Nutrient availability in urban food waste: carbohydrate bias in the Philadelphia–Camden urban matrix

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Abstract

Urban areas provide animals with both a unique set of challenges and resources. One of the novel resources available in urban areas is an abundance of human food waste. Although it is known that many urban-dwelling animals are consuming human food waste at some level, there is not a good understanding of the nutrients provided by this novel resource. Given that human food waste is unlikely to resemble an animal’s natural diet, there could be health consequences for an animal consuming human food waste. In some animals, nutritional imbalances can also lead to behavioral changes, making it important to understand more precisely what they are eating. To answer the question of what nutrients were available in urban food waste, we surveyed food waste in the Philadelphia–Camden urban matrix. We found that human food waste contained 1000% more carbohydrates than other nutrient types. Given the impact that carbohydrate-rich diets can have on human health, there may be important consequences for the animals in urban environments that consume this food waste. Therefore, it is possible that human food subsidies have cascading consequences for entire communities and their ecosystem services in cities.

Key words: urban ecology, macronutrients, food waste, carbohydrates

Introduction

We live in an increasingly urbanized world. Over half of the world’s population was already living in cities by 2014, and by 2050 this figure is expected to rise to two-thirds (Nations, 2014). The physical space taken up by urban areas is also expected to grow, with a predicted increase of 430 000–12 568 000 km² by 2030 (Seto et al. 2011). Despite these trends, research into the ecological processes in urban areas were historically neglected relative to studies in wildlands, with investigations in urban areas representing only ~4% of the literature in the most recent review (Martin et al. 2012).

Beyond the importance of city environments to humans, cities have unique environmental features. They consist of a mosaic of environments within a relatively small space, which may impact the distribution and behavior of organisms. They are also subject to high levels of chronic environmental stress, defined as a consistent press disturbances present in a city environment (Savage et al. 2015). Factors such as reduced canopy cover, pollution and disturbance by traffic and the urban heat island effect all contribute to chronic stress levels within a city (Savage et al., 2015; Youngsteadt et al., 2015). The end result is an ecosystem in which organisms are adapting to a novel and highly altered environment (Johnson and Munshi-South 2017), and frequently interacting with humans.

One way humans alter natural systems in urban areas is by introducing food waste. Up to 26% of waste in urban areas can consist of discarded food (KAB 2009), not all of which will be removed for proper disposal. Even if food waste is removed from the location which it is dropped, there are still consequences to its introduction. Most food waste is transported to landfills,
where it undergoes anaerobic decomposition. Food waste in landfills generates large amounts of methane, with urban areas specifically producing an estimated 8% of global methane emission (Adhikari et al. 2006). As a greenhouse gas, methane traps an estimated 4–36 times more heat per mole than CO₂ (Lashof and Ahuja 1990; Lelieveld, Crutzen, and Brühl et al. 1993; Chai, Tonjes, and Dvinder 2016).

Urban animals can consume food waste before it is transported to landfills, serving as another form of food waste removal. This consumption of food waste is considered an ecosystem service, given the issues associated with food waste decomposition (Oro et al. 2013; Youngsteadt et al. 2015). Generally, it has been shown that animals increasingly forage on human food waste as areas become more urbanized. This has been shown in mammals, such as coyotes (Fedriani, Fuller, and Sauvajot 2001) and kit-foxes (Newsome et al. 2010), in birds (Sauter et al. 2006), reptiles (Jessop et al. 2012) and even urban ants (Penick et al. 2015). A natural follow-up question to this observation is what the impacts of eating human food waste are for urban-dwelling animals. One possibility is that human food waste is simply a beneficial resource due to the additional calories it provides. Some studies support this idea. Access to human food waste in urban areas has been linked to reduced home ranges in raccoons (Bozek, Prange, and Gehrt 2007), increased population densities in coyotes (Fedriani, Fuller, and Sauvajot 2001) and reduction in time spent foraging in black bears (Beckmann and Berger 2003). These benefits, however, are the result of the additional calories present in the food waste. It is unclear if these anthropogenic food sources are equivalent to the diets that urban animals evolved to consume.

It is therefore important to consider the nutritional value of food waste to the animals eating it. All animals require a balance of nutrients for their continued survival, growth, and for reproduction (Raubenheimer, Simpson, and Mayntz 2009). One issue that may arise is that human food waste may be nutritionally suboptimal for urban animals. Existing studies have shown differences in the nutritional profiles of animals consuming human food waste compared with those that do not. In both brown bears (Coogan et al. 2018) and house sparrows (Gadau et al. 2019) populations with increased access to human food waste showed higher carbohydrate levels. In these cases this was not linked to negative health impacts, but there are studies showing negative health impacts in urban animals due to nutritional deficits or other imbalances. Some of these studies show effects on animals during their development. Crow and sparrow nestlings fed human food waste show reduced growth and poor condition compared with nestlings fed natural food sources (Heiss, Clark, and McGowan 2009; Meillère et al. 2015). Other work has shown negative health effects in adult animals. Although not strictly focused on urban animals, a review by Murray et al. (2016) noted the risks to herbivores supplemented with foods low in protein. A study on raccoons with access to human food waste found that they were hyperglycemic, with one individual exhibiting symptoms of diabetes (Schulte-Hostedde et al. 2018). These studies suggest that there are potential costs to urban animals that provide the ecosystem service of consuming urban food waste. Given the potential for nutritional deficits in urban animals, it would be useful to know what types of food waste are available to urban animals in general. Although studies characterizing the nutritional status of specific urban-dwelling animal populations are useful, a nutritional profile of human food waste in urban areas would enable researchers to make predictions about a wider array of species.

In this study, we sought to quantify the nutritional composition of human food waste in the Philadelphia–Camden urban matrix. We chose to focus on carbohydrates, proteins, and lipids as these are important nutrients for animals and were easy to categorize in the field.

Methods

We conducted two sets of food surveys in the Philadelphia–Camden urban matrix (Fig. 1). The initial surveys took place from September 2016 to November 2016 and utilized 26 sites. These first surveys were carried out as part of a separate project, but the results we observed were interesting enough that we felt the idea warranted further exploration. Because these first surveys had been undertaken with a narrower focus, we chose to conduct a second set with an updated site design. The later surveys took place in July and August of 2018 and utilized 15 sites. This added a component of seasonality to the study with a fall dataset and a summer dataset. For both sets of surveys, we identified and recorded food waste using a visual survey of the site. We recorded each unique food item encountered and counted it as an observation. We chose to only survey food found on the ground, as it was easily accessible to all animals. All observed food was left at the site. This choice was largely made for feasibility, as our lab lacked the space and equipment to safely transport, store and process food waste in various states of decay. Both surveys also utilized two types of sites—parks to represent lower stress areas and road medians to represent higher stress areas (Savage et al. 2015). We previously observed that food waste from passing pedestrians and cars accumulated in street medians, and were removed less frequently than food waste dropped outside of trash bins in city parks (Carpenter and Savage, pers. obs.). In both years, sites were visited multiple times. In the fall 2016 surveys, sites in Camden were visited four times, and sites in Philadelphia were visited two times. In the summer 2018 surveys all sites were visited three times.

For both surveys, we selected sites such that the area covered by surveys for both the parks and the medians was equivalent. In 2016, this was achieved by setting the length of all sites to 30 m and standardizing the widths of parks and medians located close to each other so that each site at a park was paired with a median site with the same dimensions. Site pairs were established based on proximity only, with the maximum distance between one site pair being 1.17 km. This resulted in 13 park sites and 13 median sites (Fig. 1A). This design was chosen in anticipation of a study involving urban ant populations conducted the following summer. Anthropogenic food waste was not observed during any surveys in six of the park sites in 2016. During both the fall surveys and during work done in the summer of 2017 it was observed that while food waste was frequently present at parks, it was typically more spread out than in road medians. Therefore, a slightly different approach was taken with sites in 2018, in which we paired one park site with two median sites with a combined area equal to the park site. The medians in these surveys were adjacent, and thus were considered as one singular site. This resulted in five park sites and five median sites each composed of two adjacent medians (Fig. 1B). Length and width were not standardized for these sites, simply area in m². This was done to reflect the difference in how these sites were used by people. The previous design had imposed dimensions more typical of medians onto the park sites, but people do not tend to confine themselves to a narrow strip of a park as they do with medians. Instead, they tend to...
move around whatever space the park offers them. By only matching area, we intended to get a more accurate representation of introduced food waste in parks.

Following the surveys, we organized our collected data into tables for analysis. Since we did not have weight data, we decided that we would not include any assumptions about the amount of any given food at a site. Instead, we treated any occurrence of a particular food item at a site as a singular observation, with observations resetting upon each site visit. If, e.g. we saw 30 pieces of breakfast cereal at a site during one visit we would note that the site had an occurrence of breakfast cereal on that visit. If there was still breakfast cereal during the next visit then we would note that the site again had an occurrence of breakfast cereal during this new visit.

We then classified the food items by the amount of carbohydrates, proteins, and lipids they each contained. For these data, we relied on FDA reports (https://fdc.nal.usda.gov/index.html) for each individual food item. One exception was made in the case of chicken and turkey bones, which are not found in the FDA database. For these food items, we used values reported by Cansu and Boran (2015) for cleaned chicken bones. For our analysis, we considered the presence/absence of a nutrient, the most abundant nutrient in a food item, and the relative amounts of each of the three nutrients. Presence/absence data were based purely on the presence or absence of a macronutrient, with no minimum amount set for a nutrient to be classified as present. For the analysis of the most abundant nutrient, we used the data for the total amount of each macronutrient per 100 g of a food item, and classified the dominant nutrient as the one contributing the most by mass. For both presence/absence and dominance, we constructed contingency tables using macronutrient × presence/absence (where 1 = present and 0 = absent) and macronutrient × dominance (where 1 = dominant and 0 = non-dominant). There were no cases of a tie of dominance in nutrient types. The dataset considering relative amounts also used the mass that each nutrient contributed to the food, with food weights standardized at 100 g. This was done to obtain a more fine-scale comparison than dominance. It allowed us to distinguish how much more a dominant nutrient contributed, and to consider how much each of the other two nutrients contributed.

Due to the relatively low number of unique food items found per visit across all sites in both years (52 unique items observed in 2016 and 53 unique items observed in 2018) and the variation in the number of unique food items found per site in both years (Table 1) we chose to only consider all the food data from a site across multiple visits in any one analysis, rather than compare the differences between visits. We also did not directly compare the data from both years using a statistical test. This was done both because of the change in site delineation in 2018 and because, due to lack of access, some sites in 2018 were left out and replaced with different sites.

None of our datasets (presence/absence, dominance and relative amounts) met assumptions of normality, nor could normality be imposed via data transformations. Furthermore, because food items were observed at different sites at multiple
2018 Surveys

Each site code in both years.

Most dominant nutrients in urban food waste

Nutrients were not found to be equally distributed in food waste (Fig. 3; Tables 4 and 5). Carbohydrates were the dominant nutrient in ~80% of foods discarded in road medians in both years, with GLMM results finding this dominance compared with the other nutrients to be significant both years. Carbohydrates were also the most common dominant nutrient in foods dropped in parks both years by percent, but this dominance was only significant in 2016 (Table 4) and not in 2018 (Table 5). In both years and site types, protein was the second most common nutrient to be dominant in food items (Tables 4 and 5). GLMMs suggested that they were significantly less dominant in 2016 in both site types, but only significantly less dominant in medians in 2018. Lipid dominated foods were only found in 2016 medians and 2018 parks, and even then they only accounted for <5% of the foods observed.

Relative amount of proteins, lipids and carbohydrates in urban food waste

In both 2016 and 2018 in medians and parks, there were significantly more carbohydrates in surveyed foods than lipids and proteins. For both years and both site types the relative amount of carbohydrates were significantly higher compared with the other nutrients (Fig. 4; Tables 6 and 7). In 2016, food items found in medians contained an average of 49 g of carbohydrates per 100 g of food, and food items found in medians contained an average of 54 g of carbohydrate per 100 g. In 2018, in both parks and medians food items contained an average of 32 g of carbohydrate per 100 g of food (Table 8). In comparison, the amounts of proteins and lipids were found to be significantly lower in both years and both site types. In 2016, the average amount of protein per 100 g of food was 5 g in medians, and 4 g in parks; the average amount of lipids was 4 g in both site types. In 2018, the average amount of protein per 100 g of food was 5.5 g in medians and 10 g in parks; the average amount of lipids was 4 g in medians and 7 g in parks (Table 8).

Discussion

Human food waste can serve as an important food resource for animals in urban environments. Although it is sometimes appropriate to simply consider this food waste in terms of the additional calories it provides in urban areas, the nutritional profile of the food is likely important to the animals eating it. In our surveys of the Philadelphia–Camden urban matrix, we found that human food waste is largely increasing availability of carbohydrates. This bias towards one nutrient type could have impacts on the animals’ health and potentially their foraging behavior as they attempt to correct for dietary imbalances.

There are multiple studies highlighting altered nutritional states in animals consuming human food waste, some of which indicate poor health outcomes. In urban-dwelling birds, poor provisioning of developing chicks can lead to lifelong health consequences, as has been described in crows (Tangred and Krock 1999; Heiss, Clark, and McGowan 2009) and sparrows (Meillère et al. 2015). Similarly, urban great tits provision their eggs with fewer fatty acids, known to be important in chick development, than their rural counterparts (Toledo et al. 2016). High levels of carbohydrates have been observed in house sparrows, brown bears and raccoons feeding on human food waste.

Results

Presence of nutrients of urban food waste

Overall, carbohydrates, lipids and proteins were common components of nearly all of the discard foods across both years and site types (Fig. 2; Tables 2 and 3). GLMM results in 2016 suggested that carbohydrate presence could be significantly more common in both parks and medians, and that proteins could have been slightly less common than the other two nutrients in parks. Results in 2018 suggested that carbohydrates and lipids may have been more common in medians, and that in parks proteins may have been significantly more common. It should be noted that in both years all macronutrients were found in over 50% of the food items observed.

Table 1: The amount of unique food items observed in sites across all visits in 2016 and 2018

| Site  | Items | Site  | Items |
|-------|-------|-------|-------|
| 1M    | 1     | 1P    | 2     |
| 2M    | 5     | 2P    | 5     |
| 3M    | 3     | 3P    | 4     |
| 4M    | 3     | 4P    | 3     |
| 5M    | 1     | 5P    | 1     |
| 6M    | 2     | 6P    | 0     |
| 7M    | 2     | 7P    | 2     |
| 8M    | 2     | 8P    | 3     |
| 9M    | 3     | 9P    | 0     |
| 10M   | 5     | 10P   | 0     |
| 11M   | 1     | 11P   | 0     |
| 12M   | 1     | 12P   | 0     |
| 13M   | 2     | 13P   | 0     |
| 2018 Surveys |
| 1M    | 10    | 1P    | 3     |
| 2M    | 4     | 2P    | 4     |
| 3M    | 8     | 3P    | 5     |
| 4M    | 7     | 4P    | 4     |
| 5M    | 3     | 5P    | 5     |

*Number of unique food items (referred to as # Items in table) are shown for each site code in both years.
In raccoons, this has been directly linked to poor health outcomes (Schulte-Hostedde et al. 2018). All of these studies suggest an issue with the nutritional content of food in urban areas. In our study, we found a carbohydrate-biased imbalance in urban areas. Diets high in carbohydrates are already known to lead to potential health problems in humans, such as an increased risk for diabetes (Hu et al. 2001). Although humans may

Figure 2: Occurrences of focal macronutrients in discarded food in (A) road medians in 2016, (B) city parks in 2016, (C) road medians in 2018 and (D) city parks in 2018. A macronutrient was considered present in a food item if contributed any amount to the food item. In these mosaic plots, gray bars represent absences of a macronutrient and purple bars represent presences.

Table 2: Presence of macronutrients (carbohydrates, lipids and proteins) in discarded food waste in 2016*

| Site type | Macronutrient | Percent | Effect | Z       | p         |
|-----------|---------------|---------|--------|---------|-----------|
| Medians   | Carbohydrates | 81.25   | 1.466e+00 | 3.238  | 0.00121 ** |
|           | Lipids        | 65.6    | -8.197e-01 | -1.398  | 0.16203   |
| Parks     | Carbohydrates | 85.0    | 1.7783  | 2.655   | 0.00794 ** |
|           | Lipids        | 55.0    | -1.5813 | -1.990  | 0.04657 *  |

*Results of GLMM are shown.

Table 3: Presence of macronutrients (carbohydrates, lipids and proteins) in discarded food waste in 2018*

| Site type | Macronutrient | Percent | Effect | Z       | p         |
|-----------|---------------|---------|--------|---------|-----------|
| Medians   | Carbohydrates | 78.1    | 1.2801 | 2.770   | 0.0056 ** |
|           | Lipids        | 78.1    | 0.1969 | 0.314   | 0.7537    |
| Parks     | Carbohydrates | 61.9    | 0.5101 | 1.064   | 0.2873    |
|           | Lipids        | 90.5    | 20.4188 | 0.003  | 0.9978    |

*Results of GLMM are shown.
not be a perfect comparison when predicting health outcomes of wildlife, there should be some cause to be concerned about the effect of the trends we observed.

Table 4: Dominance of macronutrients (carbohydrates, lipids and proteins) in discarded food waste in 2016

| Site type | Macronutrient | Percent | Effect | z    | P     |
|-----------|---------------|---------|--------|------|-------|
| Medians   | Carbohydrates | 78.1    | 1.2730 | 2.977| 0.00291** |
|           | Proteins      | 15.6    | -2.7393| -4.398| 1.09e-05*** |
|           | Lipids        | 3.1     | -4.7070| -4.270| 1.95e-05*** |
| Parks     | Carbohydrates | 85.0    | 1.735e+00| 2.770| 0.00561** |
|           | Proteins      | 15.0    | -3.469e+00| -3.917| 8.96e-05*** |
|           | Lipids        | 0.00    | -3.798e+01| 0.000| 1.00000 |

Table 5: Dominance of macronutrients (carbohydrates, lipids and proteins) in discarded food waste in 2018

| Site type | Macronutrient | Percent | Effect | z    | P     |
|-----------|---------------|---------|--------|------|-------|
| Medians   | Carbohydrates | 78.1    | 1.2730 | 2.977| 0.00291** |
|           | Proteins      | 21.9    | -2.546e+00| -4.210| 2.55e-05*** |
|           | Lipids        | 0.00    | -3.610e+01| 0.000| 1.00000 |
| Parks     | Carbohydrates | 57.1    | 0.2877 | 0.652| 0.51414 |
|           | Proteins      | 38.1    | -0.7732| -1.228| 0.21941 |
|           | Lipids        | 4.8     | -3.2834| -2.943| 0.00325** |

Table 4: Dominance of macronutrients (carbohydrates, lipids and proteins) in discarded food waste in 2016

Table 5: Dominance of macronutrients (carbohydrates, lipids and proteins) in discarded food waste in 2018

*Dominance was defined as the nutrient contributing the greatest amount to the total nutrient composition in the food item. Results of GLMM are shown. Asterisks denote significant results.

We conducted two sets of surveys, one in the fall and one in the summer. Although we could not directly compare these surveys, analysis found similar results in both datasets. Still, we
feel that there is potential for seasonality in the availability of anthropogenic food waste that could be revealed by further research. It may be that people change what type of foods they eat outdoors depending on the weather and the temperature. Although more specific work would be needed to verify the actual existence of any trends, the potential for seasonality in food availability raises some interesting questions. How might this seasonality affect animals who are dependent on these food sources? Are the available nutrients appropriate for the animal in that season, or are they in contrast to what the animal would typically be eating? It has already been shown that the additional calories animals gain by foraging on food waste can alter an animal’s normal patterns, such as the case of white storks which have been able to forgo migrating as a result of the additional food provided by landfills (Gilbert et al. 2016). It is also possible to imagine animals altering their foraging patterns in order to meet their nutritional needs. The geometric framework theory predicts, and has shown in the case of animals such as caterpillars (Lee et al. 2002) and locusts (Raubenheimer and Simpson 1993), that animals adjust their feeding patterns in order to meet nutrient goals. In the altered nutritional landscape of an urban area this could result in animals making changes to their behavior in order to meet nutrient goals, or perhaps the environment might be favoring species with nutritional goals more similar to the available food sources. Future studies should consider that there may be more dynamics to consider concerning the ecology of urban-dwelling animals than just counting the calories provided by urban food waste.

Although human activities and development can create environmental gradients within urban areas, our results do not suggest that anthropogenic food waste differs between the areas we studied. In the fall of 2016, we found carbohydrates to be the dominant nutrient type in both parks and medians, which we classify as having differing levels of urban stress. We only found carbohydrate dominance in medians in the summer of 2018, and not in parks. However in both years in both site types, we did see a significant difference in the relative amounts of nutrients that food items contained. The mass of carbohydrates in the food items we found was significantly higher than that of proteins and lipids. Although similar results were seen in both site types, there may be different effects of this carbohydrate-biased diet for animals living in these two site types for animals with more limited foraging ranges. An animal living in a park, for instance, may have more access to more natural sources of food. This could balance out any nutrient imbalances present in the anthropogenic food the animal is consuming. However, carbohydrate biases in road medians may have important consequences for the species that supplement their diets with urban food waste and that cannot travel beyond the median to obtain food. In laboratory caterpillars, Roeder and...
Behmer (2014) showed that carbohydrate-biased diets led to reductions in pupal mass and eclosion rates, fewer eggs and lower population sizes. Further work will be required to determine the consequences of nutrient imbalances in cities for a diversity of animals that feed on urban food waste.

Our study design did not allow us to directly measure the nutritional content of the anthropogenic food waste, and our results are instead based on estimations based on observations. It is theoretically possible that there was no carbohydrate imbalance because the mass of lipid- and protein-rich foods was much greater than that of carbohydrate-rich foods. We feel this is an unlikely, as the average amount of carbohydrates in food items we observed was at least double that of the lipids and proteins combined. Future studies that can more thoroughly quantify anthropogenic food waste would help give a better understanding of the precise nature of the imbalance we observed. Another issue to explore is that non-carbohydrate-dominated foods were consumed more quickly than carbohydrate-dominated foods, and thus were not detected in our surveys. This would potentially create a situation in which an animal’s success in urban environments is influenced by its ability to quickly monopolize new sources of anthropogenic food. However, we do not feel like this is an adequate explanation for our findings, as sites were visited multiple times during two different years. This issue could be better explored by performing experiments in which food sources are left out and monitored to observe the speed of consumption. Overall, we feel that anthropogenic food sources in urban areas are worthy of further examination.

Conclusions

There has not, to our knowledge, been any in-depth examination of the nutritional content of the available food in urban areas, a gap which our research attempts to fill. Although studies have been conducted examining the foraging and nutritional ecologies of specific urban-dwelling species, there has not been a move towards seeing human food waste as anything but a black box—a resource from which urban animals can acquire food, but not something that we can characterize. As long as animals are going to continue to dwell in urban landscapes and consume human food waste it is important to understand how this consumption will affect them. It is unlikely that we can prevent such scavenging, and it is possible that doing so would be to our detriment, as it would send more food waste to landfills. Instead, we need to take steps to understand how our food waste is affecting urban wildlife, and thus shaping the urban ecosystem. This study is a first step towards achieving that goal.

Data availability statement

Data and R scripts used in this study will be deposited in the Dryad Digital Repository.

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