

Seasonal body condition and space use of urban raccoons

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Abstract

While urbanization poses challenges to wildlife, it also provides anthropogenic resources that can be exploited by human-tolerant species. One species that is adept at using urban resources is the raccoon (*Procyon lotor*). Commonly found throughout cities in North America and parts of Europe and Asia, raccoons can use refuse to supplement their natural diets and human structures (e.g., attics, garages) as resting sites. To examine how urban resources may influence the body condition and behavior of urban wildlife, we trapped 152 (90 male, 62 female) adult raccoons from three sites across Chicago's urbanization gradient between October 2014 and January 2017. Morphometrics were used to calculate body mass indices (BMIs) and a subset of raccoons were tracked via VHF (n=12) or GPS (n=7) radiocollars. While male and female BMIs varied seasonally ($p < 0.01$), only female BMIs varied by location ($p < 0.001$). Male and female home range sizes were similar on average (males: 27.295 ± 11.483 ha; females: 20.002 ± 9.621 ha) but, when the proportion of unnatural habitat within each home range was considered as a secondary factor, males had larger home ranges than females ($p = 0.04$). The use of anthropogenic den sites and food sources were commonly observed. Regardless of how much unnatural space was used, however, raccoons consistently remained within 500m of a green space. Close proximities to more "natural" habitats suggest that, while they do use anthropogenic resources, urban wildlife still rely on green spaces for persistence. Additionally, since raccoons tend to be drawn toward particular resources (e.g., structurally damaged garages), identifying and removing attractants could be a key way to manage raccoon activity.

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Keywords

home range, body condition, habitat use, urbanization, raccoon

Introduction

Urbanization has steadily increased in recent decades, leading to once-natural areas become increasingly developed. Land use changes and increases in human activity alter wildlife in different ways, as some species are more tolerant of change than others (Ditchkoff et al. 2006; Lowry et al. 2013; Birnie-Gauvin et al. 2016). Some species are displaced as urban development occurs (Randa and Yunger 2006; Lowry et al. 2013), whereas other species adapt by learning to use combinations of natural and unnatural resources (Hoffman and Gottschang 1977; Gross et al. 2012; Cristescu et al. 2016). The benefits of living in urban settings can even positively affect survival and reproduction of certain species (Gehrt 2007; Beckmann and Lackey 2008; Bateman and Fleming 2012). A major benefit to urban wildlife is the presence of concentrated, abundant food resources (Prange et al. 2004; Gross et al. 2012). In addition to natural foods found within urban green spaces, urban wildlife have access to a variety of anthropogenic foods (e.g., human refuse). Such food sources may serve as beneficial supplements during times when natural resources are scarce (Prange et al. 2004; Pitt et al. 2008a).

The raccoon (*Procyon lotor*) is a common urban predator and is sometimes considered synanthropic (Johnston 2001; Bozek et al. 2007; Gross et al. 2012). Raccoons often den in wooded and riparian areas (Rabinowitz and Pelton 1986; Henner et al. 2004; Chamberlain et al. 2003), but are also notorious for denning in man-made structures, such as sheds, houses, and sewers (Ikeda et al. 2004; Gross et al. 2012). Similarly, raccoons naturally consume a variety of foods, including rodents, aquatic species, eggs, berries, nuts, and seeds (Hoffman and Gottschang 1977; Bozek et al. 2007; Bartoszewicz et al. 2008). Because of their flexible diet, however, they

are also able to consume human refuse (Prange et al. 2003; Ikeda et al. 2004; Gross et al. 2012). Over time, some raccoons learn to seek garbage cans as predictable food sources and become nuisances. Raccoons can also cause structural damage to buildings, invade gardens, and spread various diseases to humans and pets (Beasley et al. 2007; Rosatte et al. 2010). Because of the conflicts associated with raccoons, learning more about urban raccoon behavior is important for effective raccoon management and public education. Thus far, urban raccoon studies have mainly focused on raccoons within green spaces (e.g., parks or preserves). Little research has been conducted on raccoons that spend most of their time within urban matrices (e.g., neighborhoods).

A commonly-studied aspect of wildlife behavior is space use. When food, shelter, and potential mates are abundant, wildlife do not need to travel far to find adequate resources (Hoffman and Gottschang 1977; Beasley et al. 2007; Bartoszewicz et al. 2008; West et al. 2016). Likely because urban resources are so concentrated, urban populations of mesopredators tend to have relatively small home ranges (Prange et al. 2004; Bozek et al. 2007; Newsome et al. 2014). At a finer scale, however, animals in more developed urban areas tend to have larger home ranges than urban animals with moderately developed habitats (Riley et al. 2003). In other words, while urban areas do contain beneficial resources, resources can be scattered more widely if suitable habitats become too fragmented.

Since urban wildlife receive anthropogenic food subsidies year-round and maintain smaller home ranges, living in cities can influence their body conditions. Previous studies have demonstrated links between anthropogenic foods and higher body masses (Otalı and Gilchrist 2004; Auman et al. 2008). Since food resources are more concentrated in urban areas, more of the calories consumed by urban predators can be stored as fat rather than used for energy

foraging over a large area (Otali and Gilchrist 2004). Additionally, the consistency of food subsidies in urban systems may allow urban wildlife to aggregate near resources and maintain better body conditions throughout the year (Pitt et al. 2008a; Wehtje and Gompper 2011). Because body condition is related to survival and reproduction, increases in body condition may also promote higher densities of wildlife in urban areas (Prange et al. 2003; Otali and Gilchrist 2004; Pitt et al. 2006; Weiser and Powell 2010). High densities of human-adapted species could ultimately lead to alterations in community structure and increased incidences of human-wildlife conflict (Smith and Engeman 2002; Prange and Gehrt 2004; Bateman and Fleming 2012).

Our overarching objective was to determine whether urbanization influences raccoon behavior and body condition in highly urban settings. We trapped and assessed raccoons from a suburban site and two urban sites in the Greater Chicago Metropolitan Area. Subsets of raccoons from the urban sites were radiocollared so their movement and denning patterns could be monitored throughout a two-year period. In terms of raccoon space use, our hypotheses were: 1) raccoons in urban areas would have smaller home ranges than suburban and rural animals reported in previous studies, 2) urban raccoons would use a combination of natural and man-made structures, and 3) though raccoons would include unnatural areas in their home ranges, raccoons would still use combinations of natural and unnatural habitats within urban ecosystems. Additionally, for the body condition portion of the study, we predicted that: 1) raccoons at urban sites would have better body conditions (measured via morphometrics) than those at the suburban site, 2) urban raccoon body conditions would fluctuate less throughout the year due to a greater consistency of resource availability, and 3) the proportion of each raccoon's home range that was unnatural habitat would correlate with the raccoon's body mass index. This study is among the first to examine raccoon behavior and body condition within highly urban matrices

instead of large, green spaces adjacent to developed areas. Information learned about raccoons living among people in cities may have implications for future raccoon management and conflict prevention.

Methods

Study Areas

This study was a continuation of a larger, Chicagoland area raccoon project aiming to examine how urbanization influences raccoon behavior and physiology. Previous studies of raccoons in the area focused on individuals captured in forest preserves and parks in the suburbs of Chicago (Prange et al. 2004; Bozek et al. 2007). We selected three different study sites, two of which were in Chicago. (Fig. 1). Each study location was comprised of “natural” (e.g., forests, river edges) and unnatural (e.g., houses, industrial buildings) habitats to varying degrees.

Our least urban site was Max McGraw Wildlife Foundation (MMWF), located in Kane County, IL. The area is considered part of Chicago’s northwest suburbs and is located approximately 40 km from the city. The wildlife foundation is a 495-ha natural area, primarily used as a private hunting preserve for upland game birds. Habitats on property include forests, grasslands, riparian zones, lakes, and recreational areas. Though the foundation is not open to the public, it is bordered by neighborhoods and an amusement park that may provide refuge to wildlife residing close to the borders of the preserve. The trails and roads on property are limited and have low traffic volumes. The roads immediately around the property include two 4-lane highways with average daily traffic (ADT) counts of 21,600 and 17,900 cars (Illinois Department of Transportation 2015). The majority of the nearby roads, however, are small 2-lane roads with low to moderate levels of traffic (Prange et al. 2004).

The first urban site we sampled was Dan Ryan Woods (DR), a 104-ha Cook County forest preserve located on the South Side of Chicago. The preserve is one of the highest natural points in city limits and includes a combination of oak woodlands, savannas, open fields, and recreational areas. The central and northern portions of the preserve contain numerous picnic areas and shelters, a sledding hill, and mowed fields. Historic stone aqueducts are found in the less-used, southern portion of the preserve. Approximately 2.41km of paved and unpaved, multi-use trails are present throughout the site. Trash cans are located in picnic zones, along trails, at bus stops on adjacent highways, and in nearby neighborhoods year-round. Many trash cans are uncovered, thus they provide easily-accessible refuse to wildlife. The preserve is bordered by urban neighborhoods to the east and south, a country club and golf course to the west, and a railroad and small ballpark to the north. The site is also bordered and intersected by 4-lane (ADT counts= 37,400 and 31,400) and several 2-lane roads (e.g., ADT counts of 4,050 and 3,150), thus there is traffic in the area consistently throughout the year (Illinois Department of Transportation 2015).

The most urban site included in our study was Goose Island (GI), located approximately 2.3 km from the Willis Tower in downtown Chicago. Goose Island is a 65-ha, artificially created island located in the Chicago River. The island and the surrounding mainland are highly developed areas containing mainly industrial buildings, businesses, and a few restaurants. The only “natural”, unpaved habitats at the site are small (typically <50 m wide) strips of wooded areas directly along the river’s edge and the river itself. The site is bordered and intersected by railroads, 2-lane (e.g., ADTs= 3,000; 1,000; 800; 300), and 4-lane roads (e.g., ADTs= 31,400; 15,900; 12,900; 12,200), so traffic remains heavy year-round (Illinois Department of Transportation 2015).

Trapping and Processing

We trapped raccoons seasonally from October 2014 until January 2017. Raccoons were captured using Tomahawk (Tomahawk Live Trap Co., Tomahawk, Wisconsin) and Havahart (Havahart Traps, Lititz, Pennsylvania) box traps. Traps were baited with canned cat food raccoon-directed scent lures, marshmallows, fish oil, and/or dog food. Traps were placed at each site and checked daily for 1-2 weeks during each trapping season. Seasons were defined as fall (September-November), winter (December-February), spring (March-May), and summer (June-August). Once captured, each raccoon was immobilized with an intramuscular injection of telazol (Gehrt et al. 2001). We then measured their weights, total lengths (tip of nose to tip of tail), and tail lengths (base of tail to the tip). Age classification was conducted by examining teeth for signs of wear and external genitalia for signs of reproductive condition (Grau et al. 1970; Sanderson and Nalbandov 1973). Each raccoon was given individually numbered, metal ear tags (National Band and Tag Company, Newport, Kentucky) for future identification. Subsets of adults from DR and GI were given very high frequency (VHF) collars (Advanced Telemetry Systems, Isanti, Minnesota) or lightweight, remote-downloadable GPS collars (Lotek Wireless Inc., Newmarket, Ontario) prior to being released at the sites where they were trapped. Due to differences in trapping success, collar functionality, and mortality rates, varying numbers of individuals were collared at different times and sites. All raccoons were trapped by Max McGraw Wildlife Foundation and USDA APHIS Wildlife Services employees as part of a larger behavior and disease monitoring study. Trapping and handling protocols were conducted in accordance with the guidelines of the American Society of Mammalogists (Sikes et al. 2011) and no known mortalities occurred as a result of the study.

Radiotelemetry

Diurnal resting locations were manually triangulated using a truck-mounted, Yagi antenna (Advanced Telemetry Systems, Isanti, Minnesota) for all collared raccoons at least once per week. VHF collared raccoons were also tracked one or two nights per month, during which 5 locations from consecutive hours were recorded. Allowing a time interval of at least 60 min between triangulations was considered enough to establish biological independence between locations (Gehrt and Fritzell 1997). The program Locate III (Nams 2005) was used to calculate and record triangulations in terms of Universal Transverse Mercator (UTM) coordinates.

In addition to manually locating and triangulating the locations of all raccoons, the GPS collars collected points throughout their deployments. GPS collars were scheduled to alternate between taking locations every 15 min (at night only) and taking points every hour, depending on the dates and times that were programmed into the collars prior to deployment. The variable schedule allowed us to collect randomized, fine scale data while also increasing the GPS collar battery life. Collar-collected points were downloaded remotely by using a VHF handheld downloading unit in the field, approximately once every 6 weeks. Additionally, all final locations were directly downloaded upon recovery of the collars. After locations were collected, the coordinates from the triangulations and GPS collar downloads were uploaded to ArcMap 10.4.1, along with a digitized map of the Chicagoland area. Prior to analyzing the GPS data, erroneous points were identified by examining movement speeds and movement paths between points. Speeds were calculated using the *adehabitatLT* package (Calenge 2006) in the R statistical program (R Core Team 2016, v. 3.3.2) and each point was visualized in ArcMap 10.4.1. for viability. Only GPS fixes showing abnormally high speeds and sharp deviations from the animal's movement path (n=3) were assumed to be faulty and were removed.

Density and Home Range Estimations

To estimate raccoon densities, we calculated the minimum known number alive (MKNA) at both urban sites during each trapping season (Krebs 1966). To estimate the trapping area, we calculated a 95% minimum convex polygon for all combined raccoon location data collected within a one-year time frame (July 2015-July 2016). The MKNA was then determined by dividing the number of unique individuals captured in each season by the calculated area.

By the conclusion of the study, 12 VHF collared (6 male, 6 female) and 7 GPS collared (3 male, 4 female) animals had been tracked long enough to analyze their spatial data. To include an individual in our analyses, we required at least 30 locations (Beasely et al. 2007; Rosatte et al. 2010). For each raccoon that met that requirement, we calculated 95% minimum convex polygon (MCP) annual home ranges and 50% MCP core areas using the *adehabitatHR* package (Calenge 2006) in the R statistical program (R Core Team 2016, v. 3.3.2). When we had at least 30 locations for an individual during a single season, we also calculated seasonal 95% MCP home ranges. After calculating the home ranges, we ran a two-way analysis of variance (ANOVA) to determine whether the 95% home range or 50% core area varied by site or sex.

Anthropogenic Habitat Use

To examine the amount of anthropogenic habitat being used by raccoons, we created layers in ArcMap to represent “natural” (e.g., woods, rivers, riparian vegetation, fields) and “unnatural” (e.g., buildings, roads) portions of our sites. Afterwards, we determined the amount of overlap between the previously calculated 95% MCP home ranges and the natural habitat layer. Percentages of each animal’s home range that were covered by natural and unnatural habitat were subsequently calculated. Two-way analyses of variance were run to determine if differences in unnatural habitat use were correlated with site differences or sex differences.

To further analyze patterns of anthropogenic habitat use by raccoons, we created a buffer map in ArcMap 10.4.1. Buffer rings were placed at 100m, 200m, 300m, 400m, and 500m outside of the previously-defined “natural” habitat. The percentage of raccoon locations within each buffer ring were recorded for both VHF- and GPS- collared animals.

Cluster Point Visits

Using the digitized map that was overlaid with uploaded raccoon locations, we visually identified cluster points (i.e., areas visited repeatedly by raccoons) at DR. To characterize potential raccoon attractants and denning locations, we visited 32 of the cluster points and searched for raccoon sign. When raccoon sign or potential attractants were found, photos of the sites were taken and brief descriptions were recorded.

Body Mass Index

We calculated the body mass index (BMI) of each adult by using a modified index ratio, as it has been previously documented as the most accurate, morphometric-based measure of body condition for raccoons (Pitt et al. 2006; Kato et al. 2011). The modified index ratio is calculated by dividing body mass (kg) by the square of body length (m^2), where body length is measured from snout to vent. We obtained the snout-to-vent length by subtracting the length of the tail from the total length (tip of nose to tip of tail). After calculating the BMI of each raccoon, we ran 2-way ANOVAs on males and females to determine if their BMIs varied by site and/or season. For raccoons with >30 locations, we also ran regression analyses to determine whether the amount of unnatural habitat within raccoon annual home ranges correlated with the raccoons’ seasonal BMIs. The ANOVAs and regressions were conducted using R statistical software (R Core Team 2016, v. 3.3.2).

Results

During the study period, 297 individual raccoons were captured. Of those, 152 (90 males, 62 females) were classified as adults based on reproductive organ analysis and tooth wear (Grau et al. 1970; Sanderson and Nalbandov 1973). A total of 25 adult raccoons were radiocollared but, due to mortalities and collar losses, only 19 raccoons (9 males, 10 females) had greater than 30 locations recorded. From October 2014 to December 2016, we collected the 1,867 VHF locations and 8,488 GPS locations that were used in our density, home range, and habitat use analyses.

Density estimates, home ranges, and habitat use

Density estimates were highest during summer. The highest minimum known number alive (MKNA) for Goose Island (GI) was 13.2 raccoons per km² in July 2015. At Dan Ryan Woods (DR), the highest MKNA was 24.7 raccoons per km² in July 2016. Since each site was only trapped for ~ 2 weeks per season, our density estimates are conservative.

Site did not influence average 95% MCP annual home range sizes ($f=0.244$, $p=0.63$) or core area sizes ($f=1.325$, $p=0.27$) (Table 1). Since there were habitat variations within sites, however, we calculated the percentage of each raccoon's home range that was composed of unnatural habitat (Table 1). When the percentage of unnatural habitat within the individual's home range and the sex of the individual were used as factors in a two-way ANOVA, the annual home ranges and core areas both were influenced by sex ($f= 4.899$, $p=0.04$ and $f=5.764$, $p=0.03$, respectively) and the sex x unnatural habitat interaction term ($f=5.082$, $p=0.04$ and $f=4.923$, $p=0.04$, respectively). When examined in separate analyses, male home range sizes showed a weakly significant association with the amount of urbanization within their home ranges ($f=5.529$, $p=0.05$) but female home range sizes did not ($f=0.234$, $p=0.80$). The percentage of unnatural habitat being used was influenced by both the site ($f=12.148$, $p=0.003$) and sex

($f=9.984$, $p=0.006$) of the individuals, with GI and male home ranges tending to contain more unnatural habitat. Though all collared raccoons used some unnatural habitat, the raccoon locations were all <500 m from green spaces. On average, each DR raccoon had 81.3% of their locations <100 m from a natural area. Similarly, GI raccoons had an average of 96.6% of their locations <100 m from a natural area (Fig. 2).

In addition to examining annual trends, we used the satellite-derived data to calculate seasonal home ranges of 7 GPS-collared individuals when greater than 30 locations had been collected within a season (Table 2). Raccoons 9, 10, 13, and 23 were located mainly within the interior of the DR preserve, raccoons 1 and 64 were mostly in the urban matrix on the outskirts of the preserve (i.e., in adjacent neighborhoods, parks, railroad properties), and raccoon 107 was captured at GI. Raccoons located mainly within the preserve tended to have smaller home ranges than individuals using more urban habitat.

When we assessed locations where DR raccoons had visited multiple times (i.e., cluster points), we identified several urban features that likely attracted raccoons (Fig. 3). Of the 32 cluster points assessed, 12 sites featured garages or other buildings with structural damage, 11 sites had unsecured garbage cans or dumpsters, 10 sites had mature trees that were likely suitable for denning (often within backyards), 2 sites featured bird feeders, and 1 site had a fruiting tree. Many of the structurally damaged garages were accompanied by garbage cans in nearby alleyways. Raccoon presence in human structures was confirmed through radiotelemetry. Additionally, other raccoon locations were identified when study animals were nuisance trapped or their collars were recovered. As a few examples, one raccoon was nuisance trapped in a FedEx building, two raccoons were nuisance trapped when they fell through a bedroom ceiling near DR, and one dropped collar was recovered from inside the wall of an abandoned house.

Body condition

Body mass index (BMI) was influenced by different factors, depending on the sex of the individual (Fig. 4). While male BMIs were influenced only by season ($f=12.903$, $p<0.0001$), female BMIs were influenced by both season ($f=5.356$, $p=0.002$) and site ($f=11.704$, $p<0.0001$). Spring BMI was correlated with the sex of the individual ($\beta=-2.218$, $p=0.026$) and the percentage of the raccoon's home range that was composed of unnatural habitat ($\beta=0.059$, $p=0.020$), with an overall model fit of $R^2=0.9625$. Summer BMI was only correlated with the sex of the individual ($\beta=5.292$, $p=0.040$, overall $R^2=0.6427$). Fall and winter BMIs were not correlated with sex or the percentage of unnatural habitat in the home range ($R^2=0.037$ and 0.029 , respectively; $p>0.05$).

Discussion

The minimum known number alive at Goose Island (GI) and Dan Ryan Woods (DR) were higher than those typically reported for rural locations (Prange et al. 2003; Rosatte et al. 2010), but lower than those reported for other urban locations (Prange et al. 2003; Gross et al. 2012). Our MKNA estimations are likely conservative, however, due to the short duration of each trapping session.

Home ranges of DR and GI raccoons were smaller than the home ranges previously reported for our suburban site, Max McGraw Wildlife Foundation (MMWF) (means: 98 ha for males, 68 ha for females; Bozek et al. 2007). They were also smaller than those typically reported for rural areas (typically >100 ha; Gehrt and Fritzell 1997; Kamler and Gibson 2003; Ikeda et al. 2004), but similar to other urban areas (typically <100 ha; Ikeda et al. 2004; Totton et al. 2004; Gross et al. 2012). Small home ranges support our hypothesis that urban raccoons do not need large ranges to obtain adequate resources.

Raccoon home range and core area sizes differed by sex and an interaction between sex and the percentage of unnatural habitat within raccoon home ranges. Females typically have smaller ranges than males (Hoffman and Gottschang 1977; Chamberlain et al. 2003; Beasley et al. 2007) and the difference is often attributed to raccoon reproductive behaviors (Ellis 1964; Gehrt et al. 1997; Byrne and Chamberlain 2011). Males roam larger areas to mate with multiple females (Gehrt and Fritzell 1997; Pitt et al. 2008b), whereas females are often limited in their movements while they are raising offspring (Rabinowitz and Pelton 1986; Byrne and Chamberlain 2011). Male raccoons increased their home ranges as urbanization increased, but females did not. Highly fragmented habitats likely result in potential mates being spread more widely, thus males may increase their ranges to continue breeding polygynously.

Regardless of site, all raccoons used combinations of natural and unnatural habitats. At DR, most raccoon locations fell within green spaces. As distance from a natural area increased, fewer locations were present. At GI, on the other hand, similar percentages of locations were in the natural area (e.g., the wooded area adjacent to the Chicago River) and the 100 m buffer around the natural area. Few locations (< 4%) were > 100 m away from the green space. The difference in the rates at which raccoon locations declined outside of natural areas at the sites reflects a difference in the sites, themselves. DR gradually changes from a forested preserve, to neighborhoods, and finally to businesses. Because neighborhoods still have trees and abandoned structures for denning and there is an abundance of food sources (i.e., dumpsters, bird feeders), raccoons can use them as habitat (Hoffman and Gottschang 1977; Riley et al. 1998; Rosatte et al. 2010). In contrast, the landscape at GI changes rapidly from a riparian area to industrial buildings and paved lots. Most buildings were structurally sound and anthropogenic food sources were limited. Our results support studies that have shown raccoons are more likely to use

wooded and residential habitats than industrial, and open areas (Dijak and Thompson 2000; Prange et al. 2003; Bozek et al. 2007). No locations were >500 m from a green space, indicating that natural fragments are important for urban raccoons. Raccoons may opt for wooded areas because they provide stable sources of food, refuges, and kit-rearing sites (Rabinowitz and Pelton 1986; Henner et al. 2004; Byrne and Chamberlain 2011).

Raccoon body mass indices (BMIs) fluctuated seasonally, as has been observed in other locations (Asano et al. 2003; Pitt et al. 2008a; Kato et al. 2011). Raccoons typically are smallest in late winter and early spring due to colder temperatures limiting food and activity. Late spring through fall, raccoons gain weight as natural foods (e.g., berries) become more readily available (Pitt et al. 2008a). While both sexes were influenced by season, only female BMIs varied by site. Male BMIs consistently fluctuated seasonally and were similar across sites. Male and female BMIs fluctuated similarly at the suburban site (MMWF) but females fluctuated less at the two urban sites. DR females had consistently higher BMIs and GI females had consistently lower BMIs. The BMI patterns may relate to the amount of unnatural habitat present. At MMWF, large green spaces provide an abundance of natural resources from late spring until late fall. Most natural resources become limited in winter, however, resulting in seasonal fluctuations of body condition (Asano et al. 2003; Prange et al. 2003; Pitt et al. 2008a). At DR and GI, female raccoons tended to have slightly higher BMIs in the fall but maintained fairly consistent BMIs throughout the other seasons. The lack of BMI fluctuation the rest of the year may be due to urban raccoons having a steady supply of human food subsidies. DR raccoons had the highest median BMIs, likely because they had an abundance of natural and unnatural food sources, as opposed to mostly natural at MMWF and mostly unnatural at GI. While unnatural habitat can provide supplemental den locations and food, too much fragmentation can result in resources

becoming more widely spread throughout the landscape (Prange et al. 2003; Riley et al. 2003; Lowry et al. 2013). Male raccoons may be less influenced by variations in urbanization because they often have larger home ranges that encompass more resources in general (Gehrt and Fritzell 1998; Chamberlain et al. 2003; Beasley et al. 2007). Additionally, regardless of site, males may fluctuate seasonally due to their breeding habits. Large males outcompete small males for mates, so males naturally grow larger and faster prior to and during mating season (Pit et al. 2008).

When examined on a seasonal level, spring and summer BMIs varied by sex. Spring BMIs were taken during the latter half of the breeding season (March) and summer BMIs were measured during the kit-rearing season (July). Female BMIs were likely lower than males due to differences in energy expenditures (e.g., females lactate in summer)(Fritzell 1978). Spring BMIs were also correlated with the amount of unnatural habitat present in each raccoon's home range, with raccoons using more unnatural habitat tending to have higher BMIs. Since spring BMIs were taken in early March, they support the hypothesis that raccoons using some unnatural habitat may have better body conditions at the end of winter than raccoons relying solely on natural areas.

Overall, our findings suggest raccoons can use urban resources to their benefit, but only to a certain extent. Even the most urban raccoons rely on having small green patches. Raccoons do tend to be drawn toward certain kinds of food sources (e.g., dumpsters) and den sites (e.g., abandoned buildings), so identifying and removing attractants could be one way to manage raccoon activity (Henner et al. 2004; Beasley and Rhodes 2012). Particularly in areas near natural habitat fragments, managing raccoons is important for reducing human-wildlife conflicts.

To determine if the patterns we observed are truly related to human-supplied food subsidies, further studies are needed to examine the quantities of anthropogenic food being

consumed by raccoons. Future raccoon studies should also focus on incorporating individuals living within neighborhoods and industrial areas, as there are few studies that examine raccoons at the far end of the urban spectrum. Raccoons living in large parks have different resources available to them, so their behaviors likely differ from those exhibited by matrix animals.

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Tables and Figures:

Table 1. Mean 95% minimum convex polygon (MCP) annual home range estimates, percentages of home ranges that were composed of unnatural habitat, and 50% MCP core area estimates for male (n=9) and female (n=10) raccoons at Dan Ryan Woods and Goose Island.

	Males		Females	
	Mean	95% CI	Mean	95% CI
Annual Home Range (ha)	36.76	(14.81, 58.71)	17.68	(8.00, 27.37)
<i>% Unnatural</i>	63.59	(49.00, 78.17)	41.08	(22.22, 59.95)
Core Area (ha)	10.42	(2.10, 18.74)	2.97	(0.09, 5.85)

Table 2. Seasonal home range sizes (ha) of individual, GPS-collared raccoons. Home ranges were estimated using the 95% minimum convex polygon method.

Raccoon	Site	Sex	Seasonal Home Range Size (ha)				
			Fall	Winter	Spring	Summer	Fall
			2014	2014	2015	2015	2015
1	Dan Ryan (matrix)	M	42.0	61.4	28.3	33.0	-
9	Dan Ryan (preserve)	F	4.8	2.9	-	-	-
10	Dan Ryan (preserve)	F	3.4	0.9	-	-	-
13	Dan Ryan (preserve)	F	5.9	2.2	-	-	-
23	Dan Ryan (preserve)	M	4.9	9.6	9.6	7.1	-
64	Dan Ryan (matrix)	M	-	-	52.9	44.1	-
107	Goose Island	F	-	-	-	23.6	36.3

Study Sites

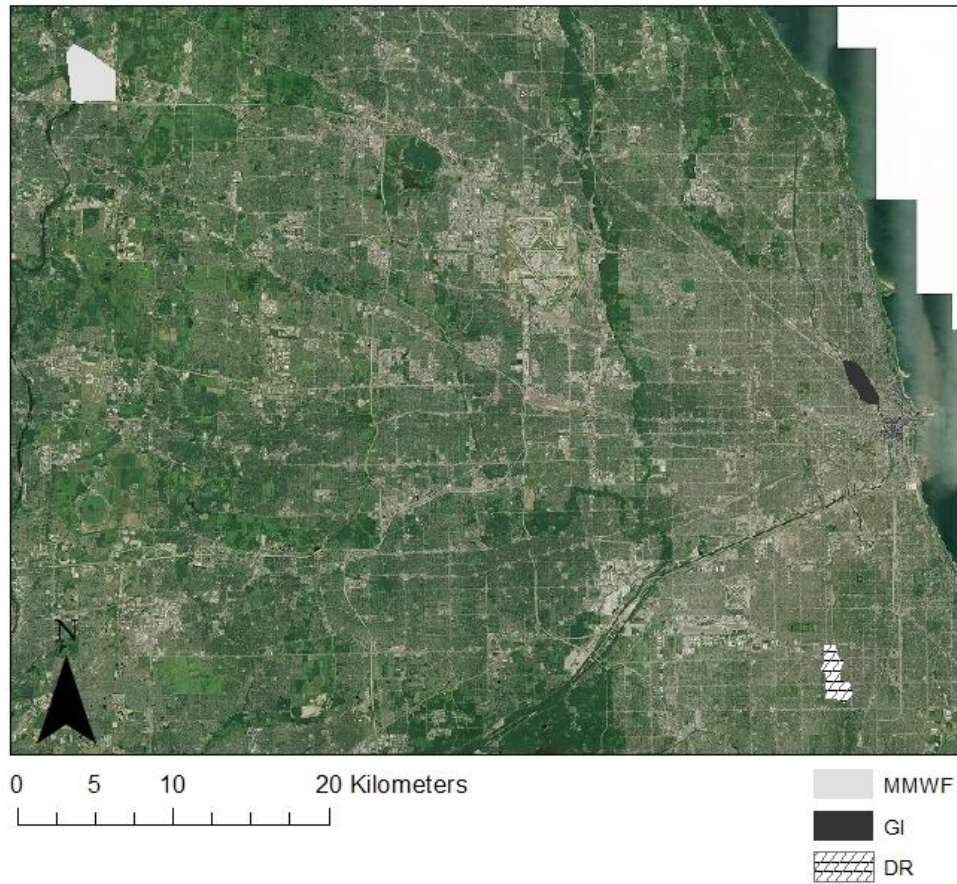


Fig 1 Study sites within the Greater Chicago Metropolitan Area, Illinois, USA. In order of increasing urbanization, the sites studied were Max McGraw Wildlife Foundation (MMWF), Dan Ryan Woods (DR), and Goose Island (GI).

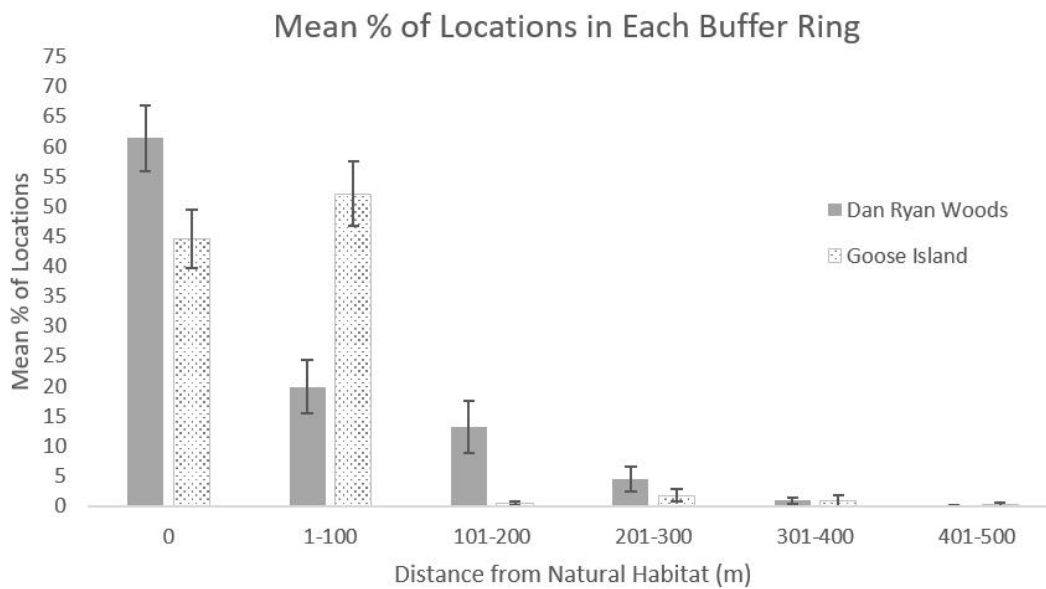
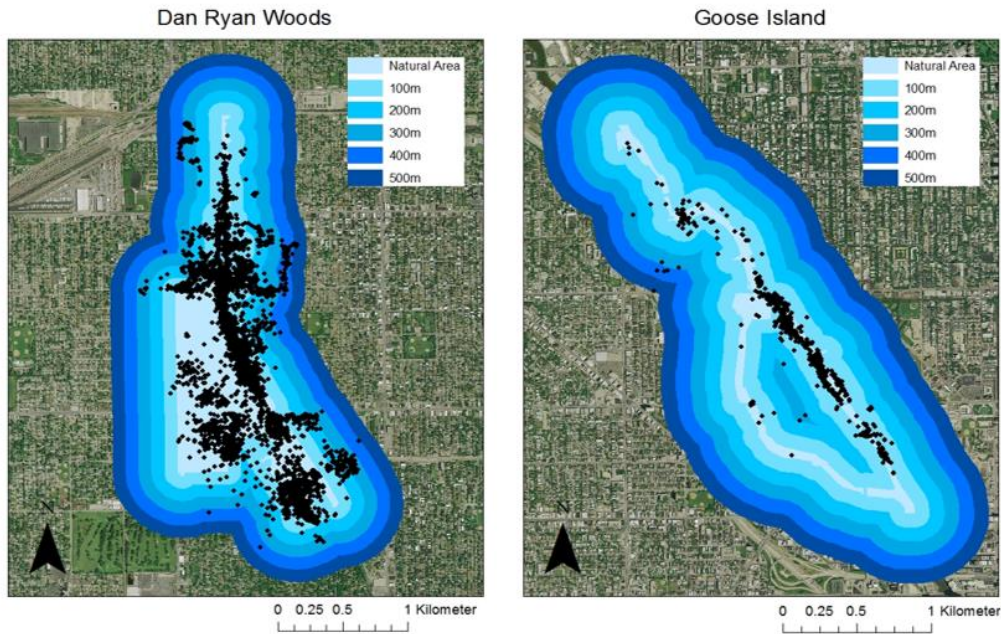


Fig 2 Mean % of each raccoon’s locations collected within natural areas (e.g., forest preserve, river edge) and the surrounding urban matrices. Buffer rings were placed around green spaces in 100m increments at Dan Ryan and Goose Island. No locations were outside of the 500m buffer ring. A total of 26,694 locations were collected for 19 raccoons (n= 14 Dan Ryan Woods, 5 Goose Island) between October 2014 through July 2016.

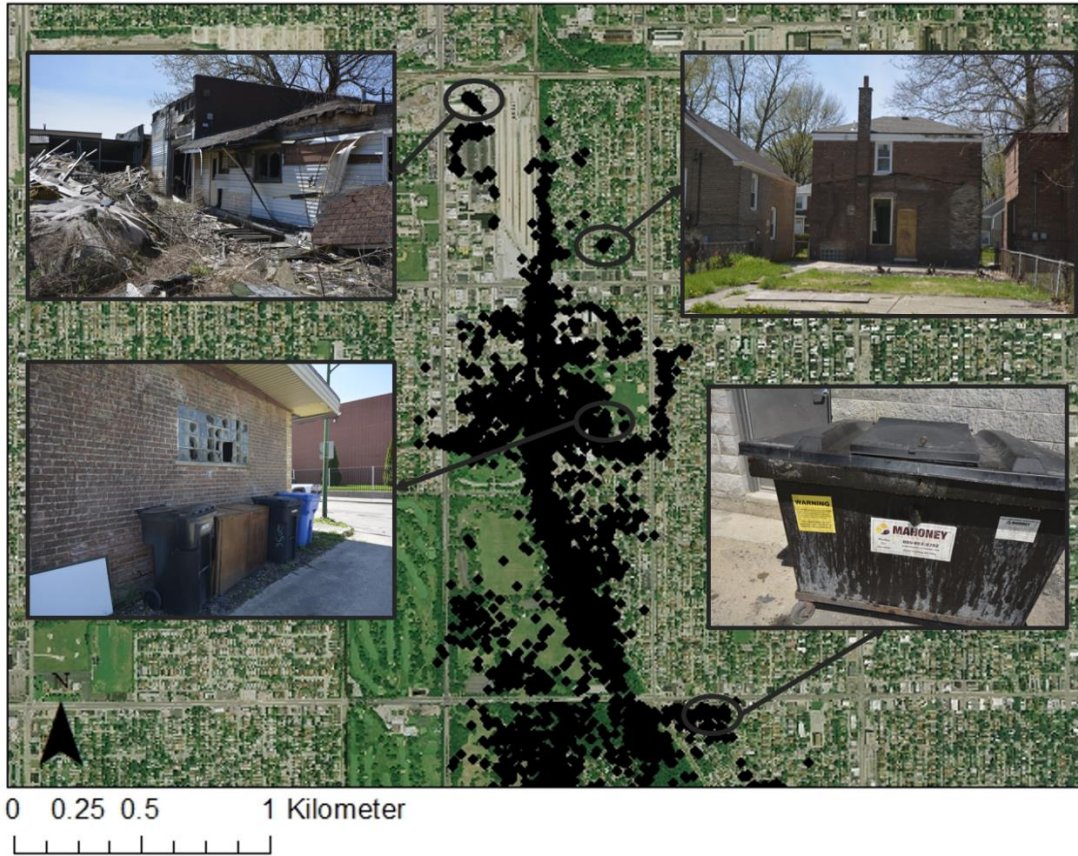


Fig 3 Examples of Dan Ryan Woods raccoon cluster points and corresponding urban site features that likely attracted raccoon activity. The depicted points are a subset of locations collected from all collared, Dan Ryan Woods raccoons (n=8 VHF-collared, 6 GPS-collared) during the full tracking period (October 2014 through July 2016).

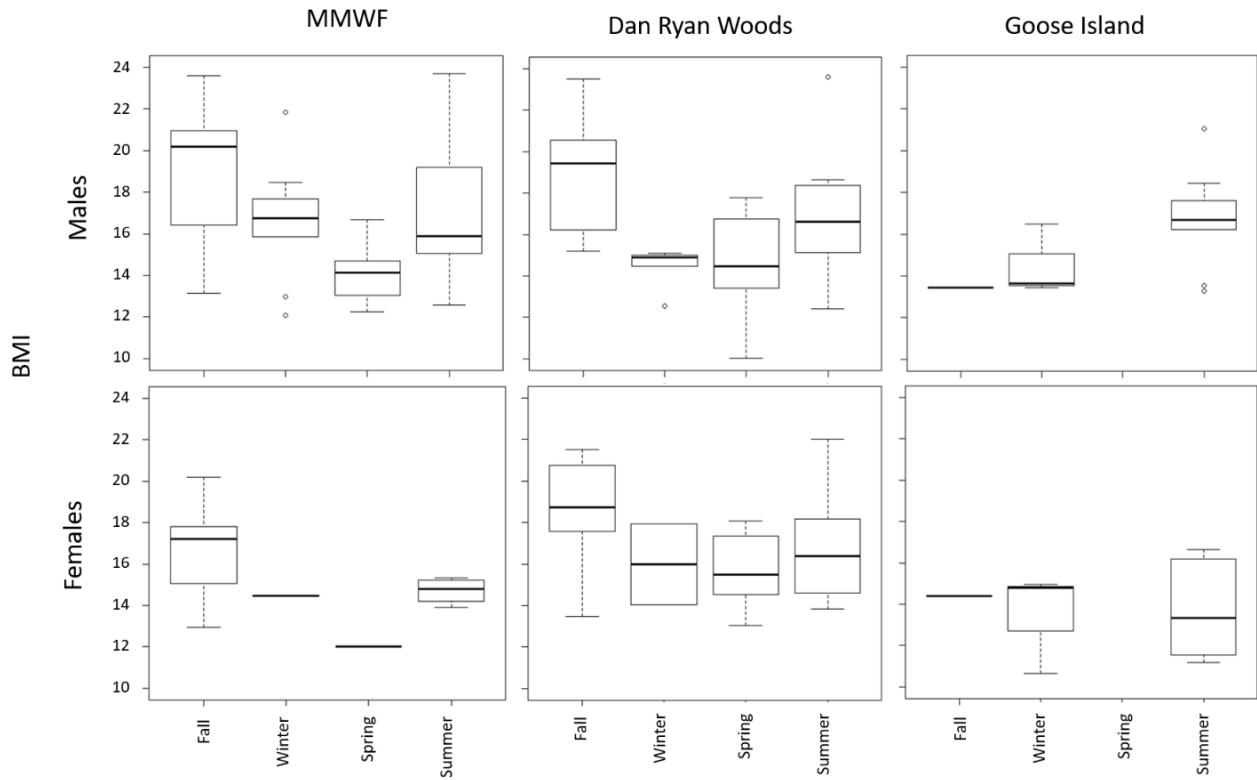


Fig 4 Seasonal adult male and female raccoon body mass indices at Max McGraw Wildlife Foundation (n: fall=24, winter=10, spring=8, summer=27) , Dan Ryan Woods (n: fall=36, winter=7, spring=26, summer=34), and Goose Island (n: fall=2, winter=7, summer=14)