide the information required to effectively manage this species.

Key Words: habitat partitioning, logistic regression, mesopredator, microhabitat, *Procyon lotor*, Raccoon, western Tennessee.

Raccoons (*Procyon lotor*) and their associated habitats have been the subject of several biological investigations (see Lotze and Anderson 1979; Kaufmann 1982; Broadfoot et al. 2001; Gehrt 2003). At a landscape level, this medium-sized predator (mesopredator) is thought to be most abundant in aquatic associated habitats (Johnson 1970; Minser and Pelton 1982). However, Raccoons can thrive in an array of habitats although seeming to depend on particular features to reach high and stable populations (Broadfoot et al. 2001; Zeveloff 2002). Several investigators (i.e., Morris 1987; Pedlar et al. 1997; Chamberlain et al. 2002) have noted that knowledge of spatial scale and landscape composition is integral to understanding habitat associations of species, though at present, much of the understanding of the relationship of Raccoons to their habitat is based on assumptions drawn from investigations (e.g., Sanderson 1987; Minser and Pelton 1982; Oehler and Litvaitis 1996) conducted at the landscape level (macrohabitat). The relationship between the occurrence (defined as presence at a location) of Raccoons and microhabitat factors has not been studied at multiple sites collectively and findings of previous investigations (Leberg and Kennedy 1988; Kennedy et al. 1991; Kissell and Kennedy 1992; Pedlar et al. 1997) indicate various associations depending on season and location. Currently the relationship between the occurrence of Raccoons and habitat variables appears to be unclear and in need of additional study (Kissell and Kennedy 1992; Chamberlain et al. 2003), and models allowing for the prediction of occurrence based on microhabitat factors are lacking from the published literature.

Previous studies (Noss et al. 1996; Oehler and Litvaitis 1996; Rogers and Caro 1998) have indicated that due to a combination of factors (e.g., removal of top predators, altered land use, reduced hunting), abundance of mesopredators has increased in recent years. Estes (1996) noted that increased mesopredator populations could influence numerous aspects of ecosystems. For example, high densities can have negative effects on populations of ground-nesting birds (Crabtree and Wolf 1988; Vickery et al. 1992; Schmidt 2003) and, by enhancing the spread of diseases, can impact negatively the health of populations (Carey and McLean 1983; Hill et al. 1993; Schuburt et al. 1998; Rosatte 2000). Predators play an important role in structuring biological communities (Meffe et al. 1997), and an increase in abundance of these species requires strong management and conservation planning to limit the negative impact of these taxa on ecosystems. However, sound management and conservation plans are difficult to derive without a clear understanding of specific habitat factors critical to target species. At this time, managers of natural resources are faced with increasing populations of Raccoons but limited habitat information on which to make management decisions (see Rosatte 2000 for the consideration of habitat factors in controlling rabies). In particular, models allowing for the prediction of Raccoon occurrence are lacking. For example, certain factors are important components in determining Raccoon occurrence (e.g., den sites and aquatic habitats, Pedlar et al. 1997; Broadfoot et al. 2001; Henner et al. 2004). However, the exact relationship among these components is not known, thereby requiring individuals to make management decisions without the necessary information (i.e., containing rabies outbreaks, Rosatte et al. 2001). Therefore, the purpose of this study was to assess at a microhabitat scale the relationship of occurrence of Raccoons (based on capture frequency) with selected habitat factors from multiple sites representing a mosaic of habitat types. Specifically, the following predictions were assessed: (1) there is an association between occurrence (based on capture) and selected (individual) habitat variables; and (2) selected habitat variables can be used to construct models predictive of species occurrence.

Study Area

This study was conducted in temperate deciduous forest in western Tennessee characterized by a fragmented landscape consisting of various levels of forest, early successional and agricultural fields, residential buildings, and road systems at three sites. Site 1 was located at the Edward J. Meeman Biological Station (Meeman), which was located approximately 20 km north of Memphis, Tennessee (35°33'N, 90°09'W). This location was comprised primarily of hardwood forests with old-field and Kudzu (*Pueraria lobata*) habitats interspersed throughout. Old-fields were dominated by goldenrod (*Solidago* spp.), fescue (*Festuca* spp.) and Switch Grass (*Panicum virgatum*). Topography of the site was characterized by numerous drainages that resulted in a gently rolling terrain throughout the area. Upland and bottomland forests included various oaks (*Quercus* spp.), hickories (*Carya* spp.), and maples (*Acer* spp.) as well as Tulip Poplar (*Liriodendron tulipifera*) and Sweet Gum (*Liquidambar styraciflua*; Maris 1998). Several small ponds and intermittent streams occurred throughout the site.

Sites 2–3 were located at the Ames Plantation (Ames; 35°06'N, 89°12'W), which was a 7462 ha farm located northwest of Grand Junction in Fayette and Hardeman counties, and was operated by The Hobart Ames Foundation in cooperation with the University of Tennessee. Ames was located approximately 79 km southeast of Meeman. Site 2 was located adjacent to the North Fork of the Wolf River. It was comprised primarily of agricultural fields and bottomland hardwood forest with some upland forest present. Site 3 was composed of upland and bottomland forest, cropland, and old-field habitats. In general, agricultural crops included Soybeans (*Glycine max*), Corn (*Zea mays*), and cotton (*Gossypium* spp.). Typical upland tree species were Loblolly Pine (*Pinus taeda*), oaks, and hickories; typical bottomland species included oaks, maples, Cottonwood (*Populus deltoides*), and Sweet Gum (Gabor 1993). Old-field habitats included native warm season grasses and were similar to those at Meeman. Topography of upland forest sites was characterized by gently rolling slopes, whereas bottomland forest, old-field, and agricultural areas constituted a flatter topography. Ponds and intermittent streams were numerous, and drainages were interspersed throughout all of these sites.

Methods

Trapping grids were established at each site. Site 1 followed a 5 × 10 trap configuration with traps located approximately 150 m apart. Sites 2–3 followed an 8 × 8 trap configuration with traps located approximately 230 m apart though two trap locations were excluded from analysis for site 2 as habitat factors were not measured. Difference in trap configuration for site 1 was due to the limited size of the area. Collectively, the three sites represented most habitat types occurring in western Tennessee.

The association of microhabitat variables and occurrence of Raccoons was assessed during two periods that coincided with times when leaves were present or absent (winter and summer, respectively) on most woody and herbaceous vegetation (Kolowski and Woolf 2002). During winter, sites were operated on selected nights from 3 November–7 April, 2000–2002; summer trapping included only sites 1–2 and were operated on selected nights from 7 May–12 October, 2001–2002. An approximate total of 2000 trap nights (one trap night = one trap set for one night) were observed for each site during both seasons.

Raccoon-size Tomahawk (Number 108; Tomahawk Live Trap Co., Tomahawk, Wisconsin, USA) and Havahart (Woodstream Corporation, Lititz, Pennsylvania, USA) live traps were used. Traps were baited with canned cat food in winter and a combination of cat food, dog food, and doughnuts in summer. Initially captured individuals were anesthetized with a mixture of ketamine hydrochloride (Ketaset; Bristol Laboratories, Syracuse, New York, USA) and acepromazine maleate (PromAce; Ayerst Laboratories, New York, New York, USA) at a 10:1 ratio with 0.1 cc of ketamine hydrochloride used per estimated kg of live weight (Bigler and Hoff 1974). Raccoons were tagged in both ears with Number 3 Monel (National Band and Tag Company; Newport, Kentucky, USA) ear tags to determine recaptures.

For the winter season, 19 habitat variables were measured to determine the influence of habitat at the micro-scale on raccoon occurrence. "Slope" represented the average percentage slope for a 32 m radius around the trap site as measured by a clinometer. "Total basal area" [≥5 cm diameter at breast height (dbh)], "basal area of small trees" (5–35 cm dbh) and "basal area of large trees" (>35 cm dbh) represented the amount of area (m^2) covered by trees per hectare and were determined through use of a prism sweep (10 basal area factor prism) conducted at the trap site and at two additional sites 11.4 m in two random cardinal directions. Heights were recorded for each tree measured during the basal area estimation using a haga altimeter (Forestry Suppliers, Inc., Jackson, Mississippi, USA) with the mean recorded as "average height". "Number of fallen logs" (≥10 cm in diameter) "number of total snags" (≥10 cm dbh), "number of small hardwood snags" (10–35 cm dbh), "number of large hardwood snags" (>35 cm dbh), "number of pine snags" (≥10 cm dbh), "number of ground dens", "number of tree dens", and "number of total dens" were counted within a 32 m radius of trap site. An opening of ≥5 cm in diameter was required to be considered a potential den. The "number of plant food species" represented the number of plant species present within a 32 m radius of the trap site that could be utilized as food sources. The "number of stems" 1–5 cm in diameter was counted for a 3.2 m radius around the trap site. The procedure was repeated in two random cardinal directions 11.4 m from the trap site and the average used. "Distance to potential water" represented the nearest distance to a water source that held water ≥30 days a year. "Distance to permanent water" was the minimum distance to a water source that held water ≥11 months a year. "Distance to road" was measured to the nearest road or man-made vehicular trail, while "distance to open area" represented the nearest distance to a non-forested patch. All distance measurements were in meters and were measured using digital orthophoto quarter-quadrangles georeferenced in ArcView software.

Seven additional variables were assessed during the summer season yielding a total of 26. "Depth of leaf litter" was averaged from 10 random measurements taken within a 32 m radius around the trap site. "Vertical cover" was assessed through the use of a 2 m × 0.2 m cover board checkered with 0.1 × 0.1 m black and white squares. The percentage of board uncovered was recorded at the trap site in all four cardinal directions. The percentage of squares uncovered on a spherical densiometer (Forestry Suppliers, Inc., Jackson, Mississippi, USA) was recorded to determine "canopy cover". Readings were taken in all 4 cardinal directions at the trap site. "Grass cover", "woody cover", "forb cover", and "bare soil cover" were visually estimated for a 3.2 m radius around the trap site. All procedures for measuring summer variables (except "depth of leaf litter") were repeated in two random cardinal directions 11.4 m from trap site and the average used.

Because the purpose of this investigation was to assess at a microhabitat scale the relationship of occurrence of Raccoons from multiple sites, statistical analyses were conducted only on data from all sites combined for both winter and summer seasons. A natural log transformation was applied to all continuous variables; percentage variables were arcsine transformed to approximate a normal distribution (Zar 1999). Univariate logistic regression was used to assess associations between single habitat variables and Raccoon occurrence with a non-adjusted $\alpha = 0.05$ to indicate significance following suggestions by Moran (2003).

In stepwise logistic-regression analyses, an $\alpha = 0.15$ was used as a minimum threshold for inclusion into the regression function to reduce the data set (Hosmer and Lemeshow 2000). Multicollinearity effects between two significant variables were addressed by assessing correlations among habitat variables. If two significant variables were correlated at $r \geq 0.70$, only the more significant variable of the pair was included in further analyses to reduce redundant variables (Agresti 1996).

Variables remaining after univariate logistic regression were included in a backward stepwise logistic-regression function and were removed from the model at $P > 0.15$. Subsequent models often contained a large number of variables. Therefore, for practicality and management purposes, these models were reduced further by forcing exclusion of variables with lowest *t* ratios resulting in a minimum variable model. The *t* ratio represents the ratio of each regression coefficient to its standard error. Relative importance of variables included in the final models was ascertained through *t* ratios, with maximal *t* ratios reflecting the best variable to predict occurrence (Hacker and Coblentz 1993; Hosmer and Lemeshow 2000; Kolowski and Woolf 2002).

Percentage correct classification of trap sites was determined using logistic regression models. Accuracy of these models was determined using the jackknife procedure as a pseudo-validation technique (Morrison 1976; Kolowski and Woolf 2002). This procedure tested percentage correct classification by removing one trap site at a time and then classified that site based on the model built from all other sites combined, resulting in a less-biased percentage classification (Hacker and Coblentz 1993; Kolowski and Woolf 2002). All statistical procedures were conducted using SYSTAT 10.0 (SPSS 2000).

Results

Trapping resulted in 209 total captures of 112 individual Raccoons obtained from 176 trap sites in winter

TABLE 1. Resulting *t* ratios and *P* values from univariate logistic regression of captures of Raccoons (*Procyon lotor*) compared to habitat variables at three sites during winter and two sites during summer 2000–2002 in western Tennessee. All variables are considered significant at $P < 0.05$. Basal area measurements are per ha. Height and distance measurements are in m. See text for explanation of variables.

	Winter (n = 12454)		Summer (n = 8406)	
Variable	*t* ratio	*P* value	*t* ratio	*P* value
Slope	2.517	0.012[a]	1.878	0.060[a]
Total basal area	4.986	<0.001	3.593	<0.001[a]
Basal area of small trees	4.252	<0.001[a]	3.400	0.001
Basal area of large trees	5.516	<0.001[a]	3.447	0.001[a]
Average height	4.052	<0.001	2.433	0.015
Number of fallen logs	4.548	<0.001[a]	2.653	0.008[a]
Number of total snags	2.677	0.007	1.753	0.080[a]
Number of small hardwood snags	1.506	0.132	1.647	0.100
Number of large hardwood snags	2.786	0.005[a]	-0.205	0.838
Number of pine snags	2.579	0.010	1.494	0.135
Number of ground dens	1.947	0.052	0.412	0.680
Number of tree dens	3.399	0.001[a]	2.556	0.011[a]
Number of total dens	3.410	0.001[a]	2.265	0.024[a]
Number of plant food species	4.411	<0.001[a]	-0.046	0.963
Number of stems	2.657	0.008[a]	2.140	0.032[a]
Distance to potential water	-6.045	<0.001[a]	-0.170	0.865
Distance to permanent water	-2.045	0.041[a]	-3.158	0.002[a]
Distance to road	0.908	0.364	2.645	0.008[a]
Distance to open area	3.669	<0.001[a]	2.023	0.043[a]
Depth of leaf litter			0.699	0.485
Vertical cover			-0.843	0.399
Canopy cover			-3.018	0.003[a]
Grass cover			0.182	0.855
Woody cover			1.353	0.176
Forb cover			-0.742	0.458
Bare soil cover			3.052	0.002

[a] Variable included in stepwise logistic-regression function.

(site 1 = 100 total captures of 49 individuals; site 2 = 40 total captures of 26 individuals; site 3 = 69 total captures of 37 individuals) and 173 total captures of 117 individuals from 112 trap sites in summer (site 1 = 93 total captures of 52 individuals; site 2 = 80 total captures of 65 individuals).

Winter.—Sixteen habitat variables were significant statistically when compared to Raccoon occurrence using univariate logistic regression; greatest positive associations occurred for basal area of large trees and total basal area, whereas the strongest negative association was for distance to potential water (Table 1). The only habitat variable not closely related to Raccoon occurrence was distance to road. Through stepwise procedures and model construction, six variables (four positive, basal area of large trees, number of plant food species, number of tree dens, basal area of small trees; two negative, distance to potential water, number of total dens) were selected (Table 2). Percentage of trap sites correctly classified was 72%.

Summer.—Thirteen habitat variables were significantly associated to Raccoon occurrence based on univariate logistic regression; strongest positive associations were for total basal area, basal area of large trees, basal area of small trees, and bare soil, whereas distance to permanent water and canopy cover had the strongest negative associations (Table 1). In general, variables associated to basal area, height of stand, number of logs, den sites, canopy cover, number of stems, bare soil, and distances to permanent water, roads, and open areas were associated to occurrence; variables not associated to occurrence included snags, leaf litter, food species, vertical density, vegetative ground cover, and potential water sources. Three significant variables (two positive, total basal area, distance to road; one negative, distance to permanent water) were selected through subsequent stepwise procedures and model construction resulting in the correct classification of 78% of trap sites (Table 2).

Discussion

Univariate analyses yielded numerous significant variables indicating those selected for the current investigation influenced Raccoon occurrence. These variables were similar to those correlated in previous investigations (e.g., association with forest characteristics,

TABLE 2. Regression coefficients, *t* ratios, and *P* values (*P*) for Raccoons (*Procyon lotor*) derived from logistic-regression functions, as well as percentage correct classifications using the jackknife procedure. Data included in analyses were as follows: winter = three sites totaling 12454 trap nights; summer = two sites totaling 8406 trap nights. See text for explanation of variables and sampling locations.

		Logistic regression			Jackknife classification		
Season	Variable	Coeff	*t* ratio	*P*	No capture[a]	Capture[b]	Combined[c]
Winter	Constant	-4.605	-10.656	<0.001	70	72	72
	Distance to potential water	-0.251	-4.671	<0.001			
	Basal area of large trees	0.194	2.732	0.006			
	Number of plant food species	0.491	2.583	0.010			
	Number of total dens	-0.389	-2.249	0.024			
	Number of tree dens	0.381	2.081	0.037			
	Basal area of small trees	0.149	2.046	0.041			
Summer	Constant	-4.605	-7.034	<0.001	57	88	78
	Distance to permanent water	-0.338	-4.177	<0.001			
	Total basal area	0.355	3.322	0.001			
	Distance to road	0.230	2.656	0.008			

[a] Percentage correct classification of sites with no captures.
[b] Percentage correct classification of sites with captures.
[c] Percentage correct classification of all sites combined.

Leberg and Kennedy 1988; Kennedy et al. 1991; Pedlar et al. 1997; Dijak and Thompson 2000; association with water sources, Leberg and Kennedy 1988; Dijak and Thompson 2000) and suggest that a strong component of forested areas with large trees and close proximity to water sources are important factors in predicting Raccoon occurrence. Additional variables significant in the present investigation were not significant in other studies (e.g., average height, slope, and distance to roads — Leberg and Kennedy 1988; Kissell and Kennedy 1992). This lack of concordance may be attributed to differences in landscape composition and a lack of replication (Maurer 1986; Temple and Wilcox 1986; Oehler and Litvaitis 1996). Baldwin (2003) found similar results when addressing individual sites for Virginia Opossums (*Didelphis virginiana*) in western Tennessee. However, by assessing multiple sites, noticeable trends were observed. The lack of concordance for individual sites was attributed to differing landscape compositions. By assessing multiple sites of similar landscape composition, the difference in significant habitat factors dissipated. Similar results were observed for Striped Skunks (*Mephitis mephitis* — Baldwin et al. 2004) and suggest that landscape composition is an important factor when constructing models predictive of occurrence (Temple and Wilcox 1986; Dijak and Thompson 2000).

Differential use of habitat by Raccoons across seasons has been documented (e.g., Lotze and Anderson 1979; Kaufmann 1982; Chamberlain et al. 2002), although quantitative assessments of these shifts among seasons have received little study. Nevertheless, concordance of significant variables across seasons was generally high although a few exceptions were noted. For example, large hardwood snags and ground dens were important factors during winter but were non-significant during summer. Both variables provide thermal shelter for Raccoons during winter (Stains 1961; Sanderson 1987) but may be less important during warmer seasons. Likewise, number of plant food species and distance to roads were significant factors during winter but not in summer. The non-significance of these variables may be related to the abundance of food and the lack of hunter use of roads during summer. This non-use of roads as travel corridors may have resulted in increased use of stream banks during winter (Hilty and Merenlender 2004), thus yielding different results between seasons for distance to potential water. Ultimately, temporal variability should be expected due to seasonality in variables measured as well as in the biological needs of Raccoons and should be considered when modeling Raccoon occurrence.

Most previous investigations have attempted to determine those factors most important in influencing Raccoon occurrence at the micro-scale but did not include modeling techniques in their analyses (Leberg and Kennedy 1988; Kennedy et al. 1991; Kissell and Kennedy 1992; but see Pedlar et al. 1997 for different modeling strategy). Such modeling strategies allow for the prediction of heavy-use areas by Raccoons and are particularly useful to managers of natural resources. Therefore, such procedures were incorporated into the current investigation and yielded models that generally included the strongest variables from univariate analyses (i.e., forest and water characteristics). Resulting models maintained high classification rates while allowing managers to focus only on those variables most important for predicting Raccoon occurrence. Such techniques have yielded slightly higher classification rates for habitat specialists [Fisher (*Martes pennanti*) = 79% — Carroll et al. 1999; Iberian Lynx (*Lynx* *pardinus*) = 83% — Palma et al. 1999] likely due to their need for more specific habitat components. Nonetheless, classification rates observed in the current study are generally higher than those reported for other habitat generalists [Bobcat (*Lynx rufus*) = 59–70% — Kolowski and Woolf 2002; Striped Skunk = 56–75% — Baldwin et al. 2004]. Therefore, models that utilize replicated sites and account for differences in landscape composition could serve as a blueprint for future investigations involving habitat generalists ultimately resulting in models more useful for wildlife managers. Unfortunately, construction of such models can be expensive. Care must be taken to develop an appropriate sampling strategy to maximize results.

Acknowledgments

Partial funding for this project was provided by the Tennessee Wildlife Resources Agency, the Ames Plantation, and The University of Memphis. Thanks are extended to S. B. Franklin for critical review of the manuscript, and to M. Biernacki, S. B. Franklin, and T. A. Wasklevicz for assistance with statistical analysis and GIS application. Special thanks go to B. D. Carver, J. R. Hisey, J. B. Jennings, S. J. Mahady, and numerous students from The University of Memphis, as well as several individuals from the University of Tennessee and the Ames Plantation for their assistance in data collection.

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Received 3 August 2005
Accepted 3 October 2005