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Raccoon Spatial Requirements and Multi-Scale Habitat Selection within an Intensively Managed Central Appalachian Forest

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ABSTRACT.—We studied a raccoon (*Procyon lotor*) population within a managed central Appalachian hardwood forest in West Virginia to investigate the effects of intensive forest management on raccoon spatial requirements and habitat selection. Raccoon home-range (95% utilization distribution) and core-area (50% utilization distribution) size differed between sexes with males maintaining larger (2×) home ranges and core areas than females. Home-range and core-area size did not differ between seasons for either sex. We used compositional analysis to quantify raccoon selection of six different habitat types at multiple spatial scales. Raccoons selected riparian corridors (riparian management zones [RMZ]) and intact forests (> 70 y old) at the core-area spatial scale. RMZs likely were used by raccoons because they provided abundant denning resources (*i.e.*, large-diameter trees) as well as access to water. Habitat composition associated with raccoon foraging locations indicated selection for intact forests, riparian areas, and regenerating harvest (stands <10 y old). Although raccoons were able to utilize multiple habitat types for foraging resources, a selection of intact forest and RMZs at multiple spatial scales indicates the need of mature forest (with large-diameter trees) for this species in managed forests in the central Appalachians.

INTRODUCTION

Intensive forest management can substantially modify forested landscapes and often results in altered vertebrate species assemblages, spatial requirements, and selection of habitat. Structural changes incurred from forestry practices, such as increased fragmentation and edge, may enhance the abundance and predatory efficiency of generalist mesopredators that are often well-adapted to these landscape-level changes (Oehler and Litvaitis, 1996; Dijak and Thompson, 2000; Chamberlain *et al.*, 2002; Beasley *et al.*, 2011). Furthermore, historic extirpation of apex predators has resulted in considerable population increases of mesopredators such as coyotes (*Canis latrans*), Virginia opossums (*Didelphis*

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virginianus), and raccoons (*Procyon lotor*) (Ritchie and Johnson, 2009). In response mesopredator overabundance has been implicated in declines in songbird nest success (Crooks and Soule, 1999; Heske *et al.*, 2001) and increased transmission of infectious diseases for humans and wildlife (Houle *et al.*, 2011).

A thorough understanding of predator assemblages and their habitat associations within human-modified landscapes is necessary to identify their influence on prey species or to mitigate potential disease spread and outbreaks; however, the majority of our understanding is based largely on data from urban areas or fragmented agricultural landscapes where many mesopredator populations have reached nuisance status (*e.g.*, Bozek *et al.*, 2007; Barding and Nelson, 2008; Beasley *et al.*, 2011). In the heavily forested central Appalachian Mountain region, most mesopredator habitat associations remain poorly documented and are incompletely understood—particularly within intensively managed forestlands.

Given their strong behavioral plasticity and ability to positively respond to habitat disturbances at multiple spatial scales (Pedlar *et al.*, 1997; Chamberlain *et al.*, 2003; Beasley *et al.*, 2007b), raccoons are an ideal model for improving our comprehension of mesopredator space use and habitat associations as they are affected by forest management. With the demonstrated need for information detailing the impacts of forest management on mesopredator populations, the objectives of our study were to describe the spatial requirements and scale-dependent habitat selection of a low-density population of raccoons within an intensively managed hardwood forest in central West Virginia.

STUDY AREA

Our study was conducted on the 3630 ha former MeadWestvaco Wildlife and Ecosystem Research Forest (MWERF) located in Randolph County, West Virginia (38°42'N, 80°3'W). The MWERF was an intensively managed forest composed mostly of second- and third-growth Allegheny-northern hardwood forest (Keyser and Ford, 2005). At lower elevations dominant tree species included black cherry (*Prunus serotina*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), yellow birch (*Betula alleghaniensis*), American beech (*Fagus grandifolia*), and northern red oak (*Quercus rubra*). At higher elevations the forest was characterized by red spruce (*Picea rubens*) and eastern hemlock (*Tsuga canadensis*) communities. Riparian areas were characterized by the aforementioned tree species and rosebay rhododendron (*Rhododendron maximum*).

We used forest inventory data to delineate six habitat types on the MWERF: (1) intact forest, (2) diameter-limit harvests, (3) riparian areas, (4) regeneration harvest (including deferment harvests and clearcuts), (5) open/nonforest areas, and (6) roads. Intact forests were 70–80 y old and composed of second- and third-growth stands with no mechanical disturbance since stand initiation, whereas diameter-limit stands had approximately 50% basal area removal during repeated harvests in the preceding two decades. Riparian areas were intact-forested areas occurring within riparian management zones (RMZ) along perennial and ephemeral streams. Deferment harvests (10% residual basal area) and clearcuts (0% residual basal area) were typically 0–10-year old stands with similar silvicultural function and structural attributes; therefore, we grouped them into a single regeneration harvest habitat type. Open and other nonforest areas typically included spaces cleared for harvested log loading decks.

METHODS

RACCOON CAPTURE

From May 2001 to Dec. 2002 we captured raccoons by use of wire cage live-traps (Havahart, Lititz, PA) baited with sardines, marshmallows, and forms of rancid meats. We chemically immobilized captured raccoons with 30 mg/kg ketamine and 4 mg/kg xylazine (Kreeger, 1999) and aged (juvenile or adult) and sexed individuals based on external characteristics (Kramer *et al.*, 1999). For each captured individual we recorded its mass, total length, ear length, and hind-foot length measurements and affixed uniquely numbered aluminum ear-tags (National Band and Tag Company, Newport, KY). We equipped all adult males and females with mortality-sensitive radio collars (Advanced Telemetry Systems, Asanti, MN); we only radio-collared adults to avoid the chance of dispersing juveniles and sub-adults leaving the study area.

RADIO TELEMETRY

Radio-tagged individuals were monitored three nights per week from May – Dec. in each year with Wildlife Materials TRX-2000S receivers (Wildlife Materials Incorporated, Carbon-dale, IL) and folding three-element Yagi antennas. We assumed animals were active/foraging if a modulating telemetry signal was recorded; if the signal was static, we assumed the animal was denning/inactive. We used triangulation techniques (simultaneous and individual observer) to determine animal locations from approximately 1 h after sunset until 1 h after sunrise and established a 3 h time interval between consecutive locations to minimize spatial autocorrelation. To reduce telemetry error, we recorded telemetry azimuths from as near the animal as possible and restricted the temporal interval between successive azimuths to 5 min. Following White and Garrott (1990) we calculated radiotelemetry error associated with our animal locations by estimating the mean difference between azimuths taken on geo-referenced transmitters hidden from the observer at >two telemetry stations. We estimated an average telemetry azimuth error of $\pm 2.3^\circ$ and an error polygon of 0.18 ha.

HOME RANGE AND HABITAT SELECTION ANALYSIS

Only individual raccoons with >30 relocations were retained within our dataset to calculate spatial requirements and habitat selection (Aebischer *et al.*, 1993). We used program LOCATE (Nams, 2000) to calculate UTM coordinates of raccoon locations based on the positions obtained from locational azimuths at georeferenced telemetry stations. We then used the Animal Movement Extension (AME; Hooge and Eichenlaub, 2000) in ArcView (Environmental Systems Research Institute, Redlands, CA) to calculate fixed-kernel (FK) home-range estimates based on 95% FK utilization distributions (UD) and core-area estimates based on 50% UD. Raccoon seasonal space use was compared for spring/summer (May–Aug.) and autumn/winter (Sep.–Dec.) time-periods, and we analyzed annual, seasonal, and gender-specific differences in home-range and core-area size using analysis of variance (ANOVA).

We investigated habitat use at three spatial scales, approximately based on orders of selection defined by Johnson (1980). First, we compared the habitat composition of each home range to the composition of random home ranges (equal to the average home-range size observed in our study) within the study area (2nd order selection). The study area boundary was defined by computing a composite minimum convex polygon (MCP) boundary derived from all raccoon locations obtained throughout the study. We evaluated core-area selection by comparing core-area composition to the composition of home ranges

(3rd order selection). Finally, we compared the composition of individual raccoon point locations (*i.e.*, foraging sites) to the composition of home ranges (4th order selection).

Habitat selection comparisons were made using compositional analysis (Aebischer *et al.*, 1993; Thomas and Taylor, 2004) to determine if habitat use significantly differed from random. Compositional analysis was conducted using the 'adehabitat' package (Calenge, 2006) implemented within program R (R Development Core Team, 2012). We computed the compositional analysis test statistic (λ) from the matrix of log-ratio differences to test for nonrandom habitat use. Habitat types were ranked in order of selection preference, and Student's *t*-tests were used to test for pairwise differences in habitat use (Aebischer *et al.*, 1993). Compositional analysis calculates log-ratios which cannot accommodate zero-values, therefore, if habitat types are available but unused zero-values must be replaced with a nominal positive value (Aebischer *et al.*, 1993). In order to reduce the likelihood of type I error rates, we replaced zero-values with 0.007 as recommended by Bingham and Brennan (2004). Means are given \pm standard errors (SE) throughout.

RESULTS

SPATIAL REQUIREMENTS

We radio-tagged and monitored 42 adult raccoons over the course of the study; however, we only obtained sufficient seasonal locations (>30 locations) from 13 female (5 autumn: 8 summer) and 17 male (6 autumn: 11 summer) individuals. Raccoon home-range size was significantly different annually ($F_{1,28} = 5.66$, $P = 0.025$), being larger in 2001 (mean = 398.3 ha \pm 46.8) compared to 2002 (mean = 283.0 ha \pm 38.6). Home-range size also differed between sexes ($F_{1,28} = 8.76$, $P = 0.007$) but not between seasons ($F_{1,28} = 0.05$, $P = 0.826$). Male Raccoons maintained larger (mean = 394 ha \pm 40.7) home ranges than females (mean = 244 ha \pm 38.0). Raccoon core-area size did not differ annually ($F_{1,28} = 0.56$, $P = 0.468$) or seasonally ($F_{1,28} = 0.05$, $P = 0.830$). Male core areas (mean = 65.9 ha \pm 13.8) were larger ($F_{1,28} = 5.72$, $P = 0.025$) than female core areas (mean = 26.6 ha \pm 4.8).

HABITAT SELECTION

Habitat composition within raccoon home ranges did not differ from habitat composition within the study area ($\lambda = 0.761$, $P = 0.256$); however, habitat composition of core areas differed from home ranges ($\lambda = 0.563$, $P = 0.006$). Raccoons selected core areas with greater proportions of riparian and intact forest habitat types, whereas diameter-limit harvests, open areas, and regenerating harvests were used less than available (Table 1). Raccoons also selected among habitat types for foraging locations within their home ranges ($\lambda = 0.301$, $P = 0.002$), using intact forest, regenerating harvests, and riparian areas more than open areas and roads (Table 1).

DISCUSSION

Raccoons on the MWERF maintained home ranges somewhat larger than those previously reported from the southeastern and midwestern United States, *i.e.*, 20–200 ha (*e.g.*, Pedlar *et al.*, 1997; Chamberlain *et al.*, 2002, 2003; Beasley *et al.*, 2007a; Barding and Nelson, 2008; Byrne and Chamberlain, 2011). Animal spatial requirements (home-range sizes) are expected to vary in accordance with the quality and distribution of available resources on the landscape (*i.e.*, Ideal Free Distribution; Fretwell and Lucas, 1969). Raccoon populations with access to concentrated anthropogenic food resources (*e.g.*, agricultural crops or suburban refuse) typically have smaller spatial requirements relative to populations without

TABLE 1.—Ranking matrices comparing composition of raccoon *Procyon lotor* habitats selected across two spatial scales on the MeadWestvaco Wildlife and Ecosystem Research Forest (MWERF), West Virginia, during May–Dec., 2001–2002. Cells indicate positive or negative selection from compositional analysis log-ratios, and triple-signs represent significant selection based on pairwise t -values at $\alpha = 0.05$. Habitat types are ranked in order of selection (5 = highest; 0 = lowest)

	Habitat type						Rank
	Riparian ^a	Intact forest	Regen. ^b	Diam.-limit	Open	Road	
Core-area selection ^c							
Riparian	0	+	+++	+++	+++	+	5
Intact forest	-	0	+++	+	+++	+	4
Regenerating	-	-	0	-	-	-	0
Diameter-limit	-	-	+	0	+	-	2
Open	-	-	+	-	0	-	1
Road	-	-	+	+	+++	0	3
Foraging-habitat selection ^d							
Riparian	0	-	-	+	+++	+++	3
Intact forest	+	0	+	+	+++	+++	5
Regenerating	+	-	0	+	+++	+++	4
Diameter-limit	-	-	-	0	+++	+++	2
Open	-	-	-	-	0	+	1
Road	-	-	-	-	-	0	0

^a Riparian management zone

^b Regenerating harvest

^c Habitat composition of core area *vs.* home range

^d Habitat composition of foraging locations *vs.* home range

access to super-abundant forage (Bozek *et al.*, 2007; Beasley *et al.*, 2007a). A patchy distribution of seasonally available food resources may explain the large spatial requirements of raccoons on the MWERF, because individuals must traverse considerable distances (*i.e.*, move among disparate habitat patches) to obtain food resources that meet energetic demands (Beasley and Rhodes, 2010). Furthermore, raccoons are also known to increase home-range size at low population densities (Ellis, 1964), possibly because of reduced intraspecific competition. We estimated raccoon density on the MWERF to be 1.5 individuals km² (Owen *et al.* 2015), which is considerably less than populations in other human-modified landscapes (*e.g.*, >30/km² in agricultural landscapes and suburban areas; Gehrt, 2003) and could further explain the large spatial requirements observed in our study.

Raccoon spatial requirements can vary according to season (Chamberlain *et al.*, 2002; Beasley *et al.*, 2007a; Byrne and Chamberlain, 2011), gender (Gehrt and Fritzell, 1997; Kamler and Gipson, 2003), food availability (Bozek *et al.*, 2007; Wehtje and Gompper, 2011) habitat type (Fritzell, 1978), and harvest pressure (Glueck *et al.*, 1988). Similar to other studies, we found male raccoons maintained larger home ranges (95% UD) and core areas (50% UD) than females. This observation is often attributed to the raccoons' polygynous mating system, whereby males will travel greater distances in search of receptive females (Kamler and Gipson, 2003). Core areas represent concentrated use within home ranges that frequently contain sites critical to survival including den sites or selected foraging areas (Chamberlain *et al.*, 2003, 2007). Female raccoons typically maintain smaller core areas than males, especially during and after the parturition period when their movements are restricted because of rearing young. Consistent with that observation, female core areas on

the MWERF typically were centered on the maternal cavity tree during spring and summer (Owen *et al.* 2015).

Raccoons on the MWERF selected riparian habitats and intact forests at multiple spatial scales. The availability of water resources is considered a limiting factor to raccoon abundance (Gehrt, 2003) and proximity to free water often influences their movement behavior (Byrne and Chamberlain, 2012) and habitat selection (Urban, 1970). Riparian management zones are uncut riparian areas within intact forests where logging has been excluded resulting in greater densities of larger-diameter trees—required for the development of den cavities (Smith and Endres, 2012). Although we did not measure micro-habitat selection in this study, selection of uncut forest may have been related to raccoon selection and use of large-diameter trees in these habitats (Baldwin *et al.* 2006). On the MWERF, large-diameter trees were extensively used by raccoons as denning and resting substrates (Owen *et al.* 2015). In particular use of tree cavities for denning resources by female raccoons during breeding and parturition may in part explain the core-area selection of this habitat type (Endres and Smith, 1993; Henner *et al.*, 2004; Beasley and Rhodes, 2012, Owen *et al.* 2015). Forest management practices that include leaving uncut RMZs along streams not only provide potential for future large-diameter cavity trees for raccoon den sites but also provide mature-forest habitat for various other vertebrate and invertebrate species (Miller *et al.*, 2004). Likewise, raccoons likely selected RMZs for foraging habitat because they provide cool environments and access to free water with food resources such as amphibians, fish, and invertebrates. Indeed, we found 63% and 82% of all foraging locations to be within 200 m and 300 m of a stream, respectively.

Away from streams, intact forests provide greater canopy cover and cooler temperatures (relative to regeneration and diameter-limit harvests) that positively influence the abundance of amphibians, invertebrates, and hypogean fungi within leaf litter, all of which account for significant proportions of raccoons' diet (Gehrt, 2003). Tree species composition also may influence raccoon food availability within managed forests (Chamberlain *et al.*, 2002). Hard-mast producing trees species (*e.g.*, *Quercus* sp. and American beech) most commonly were found within RMZs and intact forest, and mast from these trees provide valuable food resources for raccoons during autumn. Furthermore, black cherry was an abundant tree species within intact forests and produce additional soft mast during late summer and early autumn.

Raccoons exhibit a diverse diet and show an ability to quickly respond to spatial and temporal fluctuations in food resources. Although regeneration harvests were not selected at the core-area scale (probably due to a lack of general escape cover or den trees), raccoons selected this habitat type for foraging locations. Foraging raccoons likely selected regeneration harvests (<10 y old) because of the abundance of soft mast (*e.g.*, *Rubus* spp. and *Vaccinium* spp.) provided by this habitat type during summer and early autumn. Furthermore, pin cherry (*Prunus pensylvanica*) was relatively abundant within regeneration harvests along road edges, providing additional summer soft mast.

Habitat quality changes throughout the year with respect to food, cover, and presence of water, thus may influence raccoon spatial activity (Beasley and Rhodes, 2010; Beasley *et al.*, 2011). As generalists, raccoons are capable of adapting to a wide range of natural and anthropogenic changes within the environment (Gehrt, 2003; Barding and Nelson, 2008). Forest management practices conducted on the MWERF produced a shifting mosaic of disparate vegetation types, several of which appear to provide foraging and denning resources used by raccoons. Our results indicate the need for mature forest (intact forest

and RMZs) for raccoons within intensively managed forests at multiple spatial scales. Indeed, continued reductions in large-diameter trees associated with forests managed on 40–80 y rotations may impact raccoon recruitment due to loss of suitable maternal cavities (Beasley and Rhodes, 2012). Nonetheless, early successional stands (regenerating harvest) provide foraging resources to raccoons, and the presence of this habitat type in conjunction with mature forests provides a mosaic of exploitable habitat types and seasonally available food resources. Furthermore, recent concern over near-threatened passerine populations (*i.e.*, cerulean warbler [*Setophaga cerulea*] and golden-winged warbler [*Vermivora chrysoptera*]) in the central Appalachians has shifted a management focus from maintaining large contiguous forestlands to creating patchy early successional habitat interspersed within intact forest (Sheehan *et al.*, 2013). Therefore, forests managed under this structurally diverse paradigm (combining large-diameter tree retention [mature forest patches] juxtaposed to regenerating harvest) may meet raccoon foraging and denning resource requirements throughout the annual cycle. Additional research investigating variation in raccoon demographic parameters (*e.g.*, fecundity and adult survival) within managed forests (*e.g.*, among intact forest patches) will further identify how raccoon populations are affected by forest management.

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