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Home Range, Body Condition, and Survival of Rehabilitated Raccoons (*Procyon lotor*) During Their First Winter

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The effects of raccoon (*Procyon lotor*) rehabilitation on postrelease survivorship are unknown. Raccoon rehabilitation success was measured as differences in prewinter body condition, home range size, distance to manmade structures, and during-winter survival between raccoons in the wild and those who have been rehabilitated. Prewinter body condition did not differ between wild and rehabilitated raccoons, but there was a trend for rehabilitated raccoons to have better body conditions. There was no difference between wild and rehabilitated raccoon adaptive kernel (AK) home range for 95% and 90% AK home ranges, or for core (50% AK) use areas. There was no sex difference in distance traveled from the release site within rehabilitated raccoons. However, rehabilitated raccoons were found significantly closer (49.4 ± 4.7 m) to manmade structures than wild raccoons (92.2 ± 14.4 m), and female raccoons were found significantly closer (64.8 ± 4.5 m) to manmade structures than male raccoons (72.3 ± 17.6 m). The results of this study indicate that raccoons can be successfully rehabilitated, but they may occupy habitat closer to manmade structures than wild raccoons.

Keywords: home range, Northern raccoon, *Procyon lotor*, rehabilitation, survival

The human population is increasing, leading to more interactions between humans and wildlife (Beringer, Mabry, Meyer, Wallendorf, & Eddleman, 2004; Heydon, Wilson, & Tew, 2010). Because human–wildlife interactions may result in negative impacts on wildlife, many people believe we should offset the detrimental effects of humanity through positive interactions like wildlife rehabilitation (Casey & Casey, 1995). Consequently, the ultimate goal of wildlife rehabilitation is to care for sick, injured, and orphaned nonhuman animals in the wild until they can be returned to the wild where they will reintegrate into the breeding population (Beringer et al., 2004). Many states have wildlife organizations whose focus is on rehabilitation and education, and Nebraska has the Nebraska Wildlife Rehabilitation (NWRI, Louisville, NE; <http://www.nebraskawildliferehab.org>).

Large numbers of rehabilitated and translocated nonhuman animals are released into the wild every year from wildlife rescue centers around the world. The National Wildlife Rehabilitator's Association (2013) reports its members care for hundreds of thousands of animals each year. There are many possible problems associated with rehabilitation, including poor postrelease

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survivorship (Beringer et al., 2004), detrimental changes in home range size (Rosatte et al., 2010), whether the animals have enough time to prepare for the winter, and how captivity (Jule, Leaver, & Lea, 2008; Kelly, Goodwin, Grogan, & Mathews, 2008) and translocation (Calvete & Estrada, 2004) negatively affect survival and behavior. However, there has been little research on how well rehabilitated animals survive postrelease and their effect on the resident wildlife.

The few studies on postrehabilitation have shown mixed results. White-tailed deer fawns (*Odocoileus virginianus*) who had been rehabilitated had an 18.2% lower survival rate than nonrehabilitated fawns (Beringer et al., 2004). Beringer et al. (2004) suggested that rehabilitated fawns become too habituated to humans and are incapable of survival in the wild. Alternatively, a study on home range, movement, and survival of rehabilitated raccoons in Canada showed that survival was not affected by rehabilitation but was instead related to their life-span expectancy in the wild (Rosatte et al., 2010).

Home range in mammals is linked to their overall fitness and is affected by many factors, including resource availability, habitat quality, distribution of mates, and size of the individual (Beasley, Devault, & Rhodes, 2007; Lindstedt, Miller, & Buskirk, 1986; Powell & Mitchell, 2012). Wild-raised individuals acquire knowledge about how to obtain home ranges during their juvenile period; however, rehabilitated individuals may be missing this ability. Because home range is related to the overall health of an animal, the animal's natural behaviors, and the quality of habitat the animal occupies, it is important to look at how home range size differs between wild and rehabilitated individuals. It takes time to establish and become familiar with a home range, which may put rehabilitated animals at a disadvantage until they establish a home range. In fact, dispersing mammals may have higher mortality and lower reproduction rates than mammals in an established territory (Powell & Mitchell, 2012). As a result, differences in home range size between wild and rehabilitated animals may reveal underlying differences in the animals' overall fitness and provide a better understanding of rehabilitation success.

Release times are another major factor influencing the success of rehabilitation. Release times are determined by each rehabilitation center; however, most accept the general approach that the animal needs to be released at a time appropriate to the animal's seasonal needs and in an area that provides abundant natural habitat (Casey & Casey, 1995). There are many problems associated with where and when to release raccoons, especially in an urban environment. Rehabilitation centers try to release animals at their original locations, but unfortunately, it is not always possible, so some are translocated to new areas (Casey & Casey, 1995).

Although translocation is a common practice, especially by rehabilitation centers, very few consider the possible problems associated with moving an individual to a completely new location. Translocating wildlife can lead to serious problems for both the translocated animal and for the resident animals (Mosillo, Heske, & Thompson, 1999). Translocation can lead to increased competition over resources and increased rates of predation on endangered or threatened wildlife, and it may affect the social structure of resident populations (Mosillo et al., 1999). In addition, disease and parasites can be prominent problems in many rehabilitated mammals (Deem, Spelman, Yates, & Montali, 2000; Nettles, Shaddock, Sikes, & Reyes, 1979; Rosatte et al., 2010; Wise, Sorvillo, Shafir, Ash, & Berlin, 2005).

Most rehabilitated raccoons are released in late fall. However, food sources start to become scarce at this time, and if rehabilitated individuals are not properly prepared, they may face starvation. Winter can be extremely hard on raccoons, with a scarcity of food and harsh weather

conditions (Zeloff, 2002). During winter, raccoons do not hibernate; however, they will often stay in their dens during harsh weather conditions (Lotze & Anderson, 1979). This, combined with reduced resources, leads to a decrease in food consumption during winter. To offset decreased winter forage, raccoons build fat reserves during late summer and fall to provide an energetic reserve (Pitt, Lariviere, & Messier, 2008). Raccoons often double their weight during fall, with juveniles increasing fat reserves by 120% (Zeloff, 2002). Prewinter weight gain is important because raccoons can lose up to 50% of their body mass during winter (Pitt, Lariviere, & Messier, 2006a; Pitt et al., 2008). Therefore, if raccoons do not build enough fat to support this loss, they may not survive the winter (Sunquist, 1974), or they may resort to visiting human establishments in search of food, leading to further problems.

Captivity can also affect an animal's natural behaviors that are important for survival in the wild. Some of the natural behaviors captive animals may lack are foraging/hunting, social interactions, breeding and nesting, and even locomotor skills (Jule et al., 2008). Furthermore, orphaned raccoons are not only exposed to captivity, but they are also hand-reared, which could have an even stronger effect (Jule et al., 2008). Perhaps the biggest problem associated with being hand-reared is that the rearing environment is predictable and unchanging. Animals raised in a stable environment may lack the variety of behaviors needed to adapt to the uncertainties of the wild. Captive animals placed in the wild do not know how to respond to unfamiliar stimuli, especially predators (McPhee, 2003). Hand-reared, rehabilitated raccoons might have grown accustomed to humans and may associate human habitation with food or den sites, leading to increased human contact. Unfortunately, increased contact with humans may result in increased mortality (e.g., hunting, automobile collision, and pest control efforts).

Based on the high rate of rehabilitation in raccoons, the potential problems associated with rehabilitation, and the small amount of research that has been done on this topic, additional studies on raccoon rehabilitation are needed. It is important to monitor animals after release to obtain information on mortalities, distribution, and natural behavior to better prepare for future releases and increase survival (Miller, Biggins, Hanebury, Conway, & Wemmer, 1992). This study was used to measure how well rehabilitation prepared a wild animal, specifically Northern raccoons, for survival during their first winter, and whether it had an effect on their home range and survival. This study was also used to examine prewinter body condition differences between wild and rehabilitated raccoons and the distance traveled from the release site for rehabilitated raccoons, and to compare the average distance individuals were from manmade structures between rehabilitated and wild raccoons. We hypothesized that rehabilitation would have no effect on a raccoon's prewinter body condition, home range, distance to manmade structures, and survival because raccoons are highly adaptable.

MATERIALS AND METHODS

Study Area

This study was conducted in a small rural development (~163.5 ha) on the outskirts of Springfield in Sarpy County, NE. The topography of the study site consists of gently rolling landscape with private residential property, a small public area located in the middle of the neighborhoods, and a large amount (~65%–70%) of highly fragmented forest. Vegetation throughout the study site consists of lowland trees, including cottonwood (*Populus deltoides*)

and bur oak (*Quercus macrocarpa*), surrounded by farmland and crop fields (corn and soybean). This study was conducted during winter, defined as the time between the average first and last freeze, starting October 7, 2011, and ending April 24, 2012 (<http://www.NOAA.gov>).

Rehabilitation Care

Orphaned juveniles aged up to 4 weeks old were used in this study. There were three litters: two males and two females were in the first litter, one male was in the second, and one male was in the third. Rehabilitated juveniles were housed together in a “den,” usually a companion animal carrier or a large box with a heating pad to aid with thermoregulation. Newborns were fed Kitten Milk Replacement (PetAg, Hampshire, IL) formula until weaning (~6 weeks old). Weaning was completed by the time they were 8 weeks old, when all rehabilitated raccoons were moved to an outside cage (2.5 m × 3.0 m × 3.0 m) where they remained until their release. After weaning, raccoons were fed dog food and were introduced to natural food items including fruits and vegetables, as well as live fish and crayfish to promote the development of hunting behaviors. All raccoons were treated prophylactically for parasites and were vaccinated against canine distemper virus and rabies. All raccoons were released (October 10, 2011) simultaneously into the wild by gradually allowing them to have access to the surrounding habitat. Increased freedom was provided by leaving the cage open with food available for 1 or 2 weeks enabling individuals to fully disperse into the wild whenever they wanted.

Study Subjects

Six orphaned, juvenile, NWRI-rehabilitated raccoons (four male, two female) were used in this project: Four of the raccoons were brought in at 1 week old and two were brought in at 3 to 4 weeks old. These orphaned raccoons were found in and around the Omaha, NE, area by people who contacted the NWRI directly or through the Nebraska Humane Society. Rehabilitation care was provided until their release date in mid-October. Human contact was minimized during rehabilitation, but contact did occur during feeding, vaccination, health checks, and the introduction of live foods (fish, crayfish). Orphaned raccoons were not released in the area where they were caught, but they were released at the site of rehabilitation. In addition to the six rehabilitated raccoons, six wild raccoons (three male, three female) were live-trapped approximately 3.5 km from the rehabilitation release site during fall 2011 (September–December). This allowed for a comparison between wild and rehabilitated raccoons in the same environment.

Live Trapping, Immobilization, Handling, and Measuring

Six wild raccoons (two juveniles, four adults) were captured using Tomahawk #207 live traps (Tomahawk Live Trap Co., Tomahawk, WI) baited with marshmallows, sardines, and/or cat food (Prange, Gehrt, & Wiggers, 2004). Traps were set in the afternoon and checked in the morning, and following capture, raccoons were anesthetized using an intramuscular injection of 0.20 mL to 0.50 mL of Telazol (100 mg/mL, Fort Dodge Animal Health, Fort Dodge, IA; Pitt, Lariviere, & Messier, 2006b). Once they had been anesthetized, raccoons were aged (juvenile or adult), sexed, weighed (kg), and measured (cm) for total body length (TBL), tail length (TL), right ear length (EL), right rear foot length (RFL), and chest circumference (CC; Pitt et al.,

2006a). Wild raccoons were aged using a combination of mass (<6.0 kg) and tooth wear (Stuewer, 1943).

TBL is measured as the distance from the tip of the snout to the anus of the animal; TL is the distance from the base of the tail to the tip of the last tail bone; EL is the distance from the bottom of the notch of the ear to the farthest edge of the pinna; RFL is the length from the proximal edge of the foot pad to the tip of the longest digital pad; and CC is measured as the circumference of the chest posterior to the front appendages (Pitt, 2006). After the measurements were taken, raccoons were returned to their trap, allowed to recover from anesthesia, and then released at the point of capture (Pitt et al., 2006a).

In this study, both rehabilitated and wild-captured individuals were used for comparison. However, due to the difficulty in coordinating both the rehabilitation of individuals and capture of wild individuals who would be sex- and age-matched for statistical comparisons, the individuals in this study were not matched precisely by sex or age. All work met the guidelines recommended by the American Society of Mammalogists (Animal Care and Use Committee [ACUC], 1998; Sikes, Gannon, & ACUC of the American Society of Mammalogists, 2011) and was performed under an approved Institutional Animal Care and Use Protocol (#11-068-08-EP) from the University of Nebraska at Omaha.

Body Condition Measurements

There are two methods to measure body fat in wildlife: directly and indirectly. Direct methods of measuring body fat involve destruction of the animal, while indirect methods do not. Indirect methods use standard morphological measurements to calculate a condition index (Barthelmess, Phillips, & Schuckers, 2006; Pitt et al., 2006a; Stringer, Stoskopf, Simons, O'Connell, & Waldstein, 2010; Woolnough, Foley, Johnson, & Evans, 1997). Although condition indexes do not measure body composition directly, they do allow for comparison between individuals in a population and across time (Barthelmess et al., 2006). Residual indexes were used to measure body condition (Barthelmess et al., 2006; Pitt et al., 2006a). A residual index is calculated by finding the regression residuals, the distance from the regression line to individual data points of a linear regression, of body mass versus TBL. In this method, it is assumed that animals with better body conditions (i.e., more fat reserves) will have larger, positive residuals compared with animals with smaller fat reserves (Barthelmess et al., 2006).

Home Range

Before releasing rehabilitated raccoons and at initial capture of the wild ones, individuals were fitted with radio collars (Holohil, Inc., Cray, ON, Canada) to determine home range. Juvenile raccoon radio collars were left "loose" to allow room for growth. Home range was measured using handheld radiotelemetry techniques, including homing and triangulation (White & Garrett, 1990). Dens were located diurnally using homing techniques and marked using a handheld Garmin GPS Receiver (Garmin, Olathe, KS). Location and type of den were recorded for each individual. Animal locations were determined by taking three directional bearings within 5 min of each other to reduce error due to movement of the animal. Animal locations were taken from the time of release in October 2011 to April 2012 to measure home range during winter.

We performed telemetry during two major time periods: sunset to midnight and midnight to sunrise, which consisted of 6-hr to 7-hr shifts with raccoon locations taken at least 3 hr apart to

prevent autocorrelation (Bixler & Gittleman, 2000; Swihart & Slade, 1985). Once bearings were collected, they were entered into a spreadsheet and transferred into a triangulation program (Locate III, Pacer Computer Software, Tatamagouche, NS, Canada). Locate III was used to calculate animal locations through the intersection of three directional bearings and forming a 95% maximum likelihood confidence ellipse. If the three bearings failed to cross, they were thrown out and not included in further analyses. Animal locations were recorded using the Universal Transverse Mercator coordinate system. These values were then entered into ArcGIS 9.3, and home ranges were calculated using the home range extension (Rodgers, Carr, Beyer, Smith, & Kie, 2007).

Adaptive kernel (AK) home ranges were calculated for all individuals (White & Garrott, 1990). AK home ranges of 95% and 90%, along with core areas (50%), were calculated for all raccoons. Although only winter home ranges were calculated in this study, the number of locations recorded for each individual was within the minimum number of points recommended for estimating AK home range (Seaman et al., 1999).

Distance Measurements

Animal location points were used to calculate distances (m) to the nearest manmade structure or distance from release site using the linear measurement tool in ArcGIS 9.3. Every point for each individual was measured for the distance from the release site (rehabilitated individuals only) and to the nearest manmade structure. Manmade structures consisted of any building—house, barn, shed, etc. Trash piles or other debris were not considered manmade structures. An average distance measurement was calculated for each individual using all locations for that individual. In addition, each individual's mean distance was used for statistical analyses to prevent pseudo-replication.

Survival

Raccoon survival was determined across the entire study by determining whether individuals remained alive or died during the study. If possible, the cause of death, or reason for disappearance, was determined. Individuals who vanished during the study were marked as noncensused for use in the survival analysis. The percent survival was calculated for both wild and rehabilitated raccoons, and an estimate of daily survival functions was made using the Kaplan-Meier method (Kaplan & Meier, 1958).

Statistical Analyses

Raccoons were placed into two treatment groups: wild and rehabilitation. Body condition was analyzed using regression analysis. Both wild and rehabilitated individuals were used to generate a single regression of length versus body mass. Regression residuals for each individual were then exported to a new data set for comparing treatment types using an analysis of variance (ANOVA). Home range was compared using ANOVA with treatment as the main factor and sex as a potential second factor. Differences in the main effects were compared using least squares means of fixed effects—specifically, comparisons between noninteraction main effects were made using the PDIFF option in the LSMEANS statement, whereas differences in terms with significant interactions were compared using least squares means with the SLICE option (SAS Institute, 2009).

Distance from release site was compared between sexes for rehabilitated raccoons using a *t* test. Distance to the nearest human habitation was compared using a 2×2 (Treatment \times Sex) chi-squared table. Differences in survival functions were measured using survivorship curves based on the Kaplan-Meier analysis, and we used log-rank tests (PROC LIFETEST) to determine if survival differed between treatment groups. All data are presented as means \pm standard error, and all differences were considered significant at the $\alpha = .05$ level.

RESULTS

Six raccoons (four males, two females) were rehabilitated and radio-collared from May 2011 to October 2011. In addition, six wild raccoons (three males, three females) were live-trapped and radio-collared from September 2011 to November 2011. One wild raccoon's telemetry signal was lost shortly after the radio collar was attached, and no other sign of this individual was observed. The raccoon was not included in this study, except for prewinter body measurements. A final male wild raccoon was excluded from the survival analysis due to loss of contact the day after the collar was attached. It is unlikely that this individual died, but rather had the collar fail or moved away from the study area where a signal could not be received.

Body Condition

A total of 12 raccoons (6 wild, 6 rehabilitated) were used for measuring initial body condition. Prewinter mass ranged from 4.0 kg to 8.5 kg, with an average mass of 6.4 ± 0.43 kg. Raccoon mass was significantly correlated with increased length (intercept = $-6,281.0$; slope = 23.0 ; $r^2 = .58$), $F(1, 11) = 13.91$, $p = .004$ (Figure 1). When regression residuals were compared, prewinter body condition was not significantly different between treatment types—wild and rehabilitated, $F(3, 11) = 1.10$, $p = .32$ —or between sexes, $F(3, 11) = 0.64$, $p = .53$. There was

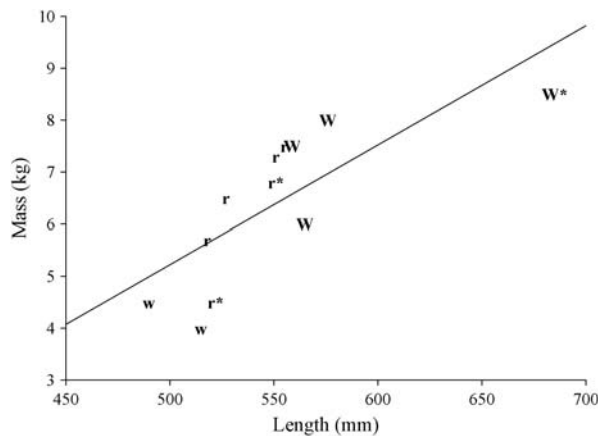


FIGURE 1 Prewinter body condition in wild (W) and rehabilitated (R) raccoons. The regression line represents the average, scaled mass by length. Individuals above the line have better body conditions than individuals below the line. Mortality is indicated by an asterisk (*) next to the individual. Adults are indicated with uppercase letters, and lowercase letters represent juveniles.

no significant interaction between sex and treatment (wild vs. rehabilitated), $F(3, 11) = 0.43$, $p = .53$.

Home Range

Five rehabilitated raccoons (two females, three males) and four wild raccoons (three females, one male) were used for home range analyses. Raccoons excluded from analysis had too small of a sample size, either due to death or loss of signal, to properly calculate home ranges. AK home ranges were roughly circular, with all raccoons, except one rehabilitated raccoon, having a single core use area (Figures 2 and 3). Average 95% AK home range size was 37.1 ± 11.8 ha for wild raccoons and 53.9 ± 36.2 ha for rehabilitated raccoons. Average home range size for all raccoons was 46.4 ± 15.9 ha (95% AK), 28.9 ± 9.0 ha (90% AK), and 4.6 ± 1.4 ha (50% AK). Individual components of the AK home range size did not differ between wild and rehabilitated raccoons for 95% AK, $F(1, 8) = 0.16$, $p = .71$, 90% AK, $F(1, 8) = 0.05$, $p = .83$, or core area size, $F(1, 8) = 0.06$, $p = .80$ (Figure 4).

A total of 22 dens were located, 9 for rehabilitated raccoons and 13 for wild raccoons. Rehabilitated raccoon dens consisted of 3 dens in woodpiles, 3 in tree cavities, 2 in drainpipes, and 1 underground den. Wild raccoon dens consisted of 8 cavities in trees, 4 underground, and 1 in a stack of cinder blocks. Rehabilitated raccoons seemed to use more manmade structures for

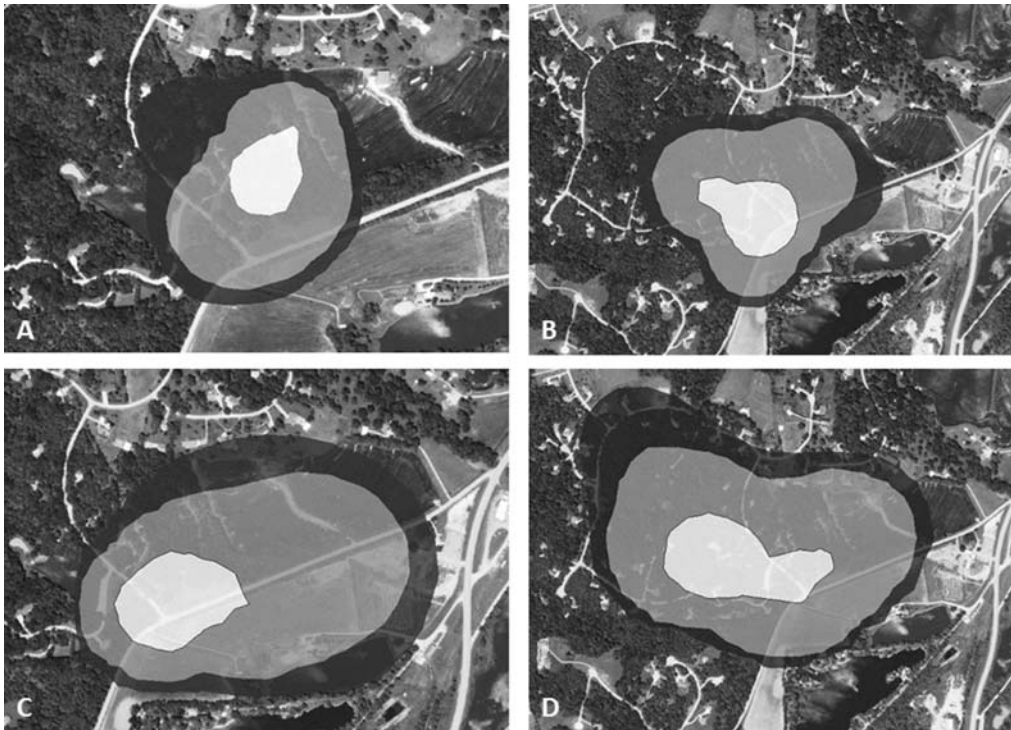


FIGURE 2 95% adaptive kernel (AK) home range (dark grey), 90% AK home range (light grey), and 50% core areas (white) for wild raccoons: (a) Wild Female #5, (b) Wild Female #1, (c) Wild Male #2, and (d) Wild Female #4.

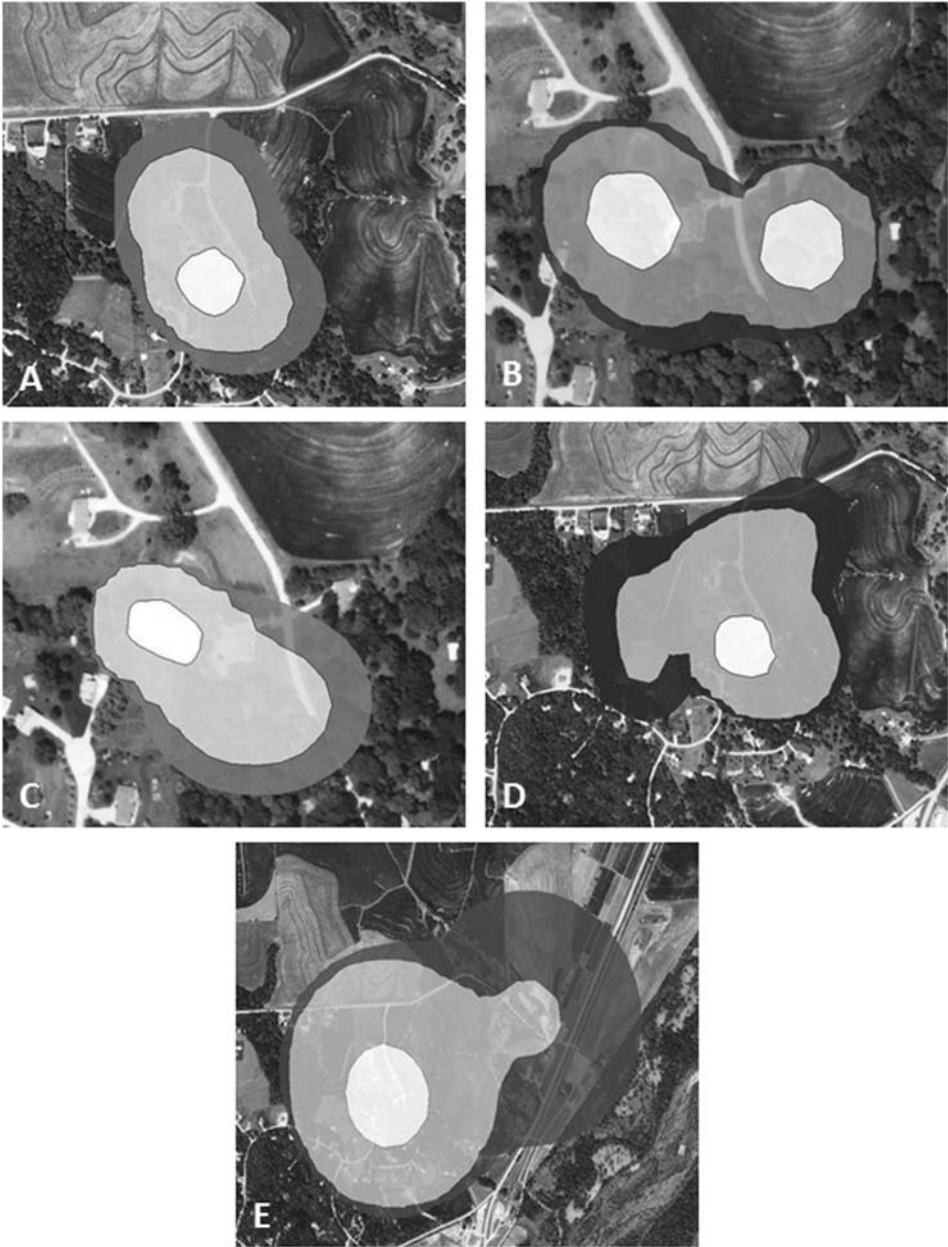


FIGURE 3 95% adaptive kernel (AK) home range (dark grey), 90% AK home range (light grey), and 50% core areas (white) for rehabilitated raccoons. (a) Rehab Female #5, (b) Rehab Male #6, (c) Rehab Male #3, (d) Rehab Female #2, and (e) Rehab Male #1.

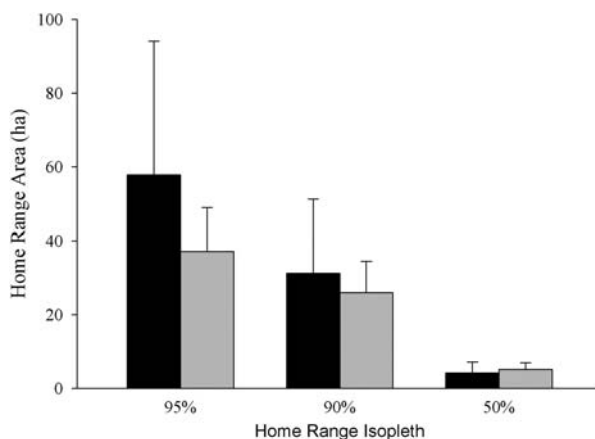


FIGURE 4 Size comparisons of adaptive kernel home ranges between rehabilitated (black) and wild raccoons (grey). Error bars represent one standard error.

dens compared with wild raccoons, even though both groups had opportunities to use natural and manmade dens. For example, rehabilitated raccoons used woodpiles and drainage pipes as their dens. Wild raccoons used underground dens and tree notches/holes, whereas only one rehabilitated raccoon was observed using an underground den.

Distance From Release Site (Rehabilitated Only)

Distance from the release site varied among the six rehabilitated raccoons and ranged from 0 m to 2,674 m, with an average distance of 111 ± 18 m. No sex difference was detected for average distance from release site, $T(191) = -0.36$, $p = .72$; however, all rehabilitated raccoons showed a similar temporal pattern in their distance from the release site. Following release, rehabilitated raccoons remained close to the release site throughout October, November, and December and traveled increasingly farther from the release site, with the farthest distances at the end of the study in March and April (Figure 5).

Distance to Manmade Structures

There was no significant interaction between treatment and sex for distance to manmade structures, $\chi^2(1) = 3.26$, $p = .07$ (Figure 6). However, there was a treatment difference, $\chi^2(1) = 35.05$, $p < .0001$, with rehabilitated raccoons (49.4 ± 4.7 m) being closer to manmade structures than wild raccoons (92.2 ± 14.4 m). In addition, there was also a sex difference, $\chi^2(1) = 15.91$, $p < .0001$, with females, regardless of treatment, being located closer to manmade structures (64.8 ± 4.5 m) compared with males (72.3 ± 17.6 m).

Survival

Both wild and rehabilitated raccoons experienced some mortality during the study (Figure 7). During the study, a total of three raccoon (one wild, two rehabilitated) mortalities were recorded.

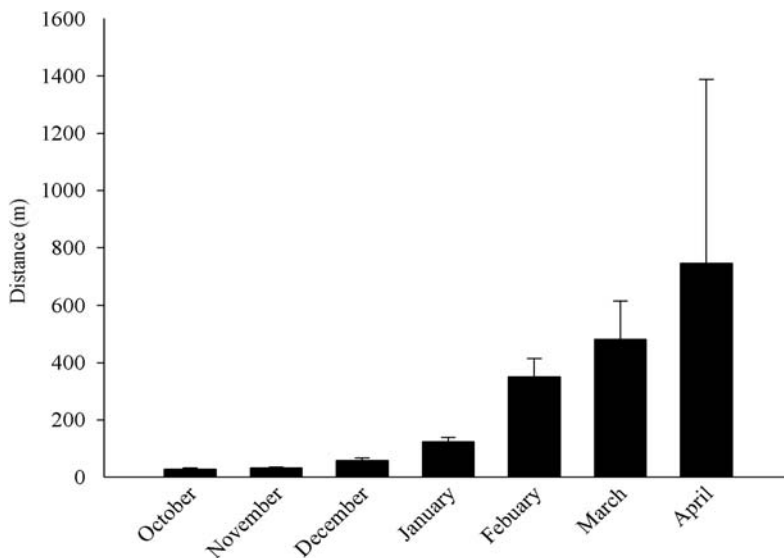


FIGURE 5 Monthly mean distance (m) from release site for rehabilitated raccoons throughout the study. Error bars represent one standard error.

The probability of survival at the end of this study was .80 and .67 for wild and rehabilitated raccoons, respectively. All raccoons who were found dead in this study were male.

The wild male raccoon was found dead from unknown causes on January 20, 2012. Of the two dead male rehabilitated raccoons, one was found on October 20, 2011, 2 weeks after the

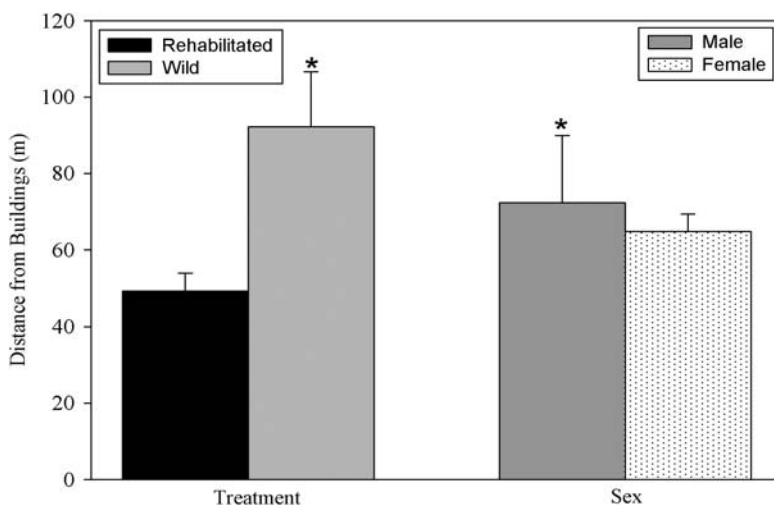


FIGURE 6 Comparisons of mean distances (m) from manmade structures between rehabilitated and wild raccoons and between males and females, regardless of treatment. Error bars represent one standard error. Asterisks (*) represent significant differences.

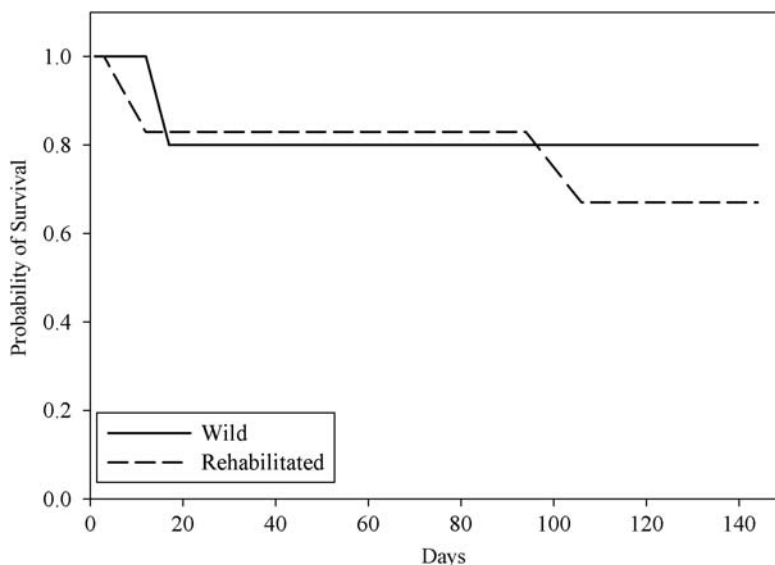


FIGURE 7 Kaplan-Meier survival functions by days postrelease or capture for wild (solid line) and rehabilitated (dashed line) raccoons trapped or released in the study area.

individual had been released and predated, likely from coyotes. The body had clearly been killed, eaten, and not buried, and within the study site, the only predator able to cause such damage would be coyotes (who are very common in the area). The second rehabilitated male was presumed dead on March 24, 2012, after noticing the animal was not leaving his den (cavity high in a tree). Access to the body was not possible to confirm mortality; however, the raccoon never left this cavity for the remainder of the study. It is possible the raccoon slipped off his radio collar; however, a lost collar is unlikely because the collar, and raccoon, had been moving for months prior to becoming stationary. There was no significant difference between the survival rates of wild and rehabilitated raccoons, $\chi^2(1) = 0.15$, $p = .70$.

DISCUSSION

Prewinter body condition, home range size, and survival did not significantly differ between rehabilitated and wild raccoons. In addition, distance from release site did not differ among male and female rehabilitated raccoons. However, mean distance to the nearest manmade structure did differ between rehabilitated and wild raccoons, with rehabilitated raccoons being found significantly closer to manmade structures than wild raccoons. This suggests rehabilitation has some effect on postrelease behavior in raccoons. Specifically, human contact during rehabilitation may lead raccoons to be found in closer proximity to humans following release, which may lead to increased human-raccoon conflict. It is possible that rehabilitated raccoons may prefer, or be forced, to use substandard dens because established wild raccoons might have occupied the best den sites. Therefore, because the winter during this study was mild, it is possible there might have been more of an effect on survival had the winter been harsh.

It is important to note that comparing juvenile rehabilitated raccoons to wild-caught adult raccoons, as was done in this study, is less than ideal for comparative purposes. However, due to the unknown timeline for receiving rehabilitated raccoons, the logistics associated with finding pregnant wild females, and problems associated with capturing their litters for use as control subjects, it was necessary to use wild adults as control subjects. We acknowledge that the comparison between juvenile rehabilitated raccoons and wild adults is not entirely valid, but given the complete lack of data for postrelease rehabilitated raccoons, we believe that wild adults provided an acceptable control for what rehabilitated raccoons should strive to achieve in their own lives. Considering the paucity of information on the success of postrehabilitation animals, this study provides some of the first data on the effects of rehabilitation in raccoons. However, because of the limited nature and small sample size of this study, additional long-term studies are needed to truly evaluate the success of rehabilitated animals.

Body Condition

Understanding the roles that fat reserves and body condition play in raccoons is especially important because they inhabit cold seasonal environments and experience cycles of food availability and fat acquisition (Barthelmess et al., 2006). Rehabilitated raccoons in this study tended to build a fat reserve slightly greater than wild raccoons in the fall, suggesting that rehabilitation provides a fat reserve as good as those obtained in the wild. However, because we were able to measure body condition all at once (i.e., before release on October 10) in rehabilitated raccoons but were limited to measuring the body condition of wild-caught raccoons on the date of capture, which varied from mid-September through November, it is possible the early measurements in rehabilitated raccoons may not provide an accurate comparison of body condition. On the other hand, because rehabilitated raccoons, in October, had similar body conditions as wild raccoons who were measured from September to November, if there is a discrepancy, then it would be in favor of rehabilitated raccoons being in better condition earlier.

Pitt et al. (2008) found the most important variable influencing winter survival was winter severity, followed by body condition. During this study, the 2011–2012 winter in Omaha was characterized as “distinctly mild” when compared with historic winters (Boustead, Hilberg, Shulski, & Hubbard, 2013) and might have offset any negatives associated with the rehabilitation process, especially finding suitably insulated dens. Both wild and rehabilitated raccoons in this study showed the classic relationship between increasing length and mass; however, differences in body condition showed a trend for rehabilitated raccoons to have better body conditions compared with wild raccoons (individuals above the regression, Figure 1). In fact, all rehabilitated raccoons, with one exception, were found above the regression line. The only rehabilitated individual to have a lower-than-expected body condition for the raccoon’s size was a rehabilitated male who was sickly from the beginning and never gained weight like the other rehabilitated raccoons. There was a trend for rehabilitated raccoons to be in better condition, and the lack of a significant difference between wild and rehabilitated raccoons might have resulted from the small sample size in this study.

Rehabilitated raccoons might have had slightly higher body conditions as a result of increased availability of high-quality food during rehabilitation, the addition of high fat or sugar treats by human rehabilitators, or reduced activity levels. Many captive/rehabilitated animals have a propensity for obesity when compared with wild animals (Clauss & Hatt, 2006; Clauss, Wilkins,

Hartley, & Hatt, 2009). Rehabilitated raccoons are typically fed a diet consisting of dry dog food, which is likely to have higher energetic content than wild food items. In addition, rehabilitators often feed their raccoons treats, including marshmallows, applesauce, dog treats, and various types of fruit, which are high in sugar/fat content. Diets high in fat content have been shown to lead to greater body fat build-up in monkeys, dogs, pigs, hamsters, squirrels, rats, and mice (West & York, 1998).

In addition, rehabilitated raccoons are confined to a small enclosure, limiting their movement. The average distance traveled for wild raccoons in Nebraska is 671.4 ± 378.5 m (Kocer, 2004), but wild raccoons have been shown to travel up to 3,700 m in a single night (Juen, 1981) and can have a home range as large as 2,560 ha (Beasley et al., 2007). Because rehabilitated raccoons have a limited area in which to move, they burn less energy than wild raccoons, so more of their incoming energy goes into their fat reserves. Increased food availability, higher-quality food, fattening or sugary treats, and a confined space could have contributed to the trend for rehabilitated raccoons in this study to have better body conditions. Further research is needed to fully understand the role of body condition in rehabilitated animals and the impacts that confinement and consumer-based diets have on rehabilitated animals.

Home Range

Home range size and shape were not affected by rehabilitation; in fact, rehabilitated raccoons built home ranges similar in size to wild raccoons. These results are similar to other rehabilitation studies, including studies of raccoons. Rosatte et al. (2010) found rehabilitated raccoons established home ranges similar to those of nonrehabilitated raccoons from the same area. Golightly, Newman, Craig, Carter, and Mazet (2002) also found rehabilitated Western gulls used an area of the same size after release as wild gulls. However, it is important to consider the effect of translocation on a rehabilitated animal's home range size. Mosillo et al. (1999) found that translocated raccoons have greater movement than resident raccoons, which led to larger home range size. In this study, home range size was similar between wild and rehabilitated raccoons; however, one rehabilitated raccoon home range was much larger compared with all of the other raccoon ranges.

Powell (2012) suggests home range is linked to both extrinsic and intrinsic factors. Home range and fitness are related because the animals use cognitive maps to make decisions on where to find food and mates and how to avoid predators or other dangers. Rehabilitated raccoons had home ranges similar to wild raccoons. This suggests rehabilitation may not affect the animals' ability to establish home ranges, as the ranges were the same even though they did not possess internal maps of their new homes (Powell, 2012; Powell & Mitchell, 2012).

With respect to the type of dens used by raccoons in this study, there was a trend for rehabilitated raccoons to use dens that were less secure and less well insulated (woodpiles and drainpipes) than the more protective dens of their wild counterparts (tree cavities and underground burrows). Although raccoon den use typically reflects den availability, a variety of structures for dens are used and some patterns of den use have been observed (Endres & Smith, 2013). For example, rock outcroppings and underground burrows were used more during the fall and winter, especially when temperatures were low. In addition, underground burrows were used more often by juveniles than adults, and females used tree cavities more than males did (Endres & Smith, 2013). In this study, it appears that rehabilitated raccoons used less established den

types. Use of poor-quality dens by rehabilitated raccoons may have been possible due to the unusually mild winter of 2011 to 2012.

Distance Traveled (Rehabilitated Only)

Rehabilitated raccoons in this study remained close to the release site during early winter and gradually moved farther from the release site each month until finally establishing their own home ranges in early spring. This pattern was similar to the one observed for other rehabilitated raccoons, who spent approximately 30 days exploring their release site before establishing a home range (Rosatte & MacInnes, 1989). In addition to increased familiarity, winter weather promotes inactivity in raccoons, as they reduce activity when the weather is bad and they avoid cold temperatures (Lotze & Anderson, 1979; Pitt et al., 2008). As spring approaches, raccoons begin searching for mates, and they may travel greater distances during their searches. This also results in a pattern of increased traveling distance during late winter and early spring (Stuewer, 1943). As a result, rehabilitated raccoons might have remained near the relocation site rather than risk going into unfamiliar territory and having prolonged exposure to cold as they attempted to find new dens and potential mates.

Some studies have shown that adult, translocated animals travel great distances and rarely stay near the site of release (Hamilton, Zwank, & Olsen, 1988; Mosillo et al., 1999). A study on relocated, adult city raccoons showed that none of the relocated raccoons remained at the release site, and 60% of them settled approximately 0.3 km from the town where they were originally found (Rosatte & MacInnes, 1989). The raccoons from this study showed a similar pattern, with only one of the rehabilitated raccoons establishing a home range near the point of release. All of the other rehabilitated raccoons moved away from the release site to establish an independent home range. The results of our study, as well as those of Rosatte and MacInnes (1989), show that rehabilitated or translocated raccoons will disperse away from a release site and establish their own home ranges. However, the specifics of how released individuals decide where to settle or what factors are important in their decision-making processes are still largely unknown.

Distance to Manmade Structures

The only significant difference observed in this study was in the distance to manmade structures, including houses, sheds, and barns. Although rehabilitated raccoons dispersed in a variety of directions and established home ranges independently of each other, there was a significant difference in distance to manmade structures between wild and rehabilitated raccoons as well as between males and females. Wild raccoons were found farther from manmade structures compared with rehabilitated raccoons. Captivity, and especially being hand-reared, has been shown to affect an animal's natural behaviors, including wariness of humans (Kelly et al., 2008). Rehabilitated raccoons are raised almost entirely in manmade structures, potentially increasing their familiarity with human habitation. All of the rehabilitated raccoons in this study spent 7 to 8 weeks living inside a house, where they were hand-fed formula. After weaning, they were moved outside but still lived in a manmade cage until their release.

Although no sex differences were detected in this study for distance traveled, our limited sample size makes statistical comparisons between sexes and treatment groups limited. However, we did find that female raccoons, regardless of treatment, were found significantly

closer to human structures. Raccoons, especially females, tend to choose trees with larger cavities for dens (Smith & Endres, 2012). In this study area, large trees are common around human houses and may be an important factor causing females to remain close to human dwellings.

Survival

Both rehabilitated and wild raccoons experienced some mortality from predation (one rehabilitated) or unknown causes (one wild, one rehabilitated); however, no significant difference in survival was observed between wild and rehabilitated raccoons in this study. The unknown wild mortality consisted of a raccoon who was found up in a tree with his collar possibly caught in the crevice of the tree. The raccoon was easily removed from the tree by lifting up on the animal, indicating the collar was not actually stuck. External examination of the body revealed that his front foot was fractured. It is important to note that although no significant difference in survival was observed in this study, the low sample size could have impacted our ability to measure any significant difference.

Raccoon mortalities are typically caused by humans, predation, and habituation problems. The main cause of mortality in captive-released carnivores was the direct result of humans including hunting, trapping, and automobile collisions (Jule et al., 2008). Although the rehabilitated raccoons in this study did not appear to die from human causes, they did come in closer contact with humans than wild raccoons, leading to potential human-caused deaths in the future. Because of their association with humans as food givers, rehabilitated raccoons may also go to humans for handouts. These nuisance animals could end up back at the rehabilitation center, trapped and translocated to unfamiliar habitat, or euthanized (Harris, 2011; Hygnstrom, 1994; Witmer & Whittaker, 2001).

Another common cause of mortality in captive-raised and rehabilitated animals is predation, which was potentially observed in one rehabilitated raccoon in this study. Studies have shown rehabilitated animals can lack the ability to effectively avoid predators (Hemetsberger, Scheiber, Weib, Frigerio, & Kotrschal, 2010; McPhee, 2003). For example, hand-raised geese are less vigilant and have a reduced stress response compared with wild-reared geese, suggesting social interactions play a role in learning predator avoidance behaviors (Hemetsberger et al., 2010). Rehabilitated animals can become too dependent on humans to be able to survive without them (Beringer et al., 2004).

Survival rates of rehabilitated animals are highly variable, suggesting that rehabilitation may not be effective for all species (Beringer et al., 2004). Studies have shown rehabilitated raccoons (Rosatte et al., 2010), seals (Vincent, Ridoux, Fedak, & Hassani, 2002), cranes (Ellis et al., 2002), hawks (Hamilton et al., 1988), bats (Kelly et al., 2008), and oiled, rehabilitated animals (Golightly et al., 2002) have survival rates similar to wild animals, but deer fawns (Beringer et al., 2004), sea otters (Nicholson, Mayer, Staedler, & Johnson, 2007), and a few species of monkeys (Cheyne, 2009) have lower survival rates than their wild counterparts.

The ultimate goal of rehabilitation is for an animal to survive and adapt (Vincent et al., 2002). Rehabilitated raccoons in this study were able to survive and establish a home range following winter. Although this study was short term and had a limited sample size, it did include data from the winter, the hardest time for raccoons (Pitt, 2006; Pitt et al., 2008). If rehabilitation does not affect the animals' survival during this time of highest mortality, then it should have little to no effect on their survival rates for the rest of their lives.

The role of rabies and canine distemper virus in the survival rates of raccoons is an important consideration, especially in the face of administering prophylactic vaccinations to rehabilitated raccoons. These diseases are common within raccoon populations and can spread quickly, causing high mortality (Deem et al., 2000). During an outbreak, rehabilitated individuals, having been vaccinated, should show increased survival compared with wild, unprotected individuals. In addition, outbreaks of rabies or canine distemper are associated with high population densities (Ballard, Follman, Ritter, Robards, & Cronin, 2001; Hoff, Bigler, Proctor, & Stallings, 1974), and the addition of rehabilitated individuals to a wild population may contribute to a disease outbreak. However, if the rehabilitated individuals have been vaccinated, then their addition should have no effect on disease transmission and may even act to reduce disease transmission.

Winter survival in raccoons shows a sex- and age-biased survival rate, with females having a higher survival rate than males and adults surviving more than the juveniles. All of the reported mortalities in this study were males, supporting this sex-biased survival rate. In addition, two of the three mortalities were juveniles, which supports the age-biased survival rate. During their 1st year of life, juveniles have to spend a lot of energy on growing instead of building a fat reserve. It is important to note, however, that the small sample size could have affected the results. Survival studies on translocated animals have contradicting results. Some studies suggest survival rates are similar to those of resident animals (Mosillo et al., 1999), while other studies suggest translocated animals are at a disadvantage compared with resident animals (Rosatte & MacInnes, 1989).

CONCLUSION

Animal Welfare Implications

As the human population continues to grow, there is an increased likelihood for negative impacts on wildlife. Wildlife rehabilitation provides a means to counteract this negative impact on wildlife. Although wildlife rehabilitation is a common practice around the world, many rehabilitators think success is when the rehabilitated animal is able to be released into the wild and not what actually happens to the animal after release (Kelly et al., 2008). In actuality, a successful rehabilitation is when an animal can adapt and survive in the wild. Few studies have measured this level of rehabilitation success, and with so few postrelease studies having been conducted, wildlife rehabilitators do not know if they properly prepare their animals for survival in the wild or if the process of rehabilitation has adverse effects on released wildlife.

Mixed results were found in this study, with rehabilitated raccoons able to build proper prewinter fat reserves, establish normal home ranges, and survive as well as wild raccoons. However, rehabilitated raccoons were found in closer proximity to human habitation and might have been using substandard dens compared with established wild raccoons. These results suggest that, in general, raccoon rehabilitation is successful, but human contact during the rehabilitation process may increase contact with humans after release into the wild. Studies have shown that changing rehabilitation techniques can have a positive effect on the development of natural behaviors. Kelly et al. (2008) found improving techniques (prerelease flight conditioning) and care for hand-reared Pipistrelle bats (*Pipistrellus spp.*) improved their postrelease survival. Overall, postrelease studies, like this one, are important for wildlife rehabilitation success and could lead to modifications in rehabilitation methodology that may increase rehabilitation success.

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