DEMOGRAPHIC CHARACTERISTICS AND HABITAT USE OF UNEXPLOITED RACCOONS IN SOUTHERN ILLINOIS

by

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SHONA E. WILSON, for the Master of Science degree in Zoology, presented on 1 August 2005, at Southern Illinois University Carbondale.

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I studied an unexploited raccoon (*Procyon lotor*) population in southern Illinois to estimate demographic rates and the influence of habitat factors on female daytime resting site (DTRS) selection. During 2003-2005, females (*n* = 54) were radiocollared. Demographic estimates included a sex ratio, 1.3:1 (M:F), an age ratio, 1.5:1 (ad:juv), a recruitment rate, 1:1.6 (ad F:juv), and a density, 1 raccoon/0.6 ha. DTRS of raccoon and control locations were investigated during the breeding season (1 Dec - 1 Mar) and cub-rearing season (15 Mar - 30 Jun); 156 micro- and macrohabitat variables were measured at each site. A logistic regression model incorporating: tree CBH (circumference at breast height), den height, distance to road, distance to water, and number of nearby dens, correctly classified 71% of DTRS locations. My model suggested that microhabitat variables influence DTRS selection; therefore, managers should focus on these features when modifying habitat to reduce raccoon populations.

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PREFACE

Raccoons (*Procyon lotor*) are almost ubiquitously distributed across North America (Lotze and Anderson 1979). They are especially abundant in bottomland forests, along riparian corridors, and in other mesic habitats (Kaufmann 1982). The ability to adapt to almost any land cover type and their omnivorous, opportunistic diet have enabled raccoons to thrive in areas where other native species have suffered significant population losses. In fact, raccoon populations have increased nearly 20-fold during the last 70 years (Zeveloff 2002). Supplemental food sources (e.g., human garbage) and dens (e.g., buildings) likely have contributed to the increased survival and recruitment rates responsible for this substantial population growth (Prange et al. 2003*a*).

Overabundant raccoon populations cause a suite of problems. They represent a public health threat as reservoirs of parasitic (Kazacos 1982) and other infectious diseases (Bigler et al. 1975). Raccoons are also often regarded as a serious nuisance species, capable of causing considerable agricultural damage (Boggess 1994). Further, raccoons are notorious for depredating nests of ground-nesting birds, songbirds, and waterfowl (Urban 1970).

Raccoons are important from the standpoints of conservation, wildlife management, and public health, so in-depth knowledge of their life history and vital rates is necessary in managing their populations. Many studies from across the species' range have reported raccoon demographic rates (Urban 1970, Lehman 1977, Fritzell and Greenwood 1984, Glueck et al. 1988, Clark et al. 1989, Hasbrouck et al. 1992, Chamberlain et al. 1999, Mankin et al. 1999, Henner et al. 2000). However, few have studied population dynamics of unharvested raccoon populations existing in bottomland habitats, which was my focus in Chapter 1. Three primary objectives are addressed in Chapter 1: (1) estimate sex and age characteristics based on trapping data, (2) estimate population density, and (3) estimate female seasonal survival and cause-specific mortality rates of an unexploited raccoon population. Knowledge of the demographics of this raccoon population will allow for comparisons at different geographic locations and provide vital information for raccoon research and management.

Although numerous studies have examined raccoon den selection (Giles 1942, Shirer and Fitch 1970, Endres and Smith 1993, Nixon et al. 2001), few have examined habitat factors influencing how raccoons select daytime resting sites (DTRS). To address this lack of information, Chapter 2 focuses on determining which habitat characteristics are most influential in raccoon DTRS. I examined differences in microhabitat and macrohabitat variables present at 3 areas of interest: (1) breeding season DTRS; (2) cub-rearing season DTRS; and (3) control locations. My aim in Chapter 2 was to provide management recommendations and data reflecting which biotic and abiotic factors affect raccoon DTRS selection during different seasons.

CHAPTER 1: DEMOGRAPHIC CHARACTERISTICS OF UNEXPLOITED RACCOONS IN SOUTHERN ILLINOIS

INTRODUCTION

Raccoons are important from both economic and ecological points of view as furbearers, nuisance animals, and harbingers of disease and parasites (Bigler et al. 1975, Kazacos 1982, Boggess 1994). Raccoon populations have grown drastically in the past several decades (Zeveloff 2002), reaching overabundant levels in many portions of the species' geographic range. Raccoons have been extensively studied, but most investigations have focused on harvested populations (Butterfield 1944, Urban 1970, Clark and Andrews 1982, Moore and Kennedy 1985, Rolley and Lehman 1992). The main purpose of this chapter was to gather and interpret trapping data, measure age and sex characteristics, and estimate density and survival of an unexploited raccoon population in a bottomland wetland habitat in southern Illinois. These data will facilitate future research, monitoring, and management of raccoons.

Trapping Data

Data gathered from trapping efforts can provide an in-depth look at specific population characteristics. Sex ratio and age structure can have important implications for reproduction and population growth (Lindstrom and Kokko 1998, Ranta et al. 1999). In addition, efficient trapping regimes are paramount for studies relying on radiocollaring animals for subsequent investigations. If biases in trappability are not accounted for, estimates of population demographics such as age structure, fecundity and survival may also be biased.

Although, understanding raccoon capture success is important, most recent raccoon investigations report trapping results as a side note to their primary research (Fritzell 1977, Chamberlain et al. 1999, Mankin et al. 1999, Henner et al. 2000). In order to use trapping data to develop valid measures of population dynamics and structure, capture probabilities and success must first be estimated. Moore and Kennedy (1985) found that raccoon response to traps varied from one trapping occasion to the next and among individuals, confirming the need for further study into the variability of raccoon trappability. Further, few data concerning sex and age structure are available for unexploited raccoon populations (Gehrt 2003). As raccoons expand into urban and suburban areas where harvest pressure is non-existent, these data will be valuable in the development of population models.

Raccoon density estimates

Accurate estimates of raccoon population densities are important due to their wide ranging ecological and economic implications. Generally, increases in population densities lead to greater impacts. Researchers have used several different techniques to index raccoon populations, including trapper harvest surveys and fur dealer records (Clark and Andrews 1982), spotlight surveys (Gehrt 2002), and road-kill surveys (Gehrt 2002). Although these methods are often easier and less expensive to carry out than mark-recapture methods, there is significant bias associated with the estimates obtained (Gehrt 2002).

Mark-recapture methods have been used to estimate population densities of many species (Otis et al. 1978, Seber 1982, Pollock et al. 1990, Corn and Conroy 1998, Tuyttens et al. 1999). When done in conjunction with a larger study, the benefits of a more precise estimate, obtained from mark-recapture methods, can outweigh some of the downfalls of the labor-intensive, expensive methodology.

Racoon survival

Studies of raccoon survival have focused primarily on harvested populations (Clark et al. 1989, Fritzell and Greenwood 1989, Hasbrouck et al. 1992). Human harvest activities are commonly cited as the most significant mortality factors in exploited raccoon populations (Sanderson 1961, Johnson 1970), accounting for up to 78% of raccoon deaths (Clark et al. 1989). Hasbrouck et al. (1992) reported yearling (0.51) and adult (0.53) annual survival of an exploited population in Iowa. Mankin et al. (1999) found an annual survival rate of 0.74 in an exploited Illinois raccoon population; again human related mortalities represented 81% of the total mortality (68% from harvest and 13% from vehicle-related injuries). In the absence of anthropogenic factors, natural mortality agents have little effect on most raccoon populations (Johnson 1970, Gehrt and Fritzell 1999).

As raccoon populations increase and the number of hunters and trappers decline (International Association of Fish and Wildlife Agencies 2005), understanding seasonal survival patterns within unexploited raccoon populations is especially important. Annual survival of an unexploited population in Texas was 0.84 (Gehrt and Fritzell 1999).

Kamler and Gipson (2003) found coyotes (*Canis latrans*) to be a significant mortality factor for an untrapped (but not unharvested) raccoon population, with an annual survival rate of 0.71, on a mixed grass prairie in Kansas. Prange et al. (2003*a*) reported higher densities and survival of female raccoons in unexploited urban and suburban sites compared to an unexploited rural site in northeastern Illinois. The prevalence of rabies and its effect on raccoon survival in an unexploited raccoon population in an urban national park have also been investigated (Riley et al. 1998).

Two primary paucities exist in the current raccoon survival literature. First, relatively few unexploited populations have been studied. Second, no research has been conducted on raccoons existing solely in a forested river-bottom wetland complex. Previous studies of unexploited raccoons predominantly occurred in urban or suburban settings (Hoffman and Gottschang 1977, Slate 1980, Brown et al. 1990, Mosillo et al. 1999, Riley et al. 1998, Prange et al. 2003*a*,*b*), with one on a wildlife refuge in the subtropical gulf plains of Texas, characterized by long hot summers and mild winters (Gehrt and Fritzell 1997).

Objectives

My objectives were to (1) estimate sex and age characteristics based on trapping data, (2) estimate population density, and (3) estimate female seasonal survival and cause-specific survival probabilities for an unexploited raccoon population in southern Illinois.

Study area

My research was conducted on the Union County Conservation Area (UCCA), a 2,510 ha wildlife refuge located in the southwest corner of Union County, Illinois (Figure 1.1). Illinois State Highway 146 serves as the northern boundary for the refuge while Route 3, Clear Creek, and Reynoldsville Road provide the western, eastern, and southern boundaries, respectively. Acquired by the Illinois Department of Conservation in 1947, the site has been managed primarily as overwintering habitat for waterfowl, particularly, Canada geese (*Branta canadensis*) (Yancy 1991). The refuge contains 1154.6 ha (46%) of forested land (14% flooded forest, 23% upland forest, and 9% shrub/scrub forest; Ryan 1995).

In addition to 3 large lakes, there are many sloughs and ephemeral ponds scattered throughout the UCCA. Together, Grassy Lake (142 ha) and Lyerla Lake (111 ha) account for almost 50% of the total permanent water (Kawula 1998). Forested and cultivated bottomlands are interspersed throughout UCCA and account for the 2,165 ha (86%) of dry land. Soybeans, corn, and winter wheat are the main crops planted annually. The topography is relatively flat (average slope of <2%) and portions of the forested land flood seasonally (Yancy 1991).

UCCA is characteristic of a bottomland mixed hardwood forest. Major tree species include red maple (*Acer rubrum*), sugar maple (*A. saccharinum*), hackberry (*Celtis occidentalis*), rough-leaf dogwood (*Cornus drummondii*), black walnut (*Juglans nigra*), sweet gum (*Liquidambar styraciflua*), sassafras (*Sassafras albidum*), red oak (*Quercus rubra*), pin oak (*Q. palustris*), and paw paw (*Asimina triloba*). Buttonbush

(*Cephalanthus occidentalis*) predominates along lake shores and green briar (*Smilax spp.*) typifies forest edge vegetation.

The temperate, mid-continental climate of southern Illinois is typified by cold winters, wet springs, and hot, humid summers. The average annual temperature is 13.8º C and there are 206 frost-free days extending from 7 April to 30 October (Miles et al. 1979). Annual precipitation for Union County is 45 cm distributed evenly throughout the year (Illinois State Water Survey 2003).

METHODS

Capture and handling

Raccoon trapping activities on the UCCA were focused in 3 bottomland hardwood forest patches, totaling 197 ha. Raccoons were live-trapped during 4 periods: 6 October-4 December 2003, 8 March-16 April 2004, 26 September-10 December 2004, and 2 March-10 April 2005. Each trapping period, 40 wire cage traps (30x30x70 cm) were set along linear transects adjacent to water or field edges, and spaced at 100 m intervals. Trap density averaged 1 trap/0.6 ha of forested land (Figure 1.2). Traps were baited with commercial cat food and checked each morning from 0730-1100 hr. Traps were moved at 10-day intervals during fall 2003 and spring 2004, and at 20-day intervals during fall 2004 and spring 2005.

Live-trapped animals were anesthetized with an intramuscular injection of Telazol (5mg/kg) based on an initial estimation of the animal’s weight (Gehrt et al. 2001). Anesthetized animals were sexed, weighed (using a spring scale), and measured for total, tail, and right hind foot length. The length and width of male testes were also recorded. Raccoons were scored from 1-4 based on the number of ectoparasites present (1 = <10, 2 = 10-50, 3 = 50-75, 4 = >75). Condition of dentition and overall physical condition were also evaluated. Animals were classified as either juveniles or adults based on weight, body size, condition of dentition, and sexual and physical attributes. An ear punch was used to collect tissue samples, and numbered metal tags were affixed to both ears to uniquely identify each raccoon. Mortality-sensing radiocollars (120 g; Wildlife Materials, Inc., Carbondale, Illinois, USA) were placed on selected females considered to be of an adequate size (> 3.5 kg). All animals were released at their capture site. Research was conducted in adherence with a university-approved animal welfare protocol (SIUC Animal Assurance #A-3078-01).

Capture success for all sex or age classes was calculated as number of raccoons captured/100 trap nights. Chi-square tests ($\alpha = 0.05$ throughout) were conducted to test for differences in capture success among sex and age classes, and seasons. After testing data for normality, I used ANOVA to test for differences in seasonal raccoon weights among sexes and age classes. I used logistic regression (SAS Institute 2000) to test for an effect of trapping day, session, or season on capture success (number captured/trap night). Here, trapping day referred to the sequential day in my 10- or 20-day long transect periods; these were pooled by capture area within each season.

Density estimation

Data from 3 trapping areas were combined to estimate population abundance.

Estimates were obtained using a Jolly-Seber (Jolly 1965, Seber 1982) open population (i.e., permitting birth, death, immigration, and emigration) analysis program (POPAN-5) (Arnason and Schwarz 1995, 1999). Due to low capture rates and limitations imposed by the open Jolly-Seber model (i.e., estimates can not be derived for the first and last trapping sessions, Pollock et al. 1990), population estimates were only obtained for the spring 2004 and fall 2004 trapping seasons. Density estimates were calculated by dividing the population abundance by the area of the trapping-grid, plus a buffer equal in width to 1 home-range diameter (assuming that the home-ranges are roughly circular). This value was estimated from the literature to be 600 m (Lehman 1977, MacClintock 1981, Moore and Kennedy 1985, Rosatte et al. 1991, Prange et al. 2003*b*).

Survival analysis

During 6 October 2003-1 March 2005, raccoons were monitored for survival weekly during daytime hours (0700-1700 hr) using a TS-1 receiver and scanner (Telonics, Inc., Mesa, Arizona, USA) and a 3-element Yagi antenna. Mortalities were investigated immediately following detection. I broadly classified causes of raccoon mortality into 3 categories: disease, predation or vehicle accident. Number of transmitter-days (Trent and Rongstad 1974, Heisey and Fuller 1985*a*, Riley et al. 1998, Nielsen and Woolf 2002) were used to estimate seasonal survival and cause-specific mortality rates of raccoons in program MICROMORT (Heisey and Fuller 1985*b*). Data from all years were pooled for analysis.

The year was sub-divided into 2 biologically significant seasons during which time survival probabilities were assumed to be constant. The fall/winter season (1 Sep-28 Feb) was a period during which vegetation was at a minimum, temperatures were colder, and free water was limited. The spring/summer season (1 Mar-31 Aug) was characterized by hot, humid weather along with abundant vegetation, standing water, and supplemental food sources.

Raccoons that died within 2 weeks of collaring ($n = 3$) were not included in the analysis. Raccoons whose radiocollars failed were censored from the analysis on the appropriate date. When the exact date of death or collar failure was unknown, the midpoint between the last known date alive and the date of recovery was used. I assumed that trapping, handling, and radiocollaring had no effect on survival.

RESULTS

Capture data

Over the course of my study, 282 raccoons (122 ad M, 39 juv M, 86 ad F, 35 juv F) were captured 391 times in 6,023 trap nights (Table 1.1). Non-target captures included 493 opossums (*Didelphis virginiana*), 2 fox squirrels (*Sciurus niger*), 3 bobcats (*Lynx rufus*), and 2 turtles (*Chrysemys geographica*). Capture success differed significantly by season, session, and trapping day (Table 1.2). Seasonal capture success held at a constant 5 raccoons/100 trap nights throughout the study until the spring of 2005, when it decreased to 3 raccoons/100 trap nights. Capture success declined with each successive trapping day (Figures 1.3 and 1.4), however the effect of season interacted with trapping day because the number of raccoons captured/day did not consistently decline as the trapping session continued in the spring 2005 session.

Sex ratios did not differ ($0.10 \leq P \geq 0.46$) among the 4 capture seasons, so data were pooled. The observed male to female ratio of 1.3:1 (proportion of males = 0.58±0.057) did not deviate significantly from 1:1 ($\chi^2_1 = 0.55$, $P = 0.46$). All animals captured during spring were ≥10 months old, so juveniles were only observed during fall trapping sessions. During fall, no difference in the adult:juvenile ratios ($\chi^2_1 = 0.54$, $P = 0.46$) was found between the 2 sessions, so data were pooled. The fall adult:juvenile ratio was 1.5:1 (proportion of adults = 0.60±0.071). The recruitment rate (adult females:juveniles) during fall was 1:1.6 (proportion of adult females = 0.38±0.087), and again no difference was found between fall sessions ($\chi^2_1 = 1.20$, $P = 0.27$).

Adult males were heavier ($t_{1,208} = 48$, $P < 0.001$) than adult females (Tables 1.3 and 1.4). Weights were similar ($t_{1,74} = 1.60$, $P = 0.21$) between juvenile males and females during the fall (Table 1.3). Raccoons caught during the spring weighed less ($t_{1,208} = 24$, $P < 0.001$) than those caught during the fall. All raccoons captured had fewer than 10 ectoparasites visible.

Throughout the course of the study, 25% (34 ad M, 5 juv M, 23 ad F, 8 juv F) of raccoons were recaptured at least once. Of raccoons that were recaptured, 18 (9 ad M, 2 juv M, 7 ad F) were recaptured twice, 6 (4 ad M, 2 juv F) were recaptured 3 times, 1 (ad F) was recaptured 4 times, and 1 (juv F) was recaptured 9 times. No sex-specific difference (proportion of M = 0.55±0.117) was found in recapture probability rates ($\chi^2_1 = 0.010$, $P = 0.95$); however, adults (proportion of ad = 0.81±0.093) were recaptured more frequently than juveniles ($\chi^2_1 = 15$, $P < 0.001$).

Density

Only 1 trapping area had sufficient data to estimate population density, and due to limitations imposed by the Jolly-Seber model, density was only estimated for the fall 2004 and spring 2004 trapping periods. Low capture/recapture rates associated with the spring 2004 period clearly downwardly biased the population abundance estimate, thus the estimate was excluded from further analysis. The fall 2004 abundance estimate of 440±167 raccoons produced a density estimate (effective trapping area = 267.5 ha) of 1 raccoon/0.61 ha.

Survival

During 2003-2005, 62 female raccoons were radiocollared on the UCCA. Of these, 53 were classified as adults (≥1 yr old) and 9 were classified as juveniles (≤1 yr old), based on weight at capture and physical and sexual characteristics. During 6 October 2003-1 March 2005, 10,312 raccoon radio-days were recorded. Three raccoons were censored due to loss of radio signal ($n = 1$) or when the collar antennae were chewed off ($n = 2$). Thirteen (10 ad and 3 juv) raccoons died during the study; 3 mortalities were categorized as predation, 4 as vehicle accidents, and 6 as disease.

Survival was higher ($\chi^2_1 = 6.5$, $P = 0.01$) during the fall/winter than the spring/summer (Table 1.5). Rates of seasonal cause-specific mortality ranged from 0.022 to 0.16 and appeared to differ across seasons. Disease accounted for more raccoon mortalities during the fall/winter season, while more vehicle accident deaths occurred during the spring/summer season (Table 1.6). Predation was attributed to more deaths occurring during the spring/summer season than the fall/winter season.

DISCUSSION

Capture data

Trapping data have long been used in the determination of population demographic parameters. However, use of these data assumes that the subset of the population captured is indeed representative of the true population. Therefore, trapping effort and sex, age, or seasonal bias must be considered before drawing conclusions based on trapping results.

Moore and Kennedy (1985) suggested that variation in trappability among individual raccoons before initial capture arises from 2 basic sources: (1) differences in individual response to the traps, and (2) differences due to the location of the animal in relation to the spacing of the traps. Because my trap lines encompassed the majority of the forested areas on my study site, I believe most raccoons had the same opportunity to encounter a trap.

Gehrt and Fritzell (1996) reported that male raccoons had a higher capture probability than female raccoons. They also found that both sexes had higher recapture rates during the winter/early spring trapping period. However, they noted food and water were in short supply on their study site. In addition, Gehrt and Fritzell (1996) cited that males on their study area maintained intrasexual social bonds and often traveled in groups. Females, on the other hand, moved independently; potentially violating the assumption that capture probabilities were independent among groups. Gehrt and Fritzell (1996) stated that although initial capture probabilities were difficult to determine, recapture rates are adequate indicators of trappability. On my study area, I was unable to reject the null hypothesis that there were no intersexual differences in recapture probability.

Season, session, and day were all found to have significant effects on the number of raccoons captured/trapping session. However, the effect of season interacted with trapping day because the number of raccoons captured/day did not consistently decline as the trapping season continued in the spring 2005 session. Seasonal effects on capture probabilities have been suggested as resulting from differences in food availability and behavior changes (Moore & Kennedy 1985, Gehrt and Fritzell 1996). A tendency to forage more heavily during the fall in preparation for harsh winter conditions may have led to the consistently high capture success I observed during the fall on my study area. The greatest number of raccoons were captured on the first day of each trapping session, with the exception of the spring 2005 session when the greatest number were caught on the second day. In the 10-day trapping sessions, captures/day dropped off considerably by day 10. The results of the 20-day sessions also indicated a decrease in captures/day around day 10, and then leveling off at a relatively constant 1-2 animals/day until day 20. More raccoons were captured during the longer sessions, although fewer animals were caught in the last days of the longer sessions than the shorter ones. Thus, extending the trapping period past 10 days resulted in the capture of additional animals. Early in the study I observed a large number of animals captured on first couple days of the trapping session followed by a drastic drop off in the number of animals caught/day towards the end of the session. This pattern reversed throughout the study, with successively fewer initial captures and a more gradual decline through time. This may be due to animals becoming more accustomed to the traps and more frequently ignoring their presence. This possibility is reflected by the relatively low capture success during my final capture season (spring 2005). It may be that over 4 trapping periods, raccoons were becoming more trap-wary.

Physical condition

Seasonal changes in raccoon body weight have been documented across the species' range. Depending on the latitude of the study site, raccoons lose from 19-50% of their body weight over the winter (Stuewer 1943, Mech et al. 1968, Johnson 1970, Moore and Kennedy 1985, Zeveloff and Doerr 1985, Rosatte et al. 1991). Raccoon weights in my study exhibited similar trends. From the fall trapping season to the spring trapping season, average body weight of adult males decreased by 26% while females lost 11% of their body weight. Greater weight loss by males has been suggested as a byproduct of polygynous breeding behavior (Zeveloff and Doer 1981, Zeveloff 2002, Gehrt 2003). Average weights (kg) of raccoons in my study (ad M:5.8, juv M:3.4, ad F:4.7, juv F:3.2) were less than those described for another raccoon population (ad M:7.3, juv M:5.0, ad F:6.1, juv F:4.7) in Illinois (Sanderson and Hubert 1980). However, Sanderson and Hubert (1980) averaged raccoon weights across the entire state, and they found mean weights to be significantly higher in north-central Illinois than in southern

Illinois. Regardless, raccoons on my study area appeared to be in good physical condition as evidenced by low prevalence of ectoparasites on captured animals, good physical appearance during handling, and relatively low incidence of death by disease or starvation.

Population density

Jolly-Seber open population estimators are generally biased low if there is heterogeneity in the capture probabilities (Carothers 1979, Hwang and Chao 1995, Pledger and Efford 1998, Huggins et al. 2003). Accordingly, the raccoon population density on my study site is at least 1 raccoon/0.61 ha, which is high relative to estimates from other studies (Table 1.7). Comparison with published reports reveals that this protected bottomland forested habitat is capable of supporting similar densities to urban and suburban landscapes.

Riley et al. (1998) reported estimates of raccoon density from mark-recapture studies across the species' range and in areas with diverse land use practices. The majority of studies reporting raccoon densities similar to mine were conducted in urban and suburban areas. In addition, most of these studies employed closed population modeling techniques, which, more often than not, are not applicable to raccoon populations due to the duration of studies and the potential for dispersal and deaths. I chose to use an open population estimator for my study, and derived my density value after an estimation of the effective trapping area (Otis et al. 1978, White et al. 1982, Pollock et al. 1990). For determining the width of the effective trapping area, I believe the diameter of a 600 m home range to be realistic given past studies conducted at similar latitudes and in similar landscapes, and the baseline movement data collected from radiocollared raccoons on my study area.

The high density exhibited on my study site suggests extremely high habitat suitability and recruitment and/or high survival rates (Riley et al. 1998). The relatively minor winter weight loss exhibited by raccoons on my study area, compared to studies in more northen climates (Stuewer et al. 1943, Mech et al. 1968, Zeveloff and Doer 1981), might indicate superior habitat suitability. Survival rates of raccoons on my study area during the fall/winter were somewhat lower than those reported for other unexploited raccoon populations (see below); again suggesting high recruitment rates and/or high habitat suitability as the explanation for the elevated densities.

Survival and cause-specific mortality

Most studies of protected raccoon populations have reported relatively high survival rates. Gehrt and Fritzell (1999) found annual survival of a nonharvested raccoon population (sexes pooled) in southern Texas to be 0.84. Riley et al. (1998) studied raccoon survival in an urban national park during a rabies epizootic and still observed high rates (0.83 and 0.85 seasonal survival rates) even at the height of the epizootic. Riley et al. (1998) also noted that canine distemper and rabies were not found to be major sources of mortality for raccoons in high density unharvested populations. Although my spring/summer survival rate (0.68) is lower than those published for unexploited raccoons, my fall/winter rate (0.84) falls well within the range of previous studies.

In unexploited raccoon populations, disease is generally the most common cause of death (Mech et al. 1968, Gehrt et al. 1990, Roscoe 1993, Riley et al. 1998). As expected, disease-related deaths were more prevalent during the fall/winter (70% of all mortalities) than during the spring/summer. This may be a reflection of stressors placed on raccoons during the breeding season and poor overwintering condition. Prange et al. (2003*a*) also saw more disease-related deaths during the late winter when raccoons were in poorer body condition than during the spring or summer. In addition, due to their polygynous mating system (Gehrt 2003), potential for disease transmission may be greater during the winter breeding season than at other times during the year.

During the spring/summer season, deaths from vehicle accidents and predation predominated as causes of mortality, as they did in the Prange et al. (2003*a*) study. During this time, females were using more temporary, exposed forms of daytime resting sites (see Chapter 2), potentially increasing their vulnerability to these mortality sources. For example, during the fall/winter, females were found to use tree cavities with cavity openings higher off the ground that possibly offered better protection from predators. In addition, Johnson (1970) found that the foraging needs of raccoons change seasonally. Raccoons rely predominantly on soft mast and insects during the spring and summer (Johnson 1970), resources which are ephemeral and spatially heterogeneous. Increased physiologic demands experienced by females due to parturition and cub-rearing during the spring/summer may induce females to venture further and encounter more hazards (e.g., predators and roads) to meet these energetic demands. Conversely, corn crops left standing through the fall/winter provided raccoons with a stable, relatively constant food source.

My findings are in direct contrast with those of Chamberlain et al. (1999), who found female survival to be 0.65 during the breeding-gestation period (1 Feb-31 May)(my fall/winter season). Conversely, my results indicate the fall/winter season to be the period of highest survival. Kamler and Gipson (2003) reported a seasonal decrease in survival from summer to winter due to coyote predation and winter severity. Despite my small sample size, my data suggests just the opposite; a decrease in the number of mortalities attributed to predation from the spring/summer to fall/winter season. Higher survival rates during the fall/winter season in my study may be the result of less severe winters. On my study area, the winters months were typified by warmer weather coupled with smaller amounts of annual snowfall and remnant agricultural grains from harvest activities; all of which increase the probability of survival during this time period relative to other studies. In addition, the almost exclusive use of tree cavities for denning may have provided females with additional protection from the elements and predators. The lower spring/summer survival estimate observed on my study site compared to other protected raccoon populations may be the byproduct of high predator densities and high-speed vehicular traffic coupled with high raccoon densities (which can facilitate the spread of disease).

RESEARCH AND MANAGEMENT IMPLICATIONS

Capture data

Today, raccoons are unharvested in many settings, ranging from protected natural areas to urban parks; thus an accurate baseline knowledge of the demographics of protected raccoons is important. The ability of regulatory agencies to accurately predict changes in population size and structure is important in the development of management decisions. Data collected during this study included information about density, sex and age ratios, and recruitment rates of raccoons. With this information, raccoon population models can be created to predict raccoon numbers in particular land use areas, given different survival or density values. These models could be used to predict levels of damage or potential for disease transmission under different management regimes.

My results concerning raccoon trappability and optimal capture session length can improve the efficiency of research programs and rabies control operations (Moore and Kennedy 1985, Gehrt and Fritzell 1996, Riley et al. 1998). Trapping has been suggested as the most effective means of removing surplus raccoons, and as an effective means of minimizing potential raccoon disease outbreaks (Mosillo et al. 1999).

In urban and suburban areas, lethal means of controlling nuisance animals may not be viable options, and in these cases, efficient live trapping can be used as an alternative. However, to be effective, an in-depth understanding of trapping trends is critical; considerable time and energy can be saved by focusing trapping efforts in the most lucrative locations for the most effective time period (McDonald and Harris 1999, Prange et al. 2003*a*,*b*). Based on my results, it appears that extending the trapping period beyond the point of capturing a low constant number of animals each day is warranted. However, if trapping goals involve a high number of catches, it would be advisable to change trapping locations after a low constant threshold has been reached.

My results also indicate that there was a difference in raccoon capture success between the fall and spring seasons on my study area, with the spring being less successful in 1 of the 2 trapping sessions. I would expect a similar pattern for other regions that experience mild winters and have abundant fall and winter food resources. Trapping day and session length were also significant for capture success. Therefore, session length should be determined based on the goals of the trapping program, which may include catching the greatest number of animals in the shortest time possible or trapping out all animals in an area.

Survival

Previous raccoon survival studies have focused on harvested populations (Fritzell and Greenwood 1984, Glueck et al. 1988, Clark et al. 1989, Hasbrouck et al. 1992), which have relatively low survival rates during certain seasons of the year. Studies of survival rates in non-harvested raccoon populations in different geographic locations are now invaluable given the considerable proliferation in raccoon numbers over the past 20 years (Mosillo et al. 1999, Zeveloff 2002, Lariviere 2004). My results add to the growing database of estimates across the species' range, thereby enhancing collective understanding of raccoon population dynamics and facilitating the construction of population models.

Seasonal survival rates of females in my study differed from those estimated in previous studies of unexploited raccoon populations (Gehrt and Fritzell 1999, Prange et al. 2003*a*). Perhaps high raccoon density on the study area, increased competition for resources, or increased movements during the spring/summer in search of food resources, placed raccoons in contact with hazards such as predators or highly traveled roads. These findings stress the need for further investigation into the demographics of protected raccoon populations.

Information regarding raccoon abundance, density, and survival rates in the absence of harvest is invaluable in the development of management programs aimed at unexploited raccoon populations. Armed with these data, wildlife managers and researchers will be better equipped to predict and ameliorate the negative effects of increasing raccoon populations.

CHAPTER 2: HABITAT CHARACTERISTICS OF RACCOON DAYTIME RESTING SITES IN SOUTHERN ILLINOIS

INTRODUCTION

Raccoons cause many problems for humans and sensitive species and therefore are of interest to wildlife managers (Urban 1970, Bigler et al. 1975, Kazacos 1982, Boggess 1994, Zeveloff 2002). This growing concern about raccoons has spurred interest in finding ways to minimize predation by raccoons or reduce their population abundance through habitat manipulation (Rollins and Carroll 2001, Chamberlain et al. 2003, Henner et al. 2004). Specifically, female-directed habitat management procedures such as removal of high-quality den sites or microhabitats used for resting sites may provide a sufficient alternative to more expensive and controversial methods such as predator exclusion or control (Herkert 1994, Rollins and Carroll 2001, Henner et al. 2004). By identifying the resources and habitat characteristics that dictate where raccoons establish daytime resting sites (DTRS), wildlife managers can potentially limit access to essential resources or harvest raccoons near these resources to ensure high catch-per-unit of effort. Currently, little information regarding habitat correlates to raccoons DTRS is available. Gross descriptions of raccoon denning ecology have been documented for various landscapes (Stuewer 1943, Urban 1970, Endres and Smith 1993, Nixon et al. 2001). However, most studies were limited to a few observations of individual animals or anecdotal evidence gathered during limited periods of the year (Berner and Gysel 1967, Shirer and Fitch 1970, Schneider et al. 1971, Rabinowitz and Pelton 1986, Endres and Smith 1993, Nixon et al. 2001).

The only study to assess habitat associated with raccoon DTRS selection was Henner et al. (2004). They found that DTRS were positively associated with woody patch size, amounts of woody and grass edge, crop field patches, and area of lakes and ponds. In addition, Henner et al. (2004) suggested that landscape configuration around the resting site was important in the selection process. However, Henner et al. (2004) only considered raccoon DTRS selection patterns at the landscape level by examining macrohabitat variables (e.g., woody patch size) and not microhabitat features such as den tree characteristics or nearby den or food resources.

A more in-depth knowledge of the habitat preferences of female raccoons is crucial to ensuring the efficacy of habitat modification to reduce raccoon populations. The purpose of this chapter is to determine which habitat factors influence the selection of raccoon DTRS in a bottomland forested habitat. To my knowledge, this is the first study to examine in detail both macrohabitat and microhabitat factors affecting raccoon DTRS selection, and to compare selection between seasons. My objectives were to: (1) quantify habitat characteristics at raccoon daytime resting sites and control sites, and (2) determine which habitat variables influence raccoon daytime resting site selection during the breeding and cub-rearing seasons. Raccoon DTRS selection information will improve understanding of raccoon ecology and habitat use that wildlife managers can use to improve raccoon research and control programs.

METHODS

Daytime resting site locations

Raccoons were captured on the UCCA following the methods described in Chapter 1. Females were the focus of research in this analysis, and I attempted to maintain a radiocollared sample of >20 individuals at all times during the study. During 2003-2005, I located raccoons during daytime hours (0700-1700 hr) using a TS-1 receiver and scanner (Telonics, Inc., Mesa, Arizona, USA) and a 3-element Yagi antenna. I homed directly to the raccoon's location (these were considered DTRS) until I could make a positive visual identification or ascertain the habitat feature concealing the animal. Raccoon locations were recorded using a GPS eTrex Summit (Garmin Corporation, Salem, Oregon, USA) and were entered into ArcView® 3.0 Geographic Information System (GIS) (Environmental Systems Research Institute, Inc., Redlands, California, USA).

I homed to DTRS during 2 periods: the breeding season (1 Dec-1 Mar) and the cub-rearing season (15 Apr-30 Jun) (Stuewer 1943, Lotze and Anderson 1979). My goal was to obtain a similar number of DTRS locations for each raccoon during each period. DTRS were categorized as internal tree cavities, bucket top tree cavities, exposed branches, piles of scrap metal on the ground, downed hollow logs, and vines suspended in tree canopies.

Control locations

I compared characteristics of DTRS to those of control locations, selected by overlaying a grid of points (spaced 200 m apart) on all forested areas in proximity to radiocollared raccoons. USGS topographic maps, Digital Orthophoto Quarter-Quadrangles (DOQQs), and a GPS were used to locate control locations. Because raccoons heavily use trees for DTRS in forested habitats (Stuewer 1943, Cabalka et al. 1953, Whitney and Underwood 1952, Rabinowitz 1981, Zeveloff 2002), a focal tree (one with a cavity >18 x 43 cm, Cabalka 1952) was selected at each control location. If a suitable tree was located ≤50 m from the control location coordinates and there was no sign that the tree was being utilized by a raccoon (e.g., no scat at the base of the tree), the location was used and habitat sampling ensued.

Microhabitat variables

Ten microhabitat characteristics I deemed most likely to influence DTRS selection were measured at DTRS sites and control locations (Table 2.1). These variables were independent of seasonal differences in vegetative growth and phenology, thereby permitting seasonal comparisons. Variables were recorded within a 50 m radius surrounding either a raccoon DTRS or a control site focal tree. Breeding season measurements were taken during 6 December 2003-10 March 2004 and 3 January–28 January 2005. Cub-rearing season measurements were collected during 17 April-1 July 2004. Measurements at DTRS and control sites were taken within 30 days of one another to ensure similarity in environmental conditions. Mast abundance was measured during the breeding season only. Nine total measurements of mast abundance were taken using a 1 m^2 frame at the base of the tree and then again at 25 m and 50 m distances radiating away from the tree of interest in 4 perpendicular directions.

Macrohabitat variables

Macrohabitat characteristics of daytime resting sites and control locations were calculated using FRAGSTATS Version 3 (McGarigal et al. 2002)(Table 2.2). Spatial coordinates of DTRS and control locations were buffered by 100 m (Henner et al. 2004) and overlaid on a land cover map of the UCCA. The original land cover map containing 23 classes (Luman et al. 1996) was reclassified to the following 10 classes that were well-represented on the study site and of biological significance to raccoons: agriculture, deep marsh, forest, forested wetlands, grass, open water, shallow wet meadow, shallow wetlands, swamp, and stream. Macrohabitat variables were calculated for each of the 10 classes as well as one for the overall landscape resulting in 156 variables for analysis.

Habitat variable reduction

To avoid pseudoreplication (Hurlbert 1984), each habitat variable was averaged over all DTRS's for each individual raccoon. Hence, the individual raccoon (and not the DTRS) was the basis for analysis. For control locations, habitat variables of 3 consecutive control locations within close proximity to each other (occupying a similar forest patch within 600 m) were also averaged to provide similar seasonal sample sizes between DTRS and control locations.

Habitat variables were tested for normality using the Shapiro-Wilk statistic (SAS Institute 2000), and non-normal variables were logarithmically transformed. An

ANOVA ($\alpha = 0.05$ throughout) was used to test for differences between variable values at (1) breeding season DTRS, (2) cub-rearing season DTRS, and (3) control locations. Variables that differed among the 3 areas of interest were retained and all others eliminated, resulting in 14 variables for further analysis. These variables were then entered into cluster analysis (PROC VARCLUS, SAS Institute 2000). Cluster analysis functions by grouping variables that are highly correlated among themselves and as uncorrelated as possible with variables in other clusters. To account for sampling variability, I chose an eigenvalue threshold of 0.7 (Jackson 1991). The variable with the highest $1\text{-}R^2$ ratios (SAS Institute 2000) were selected from each cluster, resulting in 8 variables for further analysis (Table 2.3).

Influence of habitat variables on daytime resting sites

The 8 remaining habitat variables were entered into multinomial logistic regression in SPSS 10.0 (SPSS Inc. 1999) to determine which habitat variables best differentiated among breeding season DTRS, cub-rearing DTRS, and control locations. The advantage of using multinomial logistic regression is that it allows for the comparison of predictor variables of 3 areas of interest (Wright 1985). Backward selection was used to create the most parsimonious model (Voges et al. 2002). This process involved first fitting the model with all 8 variables, removing non-significant variables, and re-fitting the model using only the significant variables (number of potential den trees, den height, CBH (circumference at breast height of the den tree, distance to nearest water, distance to nearest road). Model goodness-of-fit was assessed using Nagelkerke's R^2 and McFadden's rho-squared; model performance was evaluated based on the model classification table (SPSS Inc. 1999).

RESULTS

Daytime resting sites

Fifty-four female raccoons were radiocollared during the course of my study. Of these, 17 were tracked during both the breeding and cub-rearing seasons. Thirty-five raccoons were tracked during the breeding season (2003-2005) and 36 raccoons were tracked during the cub-rearing season (2004).

A total of 313 DTRS locations were recorded for raccoons during the study. I obtained 4.7±1.7 DTRS/raccoon during the breeding season (1 raccoon was in the same DTRS every time she was located) and 4.3±1.1 DTRS/raccoon during the cub-rearing season. Raccoons appeared to rest singly in a DTRS, except for 5 instances when 2 radiocollared individuals were in the same cavity during the breeding season and 1 instance when 2 radiocollared individuals were in the same cavity during the cub-rearing season. Ten of the 35 raccoons (29%) during the breeding season and 21 of the 36 raccoons (58%) during the cub-rearing season were found in a different DTRS each time they were located. DTRS were typically reused more frequently (1- 6 times) during the breeding season (with the exception of natal dens); in fact, 1 raccoon was found in the same DTRS each time it was located during the breeding season. In other instances, the same DTRS was found to be reused by a different raccoon at a later date on 2 occasions.

Tree cavities (bucket cavities at tree top or openings in the bole of the tree) represented 73% (*n* = 229) of the DTRS, 23% (*n* = 71) were more exposed DTRS where raccoons were resting on branches or vines. During the breeding season raccoons used tree cavity dens almost exclusively (94%), whereas during the cub-rearing season, tree cavities accounted for only 50% of DTRS. Downed logs represented 2% (*n* = 7) of DTRS overall, and 1% (*n* = 6) were in ground dens or moving.

Habitat variables associated with daytime resting sites

The overall 5 variable model (Table 2.4) was highly significant ($\chi^2_{16} = 100.3$, $P < 0.001$) and correctly classified locations 71.3% of the time (Table 2.5). Model goodness-of-fit values were satisfactory (Nagelkerke $R^2 = 0.64$ and McFadden Likelihood Ratio Tests rho-squared = 0.44).

Breeding season DTRS were farther from roads, closer to nearest water, surrounded by more potential den sites, and in dens higher off the ground than control sites (Table 2.6). Cub-rearing season DTRS were in smaller CBH trees, surrounded by more potential den sites, and farther from roads than control sites (Table 2.6). Den tree CBH was larger during the cub-rearing season than during the breeding season (Table 2.6). Breeding season DTRS were closer to water than cub-rearing season DTRS (Table 2.6). Mast, which was only measured during the breeding season and not entered into the multivariate analysis, was more abundant ($F_{1,72}$, $P = 0.049$) at DTRS (97 ± 202) than at control locations (27 ± 68).

DISCUSSION

Daytime resting sites of raccoons

Female raccoons used tree DTRS almost exclusively during my study, which was similar to other findings (Stuewer 1943, Cabalka 1952, Whitney and Underwood 1952, Berner and Gysel 1967, Rabinowitz 1981). The high use of tree DTRS was most likely the result of the abundance of potential den trees on the study area (2.8 den trees/ha). Ground DTRS comprised only 4% of the cub-rearing season DTRS locations, which concurs with Nixon et al. (1995), who reported that ground nests were not important resting sites for raccoons. Similar to Henner et al. (2004), raccoons used more exposed temporary DTRS locations during the cub-rearing season than the breeding season. From these data, it appears that tree DTRS are an important habitat feature for raccoons across their distributional range.

Lotze and Anderson (1979) reported that den site fidelity varies substantially among individuals and seasons, but that the tendency to use the same den among seasons was very low. I found similar results, as females that used a single DTRS for the entire breeding season went on to use multiple DTRS in the cub-rearing season, and vice-versa.

Previous studies have indicated that day beds are seldom used on consecutive days (Cabalka 1952, Mech et al. 1966, Shirer and Fitch 1970). Rabinowitz and Pelton (1986) cited 46% of DTRS as used more than once and that female raccoons remained in the same day bed on consecutive days 60% of the time. Raccoons in my study tended to remain in the same 400-600 m radius and 70% of DTRS were reused at least once during the breeding season and 60% of DTRS were reused during the cub-rearing season. Rabinowitz and Pelton (1986) reported that during spring, the distance between consecutive DTRS was approximately 200 m for females, and in other months, movements were approximately 350 m. These data may reflect the possibility that females with cubs change DTRS more frequently, whereas during the winter months it may be more advantageous from a thermoregulation standpoint to find a single, secure, warm DTRS.

Influence of habitat variables on daytime resting sites

The results of my study are significant in that they elucidate the importance of previously understudied microhabitat in the selection of raccoon DTRS. Henner et al. (2004) studied raccoon DTRS selection relative to macrohabitat variables in an agricultural prairie landscape in central Mississippi. Henner et al. (2004) reported that raccoons selected specific woody patches rather than all woody patches in general, and that females tended to select areas with greater access to water. They found den sites to be positively correlated with woody median patch size, woody and grass total edge, number of patches of corn fields, lake/pond area, and road class area. Henner et al. (2004) stated den sites were closer to crop fields, roads, and macrohabitat edges than control sites. In addition, they found no difference in distance to nearest water sources among den and control sites.

Unlike Henner et al. (2004), I did not find that larger scale habitat selection explained the locations of raccoon DTRS in southern Illinois. Rather, my model of raccoon DTRS selection included the 5 following microhabitat variables: tree CBH, den height, distance to nearest road, distance to nearest water, and number of nearby dens.

Discrepancies between the results of our studies may reflect differences in the quality of habitat and the resulting raccoon population densities at the different study sites. The interspersion of croplands, forest, and sloughs on my site created ideal raccoon habitat, potentially supporting higher raccoon population densities than the prairie landscape of the Henner et al. (2004) study. In fact, raccoon density on the UCCA was one of the highest reported at 1 raccoon/0.6 ha (See Chapter 1). In higher quality habitat when their most basic needs (i.e. food, water, dens) are met, raccoons may be selecting DTRS at a finer scale.

In my study, females consistently selected DTRS farther from roads during both seasons. On my study area, there was a 40 MPH limit road running through the middle, creating a hazard to raccoon movement. Previous studies have found roads to be a significant danger to raccoons (Johnson 1970, Glueck et al. 1988, Clark et al. 1989, Mankin et al. 1999). Raccoons on the UCCA experienced 2.2% and 15.9% vehicle accident cause-specific mortality rates during the fall/winter and spring/summer seasons respectively. My results suggest that females may be actively avoiding roads when undertaking foraging movements away from den sites. Raccoons selecting DTRS close to roads may in turn have lower survival probabilities.

I found that distance to nearest water was important for DTRS selection; however, it was a better predictor of breeding season DTRS than for the cub-rearing season. This may be because during the spring and summer water was so plentiful on the refuge that raccoons did not need to rely on selecting DTRS close to this resource. However, during the breeding season when water sources were frequently frozen, the selection of a DTRS near standing water still appeared to be critical. Raccoons likely foraged near water during ice-off periods due to ample food resources found in these areas.

Trees selected during the cub-rearing season were significantly smaller than DTRS trees in the breeding season and compared to control trees. During the cub-rearing season when the weather was mild and food plentiful, raccoons were using more temporary forms of shelter, such as vines suspended in tree canopies and branches. Others have noted similar occurrences (Cabalka 1952, Ellis 1964, Mech et al. 1966, Berner and Gysel 1967). Use of these more exposed DTRS in the canopy of trees may have led to the selection of several smaller trees. Females appeared to be selecting larger cavity trees during the breeding season when temperatures were cooler and protection from the elements was more crucial to survival. Schneider et al. (1971) suggested that winter dens (breeding season DTRS in my study) may be selected for the characteristics of the tree, not the site, as raccoons are looking for better protection from the weather.

During both seasons, raccoons selected DTRS with a higher number of potential den trees nearby. DTRS abundance is commonly cited as a key habitat component for raccoons (Giles 1942, Whitney and Underwood 1952, Endres and Smith 1993) and although potential DTRS were abundant on my study site, raccoons still selected DTRS near the greatest amount of den resources. In addition, during the breeding season, females typically selected cavities that were higher off the ground, presumably as increased protection from ground predators such as coyotes (*Canis latrans*) and bobcat (*Lynx rufus*), which inhabit my study area. Kamler and Gipson (2003) reported increased coyote predation of raccoons from summer to winter. My survival information (see

Chapter 1), though based on small sample sizes, may provide some evidence that this DTRS selection strategy works for raccoons on my study site, as reflected by lower predation rates during the fall/winter.

As in the Henner et al. (2004) study, I expected distance to crop field to be significantly smaller at raccoon DTRS than control locations; however, that was not the case. Perhaps female home ranges encompassed both forested patches and a neighboring crop field and so selection of a DTRS closer to the crop field was not critical. Often times, crop fields were closer to roads and thus the benefit of being closer to food may have been outweighed by the potential dangers of the road. In addition, Johnson (1970) found that corn comprised only 6% of raccoon diets and the rest was supplied by natural foods. Therefore, obtaining corn may not have been as vital to raccoon survival as avoiding roads on my study site.

Finally, I found that mast was more abundant at breeding season DTRS than at control locations. Mast has been shown to be an important food item for raccoons during both the fall and winter seasons (Yeager and Rennels 1943, Dorney 1954). Elevated levels of mast found at breeding DTRS lends further support to the active selection of DTRS with the greatest number of nearby resources.

RESEARCH AND MANAGEMENT IMPLICATIONS

I agree with Henner et al. (2004) and Herkert (1994) and their premise of potentially using habitat manipulation (e.g., identification and selective removal of den trees) as a nonlethal means of managing raccoon predation. However, unlike Henner et al. (2004), I found that microhabitat variables rather than landscape level variables were better predictors of raccoon DTRS on my study area. These findings illustrate the importance of assessing raccoon habitat selection at multiple spatial scales and in different landscapes.

My analyses quantified use versus availability differences in raccoon resting site habitat use that wildlife managers and researchers can use to improve raccoon control programs. The model presented here can aid wildlife managers in making more informed decisions about which landscape features are highly attractive to female raccoons for DTRS selection and to manage these to reduce raccoon habitat suitability in bottomland forested ecosystems. Based on my results, examples of possible habitat manipulation to reduce raccoon habitat suitability include the removal of large cavity trees (>100 cm CBH).

Serious consideration of the consequences of enacting habitat modification at the landscape scale must be taken prior to conducting management activities. Removing trees with cavities would have a profound impact on other cavity nesting species [i.e., bats, wood ducks (*Aix sponsa*)] inhabiting the area. The negative impact imposed on these potentially sensitive species must be carefully weighed against the benefits of decreasing raccoon habitat suitability. Further, managers of areas with different land-use goals will need to consider the pros and cons of implementing such a management plan. For example, managers of wilderness areas may not be as concerned with the potential for disease transmission from a surplus raccoon population as those of a residential park.

These results can also be used to target raccoon capture or oral rabies distribution programs. Knowledge that raccoons in bottomland forested landscapes den close to water and in areas with high nearby food and den resources would suggest that researchers attempting to capture raccoons or distribute oral rabies vaccines should focus their efforts in similar areas. Studies of raccoon cubs or other investigations of natal dens could target activities around larger trees in close proximity to other nearby dens and water and distant from frequently traveled roads. Similar investigations are needed in different habitat types to fully understand the effects of different habitat factors on raccoon DTRS selection.

Table 1.1. Raccoon capture success and demographic parameters in southern Illinois, 2003-2005.

Trapping Session	Total Trap Nights	Total Captured	Ad M	Ad F	Juv M	Juv F	M:F Ratio	Ad:Juv Ratio	Ad F:Juv Rate
Fall 2003	1,540	80	30	16	19	15	1.6:1	1.4:1	1:2.0
Spring 2004	1,004	52	30	22	----[a]	----[a]	1.7:1	----[a]	----[a]
Fall 2004	1,980	103	33	30	20	20	1.1:1	1.6:1	1:1.2
Spring 2005	1,499	47	32	15	----[a]	----[a]	2.1:1	----[a]	----[a]
Total	6,023	282	125	83	39	35	1.3:1	1.5:1	1:1.6

[a] Raccoons could not be separated into age classes during the spring due to similarities in size and weight

Table 1.2. Logistic regression results for the effect of trapping session variables on unexploited raccoon capture success in southern Illinois, 2003-2005.

Variable	SE	*P*-value
Season[a]	0.229	0.009
Session[b]	0.245	0.039
Trapping Day	0.017	0.001
Day*Season	0.031	0.813
Session*Day	0.039	0.042
Session*Season	0.291	0.926

[a] Traps set in the fall vs. the spring
[b] Ten vs. 20 day trapping period

Table 1.3. Measurements recorded for raccoons captured during the fall season (6 October-4 December 2003 and 21 September-2 December 2004) in southern Illinois.

Sex		Weight (kg)	Length (mm)	Tail length (mm)	Right hind foot (mm)	Testes length (mm)	Testes Width (mm)
Male							
Juvenile (*n* = 39)	$\bar{x}$	3.4	792.6	217.5	97.2	----	----
	SE	0.8	53.1	23.0	4.8	----	----
Adult (*n* = 69)	$\bar{x}$	6.3	909.9	226.5	102.3	26.9	18.0
	SE	1.3	53.2	34.4	4.7	4.7	3.8
Female							
Juvenile (*n* = 35)	$\bar{x}$	3.2	789.1	218.4	94.0	----	----
	SE	0.6	54.2	22.6	4.0	----	----
Adult (*n* = 50)	$\bar{x}$	4.9	861.3	222.0	96.8	----	----
	SE	0.7	39.1	23.9	4.3	----	----

Table 1.4. Measurements recorded for raccoons captured during the spring season (8 March-17 April 2004 and 2 March-10 April 2005) in southern Illinois.

Sex		Weight (kg)	Length (mm)	Tail length (mm)	Right hind foot (mm)	Testes length (mm)	Testes width (mm)
Male							
Adult (*n* = 62)	$\bar{x}$	5.3	887.6	237.1	104.3	28.9	22.2
	SE	0.8	46.9	20.9	4.7	4.1	3
Female							
Adults (*n* = 37)	$\bar{x}$	4.4	860.4	229.1	100.5	----	----
	SE	0.7	39	18.5	4.5	----	----

Table 1.5. Seasonal survival rates of female raccoons in an unexploited raccoon population in southern Illinois, 2003-2005.

Season	Mortalities	Radio-days	Survival Rate	SE	CI
Fall/Winter[a]	7	7,455	0.843	0.054	0.502-0.926
Spring/Summer[b]	6	2,857	0.682	0.033	0.745-0.957

[a] 1 Sep-28 Feb
[b] 1 Mar-31 Oct

Table 1.6. Seasonal cause-specific mortality rates of unexploited female raccoons in southern Illinois, 2003-2005.

Season	Mortality Cause	Mortalities	Mortality Rate	SE	CI
Fall/Winter[a]	Vehicle	1	0.022	0.014	0.000-0.066
	Predation	1	0.022	0.014	0.000-0.066
	Disease	5	0.112	0.015	0.019-0.205
Spring/Summer[b]	Vehicle	3	0.159	0.026	0.000-0.324
	Predation	2	0.106	0.022	0.000-0.245
	Disease	1	0.052	0.016	0.000-0.154

[a] 1 Sep-28 Feb

[b] 1 Mar-31 Oct

Table 1.7. Estimates of raccoon densities across the species' range.

Study Location	Site Description	Study Area Size (ha)	Density 1 raccoon/ha
Twitchell and Dill (1949) Missouri	Waterfowl refuge	41	0.4
This study (2005) Southern Illinois	Waterfowl refuge	197	0.6
Riley et al. (1998) Washington, D.C.	Urban national park deciduous forest	710	0.8
Hable et al. (1992) South Carolina, Barrier Island	NA	NA	2.3
Gehrt (2002) North-east Illinois	Urban	1,499	2.5
	Rural, agricultural	1,214	9.1
	Suburban	526	2.7
Blackwell et al. (2004) Ohio	Woodland, grassland surrounded by urban/agriculture	2,200	4.1
Kennedy et al. (1986) West Tennessee	Bottomland forest	313	17.4
Gehrt and Fritzell (1996) West Texas	Mixed grassland	1,850	25

Table 2.1. Microhabitat variables measured at raccoon DTRS and control locations in southern Illinois, 2003-2005.

Habitat Variable (unit)	How Measured
Distance to nearest water (m)	Tape
Distance to nearest permanent water (m)	GIS
Distance to nearest stream (m)	GIS
Distance to nearest crop field (m)	GIS
Distance to nearest edge (m)	GIS
Distance to nearest road (m)	GIS
Number of nearby den sites[a]	Visually
Mast abundance[b]	1 meter-squared frame
Den height (cm)[c]	Tape
CBH (cm)[c]	Tape/Visually

[a] Tree cavities ≥ 20 cm diameter, ground burrows, hollow snags within 50 m of raccoon or control location

[b] Measured during the breeding season only

[c] Measured at tree resting sites only

Table 2.2. Macrohabitat variables considered for determining factors influencing raccoon DTRS selection in southern Illinois, 2003-2005. Variables were calculated for 10 land cover classes and the landscape, resulting in 156 variables calculated. Cover classes were agriculture, deep marsh, forest, forested wetland, grass, open water, shallow wet meadow, shallow wetland, swamp, and stream.

Calculation	Variable (unit)
Area and patch metrics	
Class	Percentage of landscape (ha)
Landscape	Number of patches
Class/landscape	Patch area coefficient of variation (%)
Class/landscape	Mean patch area (ha)
Edge metrics	
Class/landscape	Edge density (m/ha)
Shape metrics	
Class/landscape	Mean shape index
Class/landscape	Mean fractal dimension index
Class/landscape	Mean perimeter-area ratio
Diversity metrics	
Landscape	Shannon's diversity index
Landscape	Shannon's evenness index

Table 2.2. continued.

Calculation	Variable (unit)
Contagion/interspersion metrics	
Class/landscape	Interspersion & juxtaposition index (%)
Isolation/proximity metrics	
Class/landscape	Mean proximity index
Class/landscape	Euclidean nearest neighbor distance
Core area metrics	
Class/landscape	Mean core area size (ha)
Class/landscape	Disjunct core area density
Class/landscape	Core area coefficient of variation (%)

Table 2.3. Habitat variables selected from cluster analysis to be entered into multinomial logistic regression to assess raccoon DTRS selection in southern Illinois, 2003-2005.

Variable Name	R^2 with own cluster	R^2 with next closest cluster	$1-R^2$ ratio
Mean patch area (ha)	0.9764	0.1708	0.0285
Crop field[a]	0.9117	0.1667	0.1059
Patch area coefficient of variation (%)	1.0000	0.2430	0.0001
CBH of den tree	0.6723	0.0533	0.3461
Number of suitable den trees[a]	0.6706	0.1013	0.3665
Den height	1.0000	0.0163	0.0001
Road[b]	1.0000	0.0878	0.0001
Water[b]	1.0000	0.0878	0.0001

[a] Within a 50 m radius of the DTRS or control location

[b] Distance from DTRS or control location to nearest landscape feature

Table 2.4. Parameter estimates for seasonal raccoon DTRS selection model, southern Illinois, 2003-2005.

ID	B	SE	Wald χ^2	df	P- value	Exp(B)
Breeding Season						
Intercept	-6.518	2.592	6.323	1	0.012	
NO_SUIT[a]	1.236	0.439	7.948	1	0.005	3.443
DHEIGHT[b]	0.267	0.116	5.351	1	0.021	1.306
CBH[c]	-0.00196	0.007	0.078	1	0.779	0.998
NWATER[d]	-0.958	0.309	9.625	1	0.002	0.384
ROAD[e]	0.00667	0.002	13.1	1	0.000	1.007
Cub-rearing Season						
Intercept	-1.324	2.405	0.303	1	0.582	
NO_SUIT	1.19	0.456	6.825	1	0.009	3.289
DHEIGHT	0.148	0.116	1.623	1	0.203	1.159
CBH	-0.03	0.008	15.003	1	0.000	0.97
NWATER	-0.0386	0.331	0.014	1	0.907	0.962
ROAD	0.0062	0.002	10.823	1	0.001	1.006

[a] Number of suitable den trees within 50 m radius
[b] Den height
[c] Diameter at breast height of den tree
[d] Distance to nearest water from den tree
[e] Distance to nearest road from den tree

Table 2.5. Classification table of the model representing the 5 habitat variables that predict raccoon DTRS versus control locations in southern Illinois, 2003-2005.

Observed Class	Predicted Class			
	1	2	3	Percent Correct
1[a]	19	6	7	59.4%
2[b]	5	25	3	75.8%
3[c]	4	4	28	77.8%
Overall Percentage	27.7%	34.7%	37.6%	71.3%

[a] Breeding season DTRS 2003-2005

[b] Cub-rearing season DTRS 2004

[c] Control locations 2003-2005

Table 2.6. Microhabitat variables measured at raccoon breeding season DTRS averaged per female (*n* = 35), cub-rearing season DTRS averaged per female (*n* = 36), and averaged per control location (*n* = 37) in southern Illinois, 2003-2005.

	Breeding Season		Cub-rearing Season		Control Locations	
Habitat variable (unit)	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Number of potential den	3.1	1.2	2.9	0.8	2.2	0.9
Den height (m)	13.2	3.8	11.3	4.2	11.1	2.4
CBH (cm)	215.5	47.6	155.4	52.1	226.7	44.8
Distance to nearest water (m)	10.4	18.2	23.2	25.5	19.5	18.7
Distance to nearest road (m)	442.8	242.1	492.5	198.6	260.8	160.6

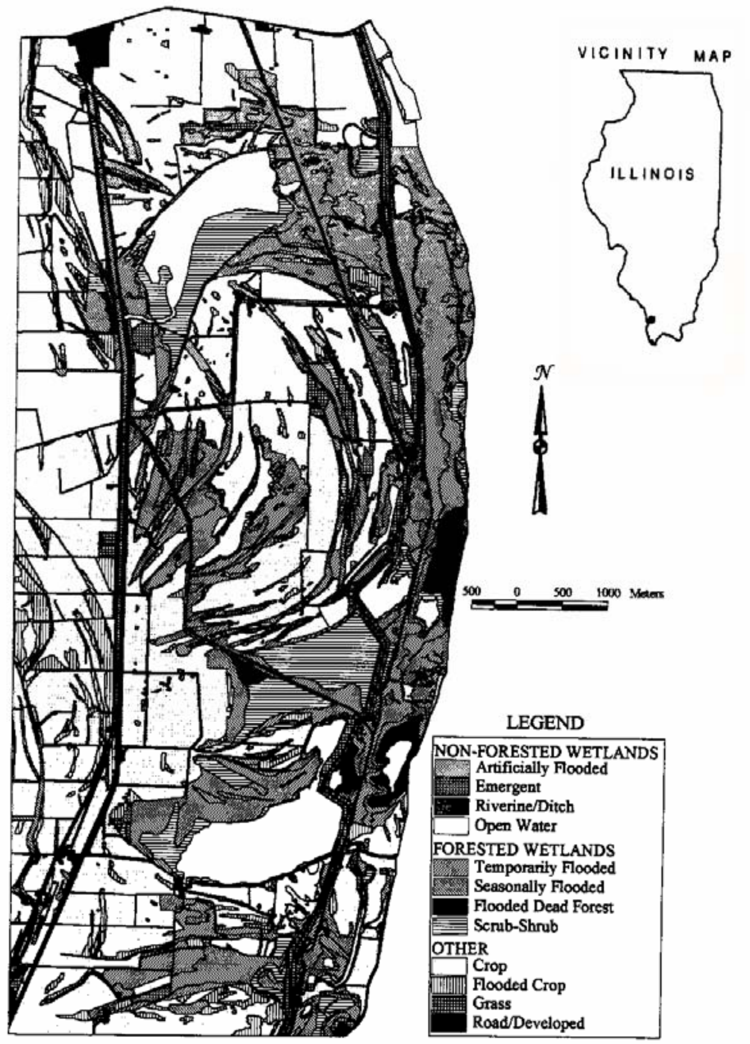

Figure 1.1. Land cover at Union County Conservation Area in southern Illinois as categorized by Kawula (1998).

Figure 1.2. Example of trapping design on the Union County Conservation Area in southern Illinois, 2003-2005. Symbols represent trap locations.

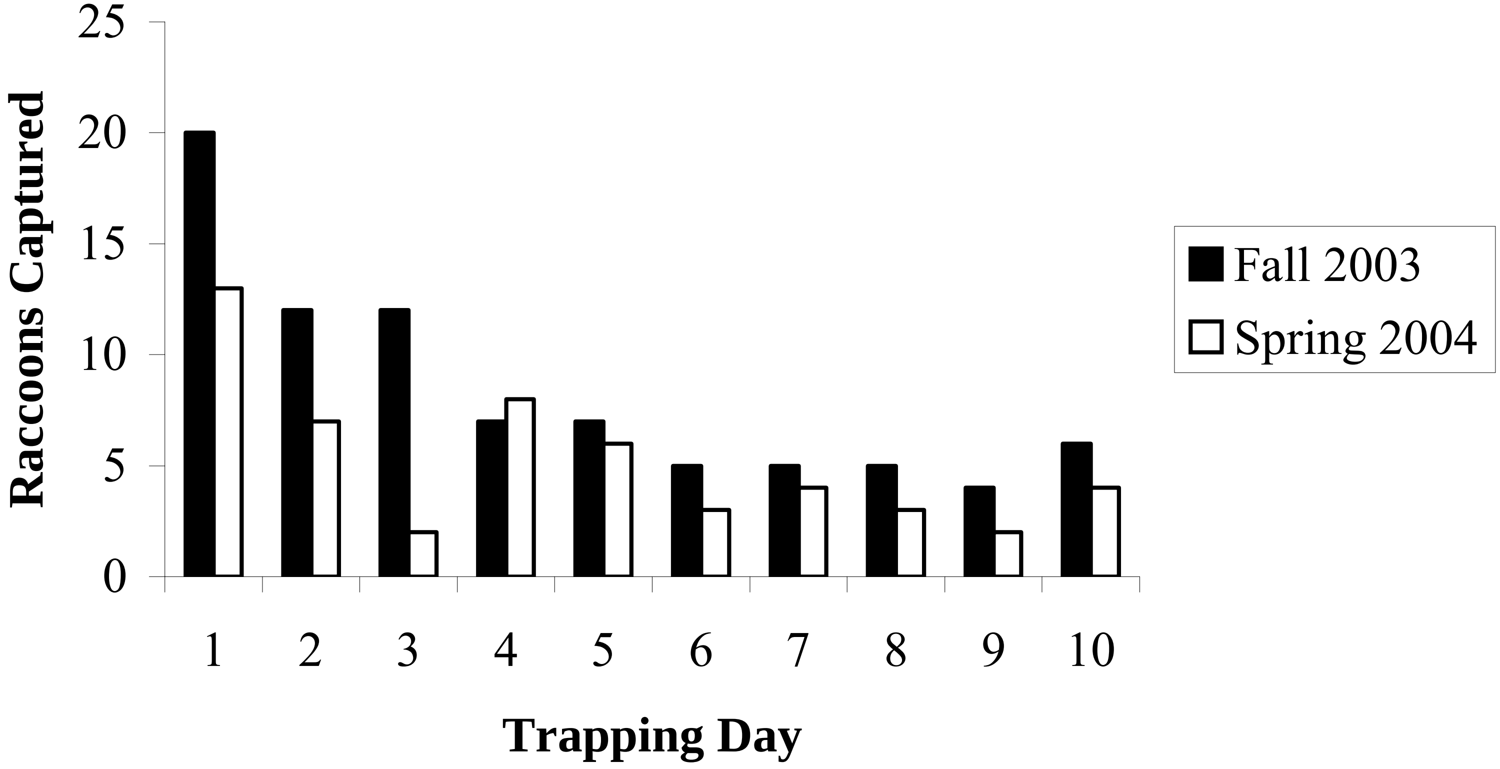

Figure 1.3. Raccoon captures during the fall 2003 (6 October-4 December) and spring 2004(8 March-17 April) 10-day trapping sessions in southern Illinois.

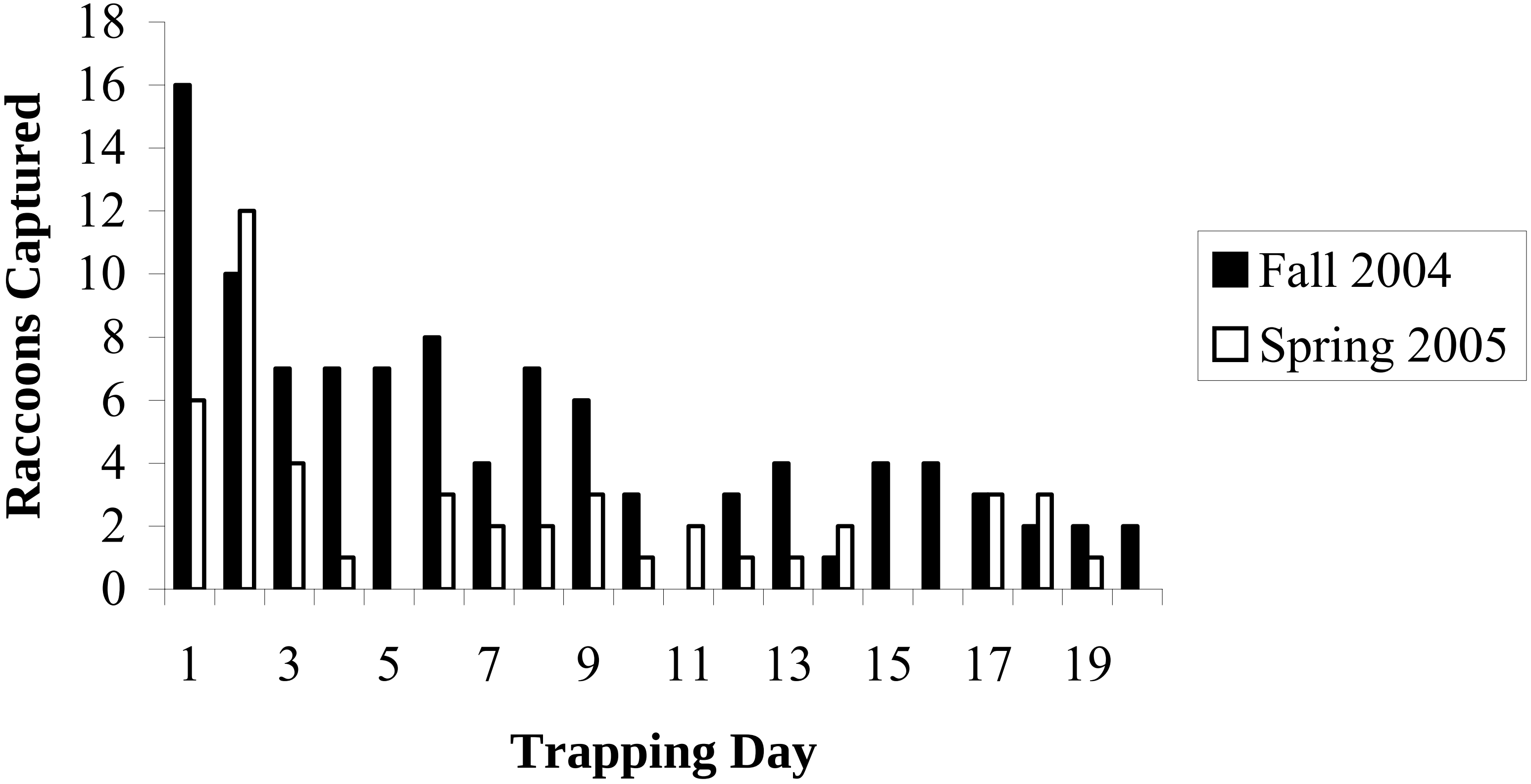

Figure 1.4. Raccoon captures during the fall 2004 (21 September-2 December) and spring 2005 (2 March-10 April) 20-day trapping sessions in southern Illinois.

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Demographic characteristics and habitat use of unexploited raccoons in southern Illinois

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