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Post-natal Survival of Raccoons in Relation to Female Age and Denning Behavior

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We measured post-natal survival of radio-collared raccoons 1-5 months old in southwest Iowa, 1988-1989. We compared survival of young nurtured by yearling and adult females and related den site selection to survival functions using proportional hazards models. Adult females used upland and farmstead habitats more frequently than yearlings, whereas yearling females used lowland habitats more frequently. Tree cavities and beds on the ground were used most frequently. Adult females denned in buildings 13% of the time and in holes in the ground 9.5% of the time, whereas yearlings frequently rested with litters in beds on the ground (31%). Microhabitat characteristics including such factors as tree size, surrounding vegetation, and den characteristics had no influence on use. We observed 9 mortalities of 64 earmarked young, 4 caused by dogs, the remaining including vehicle collisions, predation, and disease. All mortalities occurred after litters moved from their natal den to a post-natal den site. We could not show significant differences in survival of young nurtured by yearling and adult females and the best estimate of post-natal survival of raccoons from 22 May to 15 September was 0.65. Post-natal survival was positively influenced by the variety of habitats and den types used by females and their young. Denning habitat selection and post-natal survival of young, particularly those of adult females, may have an important influence on population levels.
INDEX DESCRIPTORS: den selection, Iowa, *Procyon lotor*, raccoon, survival estimation

For many medium-sized carnivores, estimates of early post-natal survival are lacking. Our ability to manage these species, often important as furbearers or predators, depends on accurate estimates of recruitment and survival early in life. Biologists often have relatively complete data regarding reproduction but not about post-natal survival, which is one of the most difficult quantities to measure. Density-dependent responses in post-natal survival have been shown to be an important mechanism by which exploited species adjust to changes in harvest level (Clark 1990, Clark and Fritzell 1992). We recognized the need for quantifying post-natal survival of raccoons (*Procyon lotor* Linnaeus) during long-term studies of the species response to an experimentally-induced increased harvest (Clark 1990, Hasbrouck 1991). Mortality rate of raccoons beginning at about age 6 months has been estimated (Stuewer 1943, Mech et al. 1968, Cowan 1973, Fritzell and Greenwood 1984, Clark et al. 1989, Hasbrouck 1991), and the effects of harvest considered (Clark et al. 1989, Hasbrouck 1991). Some studies have considered the factors that might influence the mortality rate of raccoons <5 months old (Stuewer 1943, Sanderson 1950, Mech et al. 1968, Schnell 1969, Schneider et al. 1971). Most often, habitat selection by raccoons during the post-natal period has been suggested as important (Kaufmann 1982, Sandell 1989, Stuewer 1943, Schneider et al. 1971). Glueck et al. (1988) suggested that the reduction of mature timber and loss of abandoned buildings which provide denning shelter could be related to productivity and early survival. Nobody has considered how the age and experience of the nurturing female raccoon could influence post-natal survival of young, although this factor has been shown to be important in other furbearers (Boutin et al. 1988).

We measured the survival rates and causes of mortality of raccoons between 1 and 5 months old and related them to den site characteristics and age of the nurturing females. Our study was conducted during a period of experimentally-increased harvest on a population in Iowa (Hasbrouck 1991).

STUDY AREA

The study area was a 42-km^2 tract located in Guthrie County in southwest Iowa (T79N, R31W). The area is bisected from northwest to southeast by the South Raccoon River. Land use consists primarily of corn and soybean fields, grazed pastures, and livestock forage crops. Timber comprises approximately 10% of the area and is generally confined to drainage systems, shelterbelts, and steep hills (Glueck et al. 1988).

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METHODS

Capture and recovery

From mid-March through April in 1988 and 1989, we captured female raccoons by live-trapping with cage traps baited with scent and immobilized them with an intramuscular injection of ketamine hydrochloride (Bigler and Hoff 1974) to facilitate handling. We palpated the abdomen to determine pregnancy, and pregnant females were fitted with transmitter collars (Advanced Telemetry Systems Inc., Bethel, MN). We aged all females as yearlings (1 yr. old) or adults (≥2 yrs. old) based sectioned incisors just as Clark et al. (1989).

Females localize their movements in the area around a natal den for several days prior to giving birth (Kaufmann 1982), so we could locate dens and estimate the expected date of parturition using radio telemetry. We returned 4-5 weeks later to capture the young when they had attained a sufficient body mass (approx. 700 g) which we judged to be adequate to carry radio-collars. Females with young were immobilized and removed from the den. Post-natal young aged ≥5 weeks, based on tooth eruption and replacement (Montgomery 1964), were collared with an expandable, breakaway radio-collar (Advanced Telemetry Systems, Inc., Bethel, MN, Judson 1990). All young were tagged in both ears with numbered tags. In 1988 we radio-collared 1 young from each litter and in 1989 2 young per litter were collared when possible. Young from litters were marked from mid-May until the end of July each year.

Transmitters were equipped with mortality switches (Voight and Lotimer 1981) and all instrumented animals were relocated every 3 days to determine date and location of mortalities. Cause of death was determined by field necropsy and examining surroundings. When we were unsure of cause of death, the animal was necropsied at the School of Veterinary Medicine at Iowa State University. Monitoring of young began with instrumenting the first individual and continued until 15 September in both years.

Denning habitat selection

We recorded den locations beginning at the time of parturition to determine how habitat selection influenced survival. We sampled den sites of litters by randomly selecting 2 females each day from the pool of instrumented animals. We measured macrohabitat variables including distance (to the nearest 10 m) of the den to inhabited buildings, roads, water, edge habitat, and crop fields. We characterized each den or resting location by types including buildings, ground holes, brushpiles, farm machinery, row crops, ground vegetation, tree cavities, or open tree limbs. We also classified the locations by general surrounding habitat including upland forest, lowland forest, forest edge, fencerow, or farmstead (Glueck et al. 1988). At each den we measured microhabitat variables including height of the den, height of the structure where the den was located (nearest 1 m), den cavity depth (nearest 10 cm), den opening dimensions, diameter at breast height (DBH, nearest 1 cm) and species (if the den was in a tree). For tree dens in wooded areas, the basal area of adjacent trees was measured. To prevent desertion of the den while measuring cavity depth and the den opening dimensions, all dens were marked and we returned after the litter had moved.

Data analyses

Survival rates were estimated using Kaplan-Meier (K-M) statistics modified for staggered entry of captures (White and Garrott 1990, Hasbrouck et al. 1992). Censoring was caused by shedding of a collar, radio failure, dispersal from the study area, or surviving to 15 September each year. When exact dates could not be determined, we assumed the date of death or censoring to be the midpoint between relocations. We used logrank tests (Cox and Oakes 1984) to examine differences in survivorship between age classes and years. We used two-tailed Z-tests to detect differences in survival rates between groups at a given time (Pollock et al. 1989). When censoring reduced sample size and artifactually causes $\hat{S} = 0.00$, we calculated an adjusted final survival rate (Lawless 1982:88):

$$[\hat{S}(t_j)+\hat{S}(t_j+0)] / 2.$$

We used analysis of variance or χ^2 tests to test for differences between den sites selected by yearling and adult females when measurements were continuous or categorical, respectively. Pearson correlation coefficients (SAS Inst. 1985:355-357) among habitat variables were used to investigate which variables provided unique information.

We used a proportional hazards model to relate mortality of young raccoons in litters to the important covariates related to their daytime den sites (White and Garrott 1990, Hasbrouck et al. 1992). We estimated parameters of the model with program P2L, in the BMDP statistical software package (Hopkins 1985). We took a conservative approach and analyzed only those covariates for which we had no missing values for all 34 individuals and for which univariate analyses had shown significant differences (Judson 1990). Based on this approach we deleted den height, den structure height, den cavity depth, den opening dimensions, tree species and DBH, and basal area of adjacent trees from further consideration.

We included 10 covariates in model building: age class of female parent (ADAGE, yearling or adult), number of habitat types used (NUMHAB), number of den types used (NUMDEN), type of habitat used with highest frequency (TYPEHAB, upland, lowland, or farmstead), type of den used with highest frequency (TYPEDEN, tree, building, ground hole, row crop, ground vegetation, brushpile, and other), and the mean distances of daytime dens to the nearest inhabited building (MBLDG), road (MROAD), water (MWATER), edge habitat (MEDGE), and crop field (MCROP). Multiple den sites recorded for each litter during the field seasons were assumed to be independent of one another. We used a forward stepwise model selection, initially, setting entrance and removal of covariates criteria to $P < 0.25$ and $P > 0.30$, respectively. Covariates which met these criteria were then used in a second run with P2L at a $P < 0.10$ and $P > 0.15$ criteria, to help refine the model (K.J. Koehler, Iowa State Univ., *pers. commun.*) In an attempt to select the most parsimonious set of covariates, we used likelihood ratio tests to compare models which adequately fit the data. Multicolinearity between covariates was determined by examining the estimated asymptotic correlation matrix, concentrating on those pairs of covariates with $r > 0.45$ (Sievert and Keith 1985).

RESULTS

Den selection

We tagged 64 young raccoons from litters of 23 females during late spring and early summer of 1988 and 1989. Instrumented young included 14 individuals from 12 litters in 1988 (5 from yearling, 8 from adult females and 1 unknown) and 20 from 11 litters in 1989 (4 from yearling and 16 from adult females).

Raccoon families denned in upland, lowland and farmstead habitats and rarely used edge and fencerow habitats. Adult females with litters were located in upland forests 43.1% of the time, more frequently than yearlings (29.2%; $\chi^2 = 3.67$, df = 1, $P = 0.05$). Adults also used farmsteads more frequently than yearlings (adult = 17.3%, yearling = 6.2%; $\chi^2 = 6.65$, df = 1, P = 0.01). Yearling females more frequently utilized lowland habitats (64.4%) than adults (39.6%; $\chi^2 = 9.22$, df = 1, $P = 0.002$).

Dens in tree cavities or on the ground in vegetation were used with higher frequency than any other den type and overall proportions of dens selected differed between yearling and adult females with litters ($\chi^2 = 21.53$, df = 7, $P = 0.003$). Adult females and their litters were relocated more frequently in buildings (13.1%) compared with yearling females (2.6%; $\chi^2 = 8.63$, df = 1, $P = 0.003$). Adults also used holes in the ground more frequently than yearlings (adults = 9.5%, yearlings = 1.7%; $\chi^2 = 6.64$, df = 1, $P = 0.001$). Yearling females used dens which were in vegetation and on the ground more than litters of adult females (adults = 19.1%, yearlings = 31.3%; $\chi^2 = 4.61$, df = 1, $P = 0.032$).

Macrohabitat characteristics of den sites also differed between yearling and adult females. Adults' den sites were closer to buildings and roads than yearlings', whereas yearlings' den sites were closer to water, edge, crop fields, and their last den location (Table 1). Of the preceding variables, only the distances from dens to roads and buildings were highly correlated ($r = 0.61$, $P = 0.001$).

Table 1. Distances (m) to macrohabitat features from day-time den sites used by yearling (Y) and adult (A) female raccoons in Guthrie County, Iowa 1988-1989.

Distance (m)	Age	*n*	Mean	SE	$P > F^a$
Building	Y	115	592.6	26.01	<0.001
	A	199	426.5	17.10	
Road	Y	115	412.1	28.70	<0.001
	A	199	292.9	18.42	
Water	Y	115	77.7	6.90	<0.001
	A	198	151.9	11.44	
Edge	Y	115	28.0	2.32	0.025
	A	199	37.9	3.06	
Crop	Y	115	82.1	6.89	0.027
	A	199	109.0	8.30	
Last den	Y	107	344.8	37.09	0.029
	A	83	460.3	33.83	

[a]Probabilty of yearling and adult den characteristics being equal determined by analysis of variance.

Survival

Of all marked young, we observed only 9 mortalities, 5 in 1988 and 4 in 1989. Two known mortalities in 1988 were animals which were only ear-tagged; all other observed mortalities were radio-collared individuals. Causes of mortality and number of young dying from each included: dogs (4), coyotes (*Canis latrans* Say) (1), distemper (1), and vehicle collisions (2). All mortalities occurred after litters moved from their natal den to a post-natal den site. There were no multiple mortalities within a litter on the same date and from the same cause. Age of young at death ranged from 64 to 156 days. Censoring before 15 September occurred in a large proportion of the cases (67%), primarily because 21 of the collars dropped off earlier than projected.

Causes of mortality were considered independent among individuals, even when more than 1 individual was marked in a litter. To test this assumption we calculated survival from a subset of the data which contained only 1, randomly-selected, young individual per litter. Final survival values were not significantly different between this subset and the data set of all young ($Z = -0.268$, $P = 0.394$), supporting our assumption of independence within litters.

Because of a high proportion of censoring in each year, we failed to find differences in survival of young born to yearlings and adults. The K-M survival distributions of young born to yearling ($\hat{S}_{yy}$) and adult females ($\hat{S}_{ya}$) females in 1988 suggested no significant differences between the age classes ($\chi^2 = 1.96$, df = 1, $P = 0.16$). However, there was a difference in the final adjusted estimates for young of yearlings ($\hat{S}_{yy} = 0.42$, SE = 0.15) and young of adults ($\hat{S}_{ya} = 1.00$, SE = 0.00, $Z = -7.668$, $P < 0.001$). In 1989, the final survival rate estimates were $\hat{S}_{yy} = 0.67$ (SE = 0.27) and $\hat{S}_{ya} = 0.63$ (SE = 0.18) and the rates were not significantly different ($Z = -0.113$, $P = 0.545$). When survival estimates were calculated after pooling years, there were no significant differences detected in survival patterns ($\chi^2 = 0.85$, df = 1, $P = 0.355$), although the efficiency of this test may have been low (Pollock et al. 1989). By pooling across age classes and years we increased sample size and alleviated the problem of adjusting final estimates of $\hat{S}$ (Fig. 1). Our best estimate of post-natal survival of young raccoons from 22 May until 15 September was 0.65 (SE = 0.12).

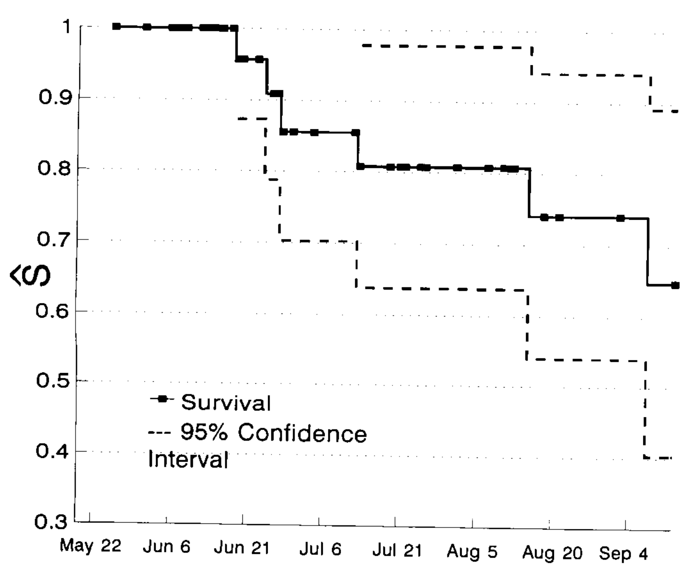

Fig. 1. Kaplan-Meier estimates of post-natal survival ($\hat{S}$) of raccoons in Guthrie County Iowa, 1988-1989.

Proportional Hazards

When we first attempted to fit the survival pattern the only 5 of 10 covariates entered the model: NUMHAB ($P = 0.005$), NUMDEN ($P = 0.002$), MBLDG ($P = 0.054$), MROAD ($P = 0.135$), and MCROP ($P = 0.229$). With the more strigent entrance and removal criteria of $P < 0.10$ and $P > 0.15$, the model included only NUMHAB, NUMDEN, and MROAD. All covariates were strongly correlated ($r > 0.45$).

We constructed all possible two-covariate models from these 3 covariates but MROAD failed to meet the entrance criteria ($P < 0.10$). The two-covariate model, which included NUMHAB and NUMDEN met the selection criteria and there was a low correlation ($r = -0.036$) between these 2 covariates. To be sure that we had found the most parsimonious model, we developed individual models with only NUMHAB or NUMDEN as the independent variable. A likelihood ratio test between the two-covariate model and the NUMHAB model was significant ($\chi^2 = 5.02$, df = 1, $P = 0.025$), as was a test against the NUMDEN model ($\chi^2 = 3.13$, df = 1, $P = 0.077$). These tests indicated that both NUMHAB and NUMDEN were important covariates to survival of young raccoons.

The negative coefficient values for NUMHAB ($\hat{\beta} = -1.774$, SE $[\hat{\beta}] = 1.148$) and NUMDEN ($\hat{\beta} = -1.702$, SE $[\hat{\beta}] = 0.997$) indicate both covariates have a negative influence on the hazard and therefore a positive influence on survival. As the number of den types and habitat types used by females with litters increased, so did the post-natal survival of their young.

DISCUSSION

There have been many causes of mortality of young raccoons reported, including disease, parasites, predators, and human-related factors although as we observed, most mortality is related to human activities. Free-roaming dogs and collisions with vehicles cause much of the mortality in most years, though disease may play an important role in some years (Kaufmann 1982). Direct mortality from predators such as coyotes apparently is not a major factor in most raccoon populations (Cowan 1973). This also seems to be the case with similar furbearers such as red foxes (*Vulpes vulpes* Merriam, Sargent et al. 1987).

Our estimate of post-natal survival of raccoons between 1 and 5 months appears reasonable but it is difficult to compare with other findings because of differences in time periods and statistical methodology. Stuewer (1943) marked individual young in the den, then later recaptured or visually observed individuals, and concluded that juvenile mortality was "low." Woods (1978) estimated survival (0.818) of pre-harvest age raccoons by subtracting the number of juveniles harvested in the fall from the total projected productivity of the population. The low precision due to small samples resulted in large confidence intervals associated with the estimates. Even when all instrumented animals were pooled into one group, the minimum sample size of 40-50 tagged animals suggested for precise estimates (Pollock et al. 1989), was not met. High censoring may also have positively biased our estimates of survival. Kalbfleisch and Prentice (1980) found that censoring in excess of 50% inflates survival estimates. Censoring related to loss of collars was related to the break-away design (Judson 1990) which allowed collars to fall off prematurely.

Small sample size may have precluded confirming our initial hypothesis that lack of nurturing experience should be related to survival of young born to yearling females. However, there was a difference in denning habitat selection of yearling and adult female raccoons at the macrohabitat level that could be related to post-natal survival. Yearling females resting on the ground in vegetation with their litters would reasonably be expected to be more exposed to mortality such as dogs and coyotes. But denning in farmsteads associated with humans would also be expected to be high risk and yet this site was frequently selected by adult females.

The covariates significant in the proportional hazards model can be related behaviorally to movements. Both the variety of habitats and the number of different types of dens selected had a positive influence on survival, suggesting the importance of diverse denning habitat to raccoons. Although we typically assume that greater movement increases mortality rates (Clark and Fritzell 1992), we found that survival of young raccoons was enhanced when nurturing females used a variety of dens in different habitat types. By moving, females may reduce their chances of a predator locating their den or increase access to essential foraging areas.

We observed no mortality of young raccoons prior to the shift in den sites from their natal den sites to post-natal ground resting sites. This shift was likely associated with weaning of young raccoons when they begin to actively follow the female outside the den (Kaufman 1982). Boutin et al. (1988) also showed that mortality factors affecting young muskrats in the same litter (*Ondatra zibethicus* Linnaeus) changed after weaning. As individuals become more behaviorally independent, multiple mortalities within a litter at the same time become less likely, as we observed. Even though our statistical support for independence among litter mates is weak, estimates of survival should not be biased although we may have underestimated their variance (Pollock et al. 1989).

Our survival estimates may have been influenced by the experimentally-induced high exploitation (Hasbrouck 1991) which ran concurrent with our study. In particular, we could have observed high post-natal survival of young which was a compensatory response to high harvest mortality the previous fall and winter. Nonetheless, we have shown that selection of denning habitat by female raccoons and post-natal survival of their young can have an important influence on population demographics.

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