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Food subsidies of Raccoons in anthropogenic landscapes

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ABSTRACT Food subsidies from human sources are often exploited by free-ranging vertebrates living in human-dominated landscapes. To explore the importance and attempt to estimate the reliance of raccoons (*Procyon lotor* Linnaeus, 1758) – common synanthropes in North America – on such food subsidies, we analyzed hair samples from 122 raccoons collected across four states in Midwestern North America (Wisconsin, Minnesota, Iowa and Illinois), including 9 raccoons that were live-trapped and sampled in Madison, Wisconsin USA. We found that raccoons inhabiting areas with more agriculture had higher $\delta^{13}\text{C}$ values, indicating a diet enriched with anthropogenic food from C_4 photosynthetic plants, like *Zea mays* L. Surprisingly, raccoons inhabiting increasingly urban areas showed lower $\delta^{13}\text{C}$ values, suggesting a diet with less anthropogenic food. Regardless, raccoons in urban areas enriched in ^{13}C possessed high indices of body condition, suggesting that anthropogenic food subsidies are contributing to their overall nutritional condition. Our findings reveal that the degree to which synanthropes rely upon human foods differs by land cover type, and that the use of these calorically-rich subsidies has important implications on individual health.

KEY WORDS

body mass, enrichment, Midwest, land cover, *Procyon lotor*, raccoon

41 INTRODUCTION

42 Many wildlife habitats are modified due to the presence of humans by being converted from
43 natural areas to urban areas and agricultural land (Koh and Gardner 2010). Consequently, these
44 highly altered systems are commonly used habitat by a wide variety of species (Koh and Gardner
45 2010). Synanthropes – species that live in close proximity with humans – are well-suited to live
46 within these increasingly altered landscapes and are effective at extracting resources provided by
47 humans (Gehrt et al. 2011). Associated with the presence of these landscapes is increased food
48 subsidies that are often easily accessible and calorically rich (Birnie-Gauvin et al. 2017). In
49 urban areas food subsidies are typically in the form of food waste; in agricultural lands they are
50 often crops (Kirby et al. 2016). Human food subsidies are an important part of an animal's diet in
51 human-modified landscapes as compared to animals in wild or remote areas (Newsome et al.
52 2010; Kirby et al. 2016). This use of anthropogenic food is beneficial to many wildlife species
53 (Birnie-Gauvin et al. 2017), but the consequences of consumption are not always positive (Moss
54 et al. 2016a).

55 The analysis of stable isotopes (in particular ^{13}C and ^{15}N) provides an effective method
56 for determining exploitation of anthropogenic food due to the scarcity of C_4 plants on the
57 landscape and the abundance of C_4 plants in anthropogenic foods (Newsome et al. 2010).
58 Previous researchers have shown that the isotopic signatures of small urban carnivores, like
59 foxes (*Vulpes macrotis* Merriam, 1888; Newsome et al. 2010) and coyotes (*Canis latrans* Say,
60 1823; Newsome et al. 2015) were similar to those of people in residential areas. In addition,
61 larger carnivores including bears (*Ursus americanus* Pallas, 1780; Kirby et al. 2016) and cougars
62 (*Puma concolor* Linnaeus, 1771; Moss et al. 2016b) in areas with higher housing density and
63 increased human activity showed enriched ^{13}C signatures reflecting greater reliance on human-

derived foods. While the changes to the diet of urban wildlife are well studied, the effects of a subsidized diet on individual health are less known. Among humans, those living in urban areas are enriched in ^{13}C , reflecting increased consumption of corn and cane sugar and processed foods, which can lead to increased body fat and rates of obesity (Jahren et al. 2014; O'Brien 2015; Davy and Jahren 2016). Since synanthropes consume human food, it is plausible that they would experience similar health effects as humans with increased consumption of these subsidies.

Raccoons (*Procyon lotor* Linnaeus, 1758) are common synanthropes of human-modified landscapes (Prange et al. 2004). They are omnivorous and opportunistic foragers that consume a wide range of plant and animal matter. Their diet mainly depends on the environment they inhabit as they consume any food that is available to them within that habitat (Whiteside 2009). In natural areas, most of their diet consists of plants and invertebrates, such as berries, nuts, and arthropods (Lotze and Anderson 1979; Whiteside 2009); in human dominated landscapes, raccoons primarily consume food at bird feeders, table scraps, pet food and other available garbage (Whiteside 2009). Their body masses fluctuate seasonally, with an increasing mass in the fall and decreasing mass in the spring (Whiteside 2009). The difference in food items across land cover types most likely has important implications for their diet and overall nutritional condition.

Herein, we studied anthropogenic food consumption of raccoons at both a regional and local scale. In particular, we compared a large sample of raccoons collected across four states in Midwestern North America (Wisconsin, Minnesota, Iowa and Illinois) to explore the relative influence of agriculture and urban areas in relation to anthropogenic food consumption by this common synanthrope. We combined this broad-scale survey with a local study to explore the

effect of increasing human food subsidies on the body condition of raccoons within an urban area. We predicted that raccoons inhabiting urban areas would consume more anthropogenic food compared to raccoons inhabiting agricultural areas. We also predicted that increased reliance on anthropogenic food subsidies would be reflected in high body conditions of raccoons (i.e., a relatively large body mass for their structural size).

MATERIALS AND METHODS

From 2011-2013 we collected 119 hair samples from road-kill raccoons (Figure 1A). From September to November of each year, raccoons were conveniently sampled as encountered; their location was recorded with a handheld GPS and hair was plucked from the carcass and prepared for bulk analysis of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ via mass spectrometry following standard procedures (Pauli et al. 2009). To explore how these land cover types influenced raccoon isotopic signature, we buffered each raccoon sampling location with a 1-km radius (Prange et al. 2004) and extracted 2 general cover types from the National Land Cover Database (NLCD 2011): urban (a combination of low, medium and high intensity developed) and agriculture (i.e., cultivated crops). The proportion data were coupled with the $\delta^{13}\text{C}$ isotope signatures to explore the relationship between land cover type and isotopic values.

We live trapped raccoons at three locations in Madison, Wisconsin USA: 1) University of Wisconsin-Madison's campus (43.0766° N, 89.4125° W); 2) University of Wisconsin-Madison Arboretum (43.0429° N, 89.4243° W); 3) USGS National Wildlife Health Center (NWHC) (43.0464° N, 89.4842° W). Within each site 3-6 Tomahawk cage traps (Tomahawk, WI) were deployed, each baited with marshmallows or cotton balls soaked in vanilla extract. Traps were checked once every 24 hours between the time period of 0800 to 1100. Captured adult raccoons

were immobilized using an intramuscular injection of Telazol at the dosage of 0.05 mL/kg (Gehrt et al. 2001). Immobilized raccoons were identified to sex and measured for body mass using a hand scale and hind foot length using a caliper. We also collected hair samples for isotopic analysis which were prepared following methods described above. Captured juvenile raccoons were not immobilized and only hair samples were collected prior to their release. Our methods were approved by the University of Wisconsin-Madison IACUC (protocol number: A005926-A01). To explore whether body condition was related to dietary input, we generated a linear regression of body mass versus hindfoot length (Schulte-Hostedde et al. 2005) and used the standardized residuals from this relationship as a proxy for body condition corrected for structural size. We then regressed this body condition index versus $\delta^{13}\text{C}$.

RESULTS

Raccoons inhabiting increasingly agricultural areas exhibited a significant ($F_{1,118} = 18.65$, $P < 0.001$) enrichment in ^{13}C (Figure 1C). In contrast, raccoons inhabiting increasingly urban areas exhibited lower values of ^{13}C ($F_{1,118} = 12.13$, $P < 0.001$; Figure 1B). Raccoons in more agricultural areas also exhibited a positive relationship with ^{15}N ($r^2 = 0.065$; $F_{1,118} = 8.28$, $P = 0.005$) but we did not detect a relationship between urban areas and ^{15}N ($F_{1,118} = 1.15$, $P = 0.285$). Of the 9 raccoons sampled, five were adults (3 males and 2 females). The range in body mass was 6.4 kg to 12.3 kg with a mean body mass of 8.7 kg. Residuals from a regression of body mass and hindfoot ($y = 0.41x - 33.4$, $r^2 = 0.51$) were used as an index to body condition for each raccoon. We detected a significant ($F_{1,8} = 12.97$, $P = 0.037$) positive relationship between $\delta^{13}\text{C}$ and body conditions of the raccoons (Figure 2A), suggesting that increasing consumption of human derived food items was an important factor (Figure 2B).

DISCUSSION

Our analyses of $\delta^{13}\text{C}$ across land cover types throughout Wisconsin, Minnesota, Iowa and Illinois demonstrated a surprising departure from our hypothesis. While we predicted that urban areas would be the most closely associated cover type with ^{13}C enrichment, we found that agriculture was the land cover type most associated with ^{13}C enrichment. Our results differ compared to previous studies (Kirby et al 2016; Moss et al. 2016b) which found that large carnivores have greater reliance on human food subsidies when they inhabit human-dominated areas. As opportunistic omnivores, raccoons eat what is available (Whiteside 2009). Agricultural foods such as corn are more readily available at the end of summer into the fall, which coincides with the annual molt of raccoons (Lotze and Anderson 1979). Consequently, analysis of hair likely captures this pulsed resource in agricultural landscapes. The fact that we found a negative relationship between urban areas and raccoon consumption of anthropogenic food could be a result of mischaracterized urban areas within the 1-km buffers, although the observed relationship between agricultural areas and raccoon consumption of anthropogenic food suggests that such buffers were effective in capturing habitat context. It is possible that raccoons are not as reliant on anthropogenic food as they are on natural prey in urban areas even though it provides important nutritional gains. Indeed, efforts to reduce human food waste availability in urban areas might be having their desired effect. Or, it is possible that raccoons are being precluded from accessing food subsidies in urban areas due to the recent colonization of larger and competitively dominant carnivores like coyotes (Garwood et al. 2015) and foxes (Mueller et al. 2018) in these urban areas.

Finer-scale analysis revealed that our sample of raccoons in Madison had an enriched ^{15}N , and, especially ^{13}C indicating that raccoons in urban areas are consuming anthropogenic

food, and that increasing reliance on these human food subsidies lead to increasing indices of body condition. While high body condition is generally regarded as a benefit for wildlife, extremely high body condition may lead to negative health consequences such as obesity, which is a relatively novel health concern for wildlife (Birnie-Gauvin et al. 2017). Indeed, recent research in urban areas in Canada have revealed that raccoons with greater access to human food exhibited larger body size and even hyperglycemia (Schulte-Hostedde et al. 2018). Regardless, our work demonstrates that wildlife living in human-modified landscapes that consume human food subsidies tend to have high body condition indices from this consumption.

Overall, we found that on a broad scale agriculture was the land cover type associated with increased human food enrichment, while urban surprisingly led to a reduction in the use of human food subsidies. Regardless, in urban areas more human food consumption by raccoons led to increased body conditions. These results suggest that while efforts to control human food availability might be working, individuals still find access to these items that affect their health. Consequently, the availability of human food subsidies in both urban and agricultural areas allows synanthropes such as raccoons to have high population densities (Prange et al. 2003). To decrease the abundance of raccoons within human-dominated landscapes management efforts should consider further controls on human food availability and the human tolerance of larger carnivores that may regulate the access of anthropogenic food to mesopredators like raccoons.

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261 **Figure 1A.** Location of 119 hair samples collected (2011-2013) from raccoons (*Procyon lotor*
262 Linnaeus, 1758) across Wisconsin, Minnesota, Iowa and Illinois overlaid on general land cover
263 types derived from National Land Cover Database (NLCD 2011): open water, urban (low,
264 medium and high intensity developed), natural areas (deciduous, coniferous and mixed forests;
265 wetlands; shrublands; grasslands) and agriculture (cultivated crops). **B.** $\delta^{13}\text{C}$ versus percent
266 urban cover type and **C.** $\delta^{13}\text{C}$ versus percent agriculture cover type for all sampled raccoons.

267
268 **Figure 2A.** Relationship between $\delta^{13}\text{C}$ signature and body condition for 5 live-trapped adult
269 raccoons (*Procyon lotor* Linnaeus, 1758) in Madison, Wisconsin, 2017. Body condition was
270 estimated from the residual of body mass (kg) versus hindfoot length (cm). **B.** Isotopic bi-plot
271 illustrating 9 raccoon isotopic signatures (open circles) relative to other potential prey/food items
272 in urban landscapes. Isotopic signatures for native plants from Kirby et al. 2017; human foods
273 from Jahren and Kraft 2008; corn from Ditmer et al. 2015; freshwater food from Glon et al.
274 2015; all food/prey items trophically corrected (2.59‰ for nitrogen [Caut et al. 2009] and 0.60‰
275 for carbon [Roth and Hobson 2000]) for direct comparison with raccoons.

A.

B.

A.

B.