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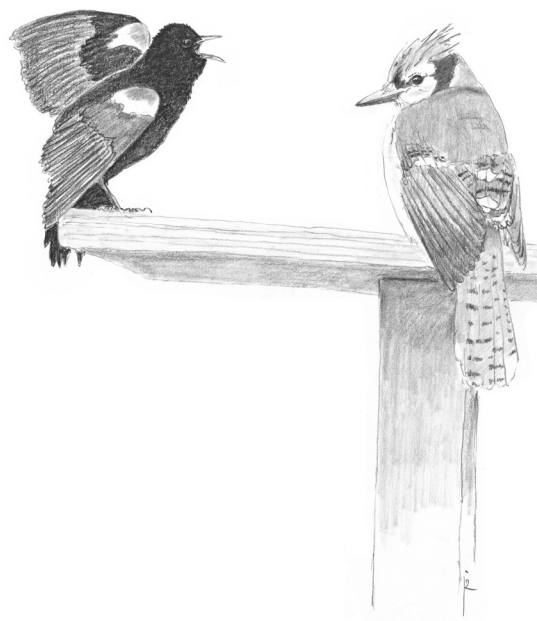
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Short notes

Birds foraging on human-derived foods in suburban areas

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Humans have significantly impacted birds' habits, inducing changes across many aspects of foraging behaviour. Birds eat seeds provided at feeders, help themselves to cattle feed at farms, eat insects smashed on cars, feast on leftovers in the garbage, even swoop in to steal ice cream cones at the beach. These human-provided foods vary from natural to ultra-processed (food made via industrial factories using manufactured ingredients). How much birds eat ultra-processed foods and how exposure to processed foods impacts avian dietary choices, should be investigated. Additionally, most studies on urbanization compare behaviour at extremes of highly urban or highly rural, leaving suburban environments relatively understudied. We therefore investigated wild birds' feeding behaviour at two suburban sites on Long Island, New York: a university campus and a bird sanctuary. We provided unprocessed food (sunflower seeds, milo, millet and cracked corn), minimally processed food (dry-roasted peanuts) and ultra-processed food (peanut butter protein bars). We observed more birds feeding on the unprocessed food at both sites, perhaps implying a preference for natural or familiar foods. Campus birds were observed eating the peanut butter protein bar and roasted peanuts more than sanctuary birds. These results suggest that while birds are more likely to eat natural foods, they also exploit processed and ultra-processed foods. Overall, our study sheds light on how birds forage on human-provided food in suburban areas and offers a guide for future studies combining data from multiple field sites or investigating how foraging behaviour changes over time with exposure to anthropogenic food.

Key words: foraging, avian, processed food, ultra-processed food, urban biology, feeding behaviour

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For birds, the rise of human activity globally has meant a collapse in biodiversity, a shift in species distributions and many evolutionary changes related to morphology (Hudín *et al.* 2016, Benmazouz *et al.* 2023), behaviour (Evans *et al.* 2011, Overington *et al.* 2011) and feeding innovations (Jokimäki *et al.* 2016, Lefebvre 2021, Jokimäki & Kaisanlahti-Jokimäki 2023, Jokimäki & Ramos-Chernenko 2024). One crucial change is dietary, which may be driven in part by the human tendency to feed birds (Jones & James Reynolds 2008, Gatesire *et al.* 2014, Lepczyk *et al.* 2017, Støstad *et al.* 2017, De León *et al.* 2019). For example, bird feeders have exerted such a strong selective pressure on birds that some European passerines have even evolved narrower

beaks specialized to feeder openings (Bosse *et al.* 2017). In addition to providing natural seeds, humans also feed birds unintentionally via garbage. Food from the garbage is likely to be highly processed, i.e. created using industrial processing and combining ingredients from many foods, following the NOVA classification system (Monteiro *et al.* 2010). For example, high fructose corn syrup, a common sweetener in ultra-processed foods, is created in a multistep process including the addition of several enzymes to convert corn starch into glucose, activated carbon filtration and demineralization using ion-exchange resins (Hobbs 2009). This factory-produced ingredient is then combined with other ingredients to create products as

diverse as candy and Burger King chicken sandwiches. In humans, ultra-processed foods are associated with a number of health issues, including cardiovascular diseases, type 2 diabetes and certain cancers (Monteiro *et al.* 2010, Poti *et al.* 2015, Lawrence & Baker 2019, Zhang & Giovannucci 2022, Hall 2023). It is possible that birds that are exposed to ultra-processed foods would eat these foods and develop similar health issues. American Crows *Corvus brachyrhynchos*, for instance, develop high cholesterol when given fast food cheeseburgers (Townsend *et al.* 2019).

Prior examination of avian foraging behaviour and potential preference for processed foods has been inconclusive, even within clades, and focused on urban-rural comparisons rather than on intermediate suburban habitats. For instance, in a study of four species of Darwin's finches (Thraupidae), birds in urban areas preferred human-derived food but birds in non-urban areas did not (De León *et al.* 2019). Conversely, another study on two species of Darwin's finches found that birds with varying exposure to humans did not have an acquired or latent taste for human-derived flavours (Lever *et al.* 2022). Furthermore, prior studies have primarily compared only urban and rural sites; despite rapidly increasing suburban land use globally, few experimental studies have been done in these intermediate environments (Seress & Liker 2015, Mahtta *et al.* 2019, Gao & O'Neill 2020, Miljanović *et al.* 2023). Investigating how birds forage on human-provided foods in suburban areas and whether foraging is shaped by exposure to humans, would improve our understanding of bird diets and foraging behaviours.

We therefore investigated birds' dietary choices of unprocessed, minimally processed and ultra-processed foods in suburban areas and whether foraging behaviour is influenced by how much prior exposure birds have likely had to processed foods. Bird feeding is popular in suburban areas; bird seed and suet may act as a substitute for the lack of natural food sources such as insects following urbanization (Jokimäki & Ramos-Chernenko 2024). We used two nearby sites that varied in how much prior exposure to ultra-processed foods birds experience: a university campus and a bird sanctuary. Campus birds were regularly observed eating processed food from garbage cans, whilst birds at the sanctuary were not. Although sanctuary birds can access human foods outside the sanctuary, they would not have been exposed to ultra-processed foods within the sanctuary. Our study explored the following questions: (1) Do birds eat more unprocessed, minimally processed or ultra-processed food when given a choice?

(2) Is there an association between choice of food types and environments with high or low human presence? (3) Which species make use of human-provided food sources in suburban areas? We predicted that birds would be more likely to eat processed foods at the campus site with more human presence.

Methods

Two study sites on Long Island, New York, USA, were used in this study, one at Adelphi University (40.72°N, 73.65°W) and the other at the Garden City Bird Sanctuary (40.73°N, 73.67°W), separated by 2.7 km. Adelphi's 30-ha campus has a high level of human activity, with 8500 students, faculty and staff, buildings and cars. The 3-ha Garden City Bird Sanctuary, conversely, is only open to the public on weekends in the spring and summer, when it receives approximately fifteen visitors a day and comprises natural forests. It was designated as a sanctuary in 1996, 27 years prior to this study. Sanctuary birds have been fed suet and bird seed mixes, including the one used in this study, but are not exposed to other human-provided foods within the sanctuary. Campus birds have been fed bird seed. The observation period ran for a month, twice a week, in June and July 2023, when temperatures range from 15°C to 26°C and mean monthly rainfall is 8.6 cm. All observations took place on sunny days with temperature around 22°C during observations. Observations were carried out between 7:00 and 12:00.

We measured which food types were chosen from a selection of varying processed foods. Using an existing bird feeder at each site, so that local birds would be familiar with the area as a foraging spot, we created an experimental arena with unprocessed, minimally processed and ultra-processed food (see Table S1 for nutritional details). These feeders were the same design: a pole-mounted feeder with seeds inside a plastic tube cylinder and four perches for birds. We placed food options on the ground one meter away from the feeder. We chose a bird seed mixture containing milo, cracked corn, millet and sunflower seeds (Companion Basic Blend) as our unprocessed option, because this mix is commonly used and attractive to birds from NY. We chose dry-roasted and unsalted peanuts as our minimally processed option, because these peanuts were changed from their natural state by a basic cooking process (heat), but contain only one ingredient (Monteiro *et al.* 2010). We chose a crunchy peanut butter Clif bar as our ultra-processed option since these protein bars are industrially produced, while still mirroring the minimally processed peanuts and being unlikely to harm birds (Monteiro *et al.* 2010). We ripped the peanut butter bar

and crushed the dry roasted peanuts into smaller pieces, to standardize all foods to approximately equal size. Although the bird seed differed from the peanuts and protein bar by not containing legumes, it is still plant-based and all three food types can be eaten by similar bird species, although to differing degrees (Horn *et al.* 2014, Støstad *et al.* 2017).

We placed 40 g of each food type in their respective locations as soon as we arrived at the sites. We alternated where the food was placed to control for location effects. Bird seed was located both inside the existing feeder and directly below it. Birds foraging on bird seed on either the feeder or the ground were counted during scans. We observed birds visiting the arena for a total of ten observation hours on seven different days, five hours at each site, from ten meters away using binoculars. Apart from two days, we carried out observations at both sites on the same day to reduce any weather effects, alternating whether we started at the sanctuary or the campus. Two individuals recorded the number and species of birds on the food choices once every three minutes (i.e. 20 counts per observation period and 10 observation sessions in total). One 'visit' was defined as one bird being present at each food choice at the moment of the scan; this is known as a scan-sample method (Støstad *et al.* 2017). We also recorded every unique visit made to either of the processed food options during the hour observation (nine observation sessions, as one hour had to be excluded for missing data). The largest number of birds recorded during a single scan was 11 individuals, with a mean of 2.55 ± 0.19 (SE) individuals. It was uncommon to observe an individual bird at a food source for multiple scans in a row, so our study did not simply capture one bird sitting on the food for an hour. In fact, 29% of scans had zero birds present at any food type; and if we consider each food type separately, 71% of scans had zero birds present.

In order not to disrupt existing foraging behaviour or disease risk dynamics, we took care to feed birds only at sites where they were already used to congregating and receiving food from humans. We broke up the peanuts and bars into small pieces to reduce the risk of choking. Our experiment complied with the Association for the Study of Animal Behaviour (ASAB) Guidelines for the Treatment of Animals in Research (ASAB Ethical Committee/ABS Animal Care Committee 2023) and Adelphi University's Animal Use Protocol.

STATISTICAL ANALYSIS

All analyses were conducted using R v. 4.3.0 (R Core Team 2023). Figures were created using ggplot2

(Wickham 2016). We tested whether there was an effect of food type and site on the number of birds present on a food type during a scan and whether there was an interaction between these factors. To analyse this, we used a zero-inflated Poisson regression (zeroinfl) from the PSCL package (Zeileis *et al.* 2008, Jackman 2020). This model combines a Poisson with log-link model (for the count data) with a binomial with logit-link model (for the zero-inflation data). The binomial zero-inflated model accounts for both zero-inflation and over-dispersion in the Poisson model. We controlled for date as a fixed effect, because this zero-inflated model does not allow random effects. We removed non-significant interactions (Cohen *et al.* 2013), but otherwise the regressors were the same in both models. We recorded the number of different species present during scans. Species were considered present if at least one bird of that species was present at the food type during the scan, and absent if no individuals from that species were present at the time of the scan. Since this count data was not zero-inflated or over-dispersed, we analysed it using a GLMM Poisson regression model in the lme4 package, controlling for date as a random effect (Bates *et al.* 2015). Significance for this species' presence data was assessed using Satterthwaite's degrees of freedom method from the lmerTest package (Kuznetsova *et al.* 2017). We used a conservative significance cut-off of $P < 0.01$ for all models because of overdispersion in our zero-inflated data.

Results

Birds' foraging behaviour was influenced by both food type and site (interaction: $z = -1.70$, $P = 0.0028$; Figure 1, Table 1). More birds visited our experimental arena at the university campus than at the bird sanctuary (mean number of birds present per scan at campus: 1.10 ± 0.11 (SE), at sanctuary: 0.60 ± 0.09). Birds in both locations were more likely to eat unprocessed food compared to minimally or ultra-processed food (mean number of birds present per scan for bird seed: 2.33 ± 0.18 (SE), dry-roasted peanuts: 0.13 ± 0.03 , protein bars: 0.09 ± 0.02). Birds at the campus location were more likely to forage on the peanuts and protein bar than birds at the sanctuary: sanctuary birds were never observed at the protein bar during a scan.

Eleven different species ate food at our arena, six of which were seen at both sites. In order of abundance, these were House Sparrow *Passer domesticus*, Mourning Dove *Zenaidura macroura*, Brown-headed Cowbird *Molothrus ater*, House Finch *Haemorhous mexicanus*, Blue

Jay *Cyanocitta cristata*, Eastern Wood-pewee *Contopus virens*, Northern Cardinal *Cardinalis cardinalis*, Common Grackle *Quiscalus quiscula*, Red-winged Blackbird *Agelaius phoeniceus*, Common Starling *Sturnus vulgaris* and Song Sparrow *Melospiza melodia* (see Table S2 for more details on species presence). Seven different species were observed eating the

protein bar and eight different species eating the peanuts. The unprocessed food (bird seed) attracted more different species than the peanuts ($z = -10.52$, $P < 0.0001$) or the peanut butter protein bar ($z = -7.51$, $P < 0.0001$). Given their prevalence, our data on foraging behaviour mostly reflects the behaviour of House Sparrows. There were more different species present at the campus than the sanctuary ($z = -2.05$, $P = 0.041$). The bird seed attracted more different species than the peanuts ($z = -10.52$, $P < 0.0001$) or the peanut butter protein bar ($z = -7.51$, $P < 0.0001$).

Discussion

We investigated whether wild suburban birds chose to eat processed or unprocessed food and whether that choice was associated with locations with high and low human presence. Overall, birds ate the unprocessed bird seed more than minimally processed dry-roasted peanuts or ultra-processed peanut butter protein bar. However, birds on the university campus were more likely to forage on processed foods than birds at the sanctuary. Although we did not directly measure exposure to processed foods, we assume that campus birds have had more exposure to these foods than sanctuary birds because of how much more human activity the campus has, including a cafeteria and many accessible garbage cans on campus. Our study suggests that suburban birds, especially the House Sparrow, exhibit behavioural flexibility, becoming more willing to exploit human-derived foods when they have had more

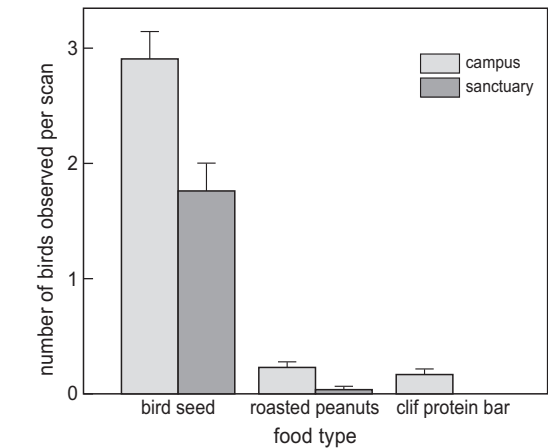


Figure 1. Wild birds ate bird seed more than roasted peanuts or peanut butter protein bars, especially within sanctuaries. Birds at the campus (light grey) foraged on dry-roasted peanuts and peanut butter protein bars more than birds at the sanctuary (dark grey, interaction between site and food type in a zero-inflated Poisson model: $z = -1.70$, $P = 0.0028$). Bars show mean (\pm SE) number of birds observed at each food station during each scan. Based on 200 scans during 10 observation hours.

Table 1. The effect of food type and site on foraging behaviour. Results of zero-inflated Poisson model on how many birds were present on each food type (count data, Poisson model) and whether any birds were present at all on each food source at the three-minute scans (present/absent data, Binomial zero-inflation model). We used a conservative significance cut-off of $P < 0.01$ because of overdispersion in our zero-inflated data. Significant terms are in bold.

	z-value	P-value	95% CI lower	95% CI upper
POISSON MODEL				
Intercept	1.64	<0.0001	1.24	2.05
Peanuts	-2.69	<0.0001	-3.13	-2.26
Clif bar	-2.95	<0.0001	-3.44	-2.46
Site (Sanctuary)	0.08	0.4800	-0.13	0.29
Site (Sanctuary): Peanuts	-1.70	0.0028	-2.78	-0.62
Site (Sanctuary): Clif bar	-0.25	0.9900	-1455	1423
Date	-0.03	0.0250	-0.04	-0.003
BINOMIAL ZERO-INFLATION MODEL				
Intercept	-4.57	<0.0001	-6.44	-2.70
Peanuts	-4.78	0.7800	3975	3971
Clif bar	-5.16	0.8700	1159	1137
Sanctuary	1.60	<0.0001	0.73	2.47
Date	0.11	0.0030	0.04	0.18

exposure to processed foods. House Sparrows, one of the most successful invasive avian species, are known to be especially flexible (Overington *et al.* 2011, Lefebvre 2021, Jokimäki & Ramos-Chernenko 2024). As humans continue to change the foraging landscape for bird species, this behavioural flexibility may become more important (Vardi & Berger-Tal 2022, Biondi *et al.* 2024, but see Evans *et al.* 2011). Although our study is suggestive rather than conclusive due to our small sample size and pseudoreplication, it highlights avenues for future work and collaborations on which species are able to thrive across urbanization gradients and how individual birds might flexibly adjust their behaviour to living alongside humans.

Overall, the birds in our study ate more of the less processed options, eating mostly bird seed, then dry-roasted peanuts and finally the peanut butter protein bar. This finding is similar to Størdard *et al.* (2017), who found that birds chose peanuts over bread or cheese. However, we did find that birds located on a bustling college campus tended to eat more processed foods than birds in a protected sanctuary. This result supports previous studies showing that birds in more urban areas are more likely to forage on human-derived foods, perhaps due to familiarity (De León *et al.* 2019). The birds at the sanctuary site may have avoided the processed foods due to neophobia, or because they did not recognize it as food (De León *et al.* 2019, Miller *et al.* 2022, Vardi & Berger-Tal 2022). This is despite the fact that processed (dry roasted peanuts) and ultra-processed (protein bar) options had higher fat and protein content than the unprocessed bird seed (Table S1). The campus birds engaged more with our experimental foods, as previously shown in urban birds in general (Lepczyk *et al.* 2017, Neate-Clegg *et al.* 2023). This could be due to a variety of reasons, such as the lower exposure the sanctuary birds had to human-provided food or because the sanctuary had more naturally grown food. Our snapshot study could not capture an increasing preference for ultra-processed food, and it is possible that a longitudinal study within individual birds would reveal increasing preferences for processed food. Over time, people also change what kind of foods they place in feeders: for example, in Finland, provisioning of nuts has increased since the 1980s (Deshpande *et al.* 2024). Future research could investigate how birds respond to different food types and how food use shifts over time.

Our study suggests that humans may affect birds' foraging behaviour or reveal existing behavioural flexibility. In the future, as humans continue developing the globe, we expect that many more birds will be

confronted with suburban and urban areas. Species might persist and succeed through innovatively utilizing more human-derived food (Lepczyk *et al.* 2017, Mahtta *et al.* 2019, Neate-Clegg *et al.* 2023, Jokimäki & Ramos-Chernenko 2024). These dietary shifts may have profound impacts on the health (Knutie *et al.* 2019, Townsend *et al.* 2019, Gadau *et al.* 2019), fitness (Heiss *et al.* 2009, Pollock *et al.* 2017) and morphology of birds (Bosse *et al.* 2017, Benmazouz *et al.* 2023). By conducting our experiment in areas where birds were already accustomed to receiving food, we were able to capture how birds are actually using human-provided food (Jones & James Reynolds 2008). Future studies could expand to compare a site with near-zero prior exposure to processed foods (e.g. a remote national park), a suburban site with low contact (e.g. a sanctuary), a suburban site with high contact (e.g. a campus) and an urban site with extreme human contact (e.g. a megacity). While the scope of our straightforward study was relatively small, future studies and collaborations across sites could explore avian dietary variation by observing the foraging behaviour of marked individuals, analyses of differences in microbiomes via faecal sampling, longitudinal experiments on the development of dietary preferences and a larger gradient of human activity.

As a caveat, there is pseudoreplication within our study: we sometimes recorded the same birds making multiple visits, rather than unique birds visiting, and since we worked with unmarked wild birds, we cannot control for this. However, as our question was related to how birds forage on different food types, a larger number of visits would still indicate a greater use of that resource. Another limitation of our study was that we cannot be sure we captured birds' preferences, rather than, for example, how long it takes a bird to eat and digest a particular food source (Underwood *et al.* 2004). Birds may choose foods based on their nutritional content, handling time, digestion time, textures and familiarity, all of which may differ between processed and unprocessed foods. Future studies could attempt to disentangle food preferences from other sources of variation by, for instance, varying whether birds have a choice between options and recording how much a food type is eaten when birds do not have a choice. Studies could also standardize the nutritional content, handling time, and texture of food sources, to remove this source of variation.

We sought to provide a proof of concept for a study design that can be replicated easily at more sites. The main limitation of our study, a low sample size due to having only two sites, restricts how generalizable our

findings are. A future collaboration across many universities in different regions would provide invaluable information on human-induced changes in bird foraging behaviour. Our experiment is cheap, costing only the price of food, can be done by anyone able to identify birds and can be conducted quickly. Interested labs should contact the corresponding author.

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Samenvatting

Mensen hebben een grote invloed op de gewoontes van vogels, waaronder het foerageergedrag. Vogels eten zaden van voertafels, van veevoer op boerderijen, dode insecten van auto's, etensresten in afval en ze stelen zelfs ijsjes van badgasten op stranden. Dit voedsel varieert van natuurlijk tot bestanddelen die een complexe industriële bewerking hebben ondergaan (ultrabewerkt voedsel). Hoeveel vogels ultra bewerkt voedsel eten en hoe blootstelling aan bewerkt voedsel de voedselkeuze van vogels beïnvloedt, is niet bekend. De meeste onderzoeken naar de effecten van verstedelijking op het gedrag van vogels vinden plaats in zeer stedelijke of zeer landelijke gebieden. Randstedelijke gebieden blijven hierdoor onderbelicht. Daarom hebben wij het foerageergedrag van wilde vogels op twee zulke locaties (universiteitscampus en vogelreservaat) op Long Island, New York, onderzocht. Wij boden op beide locaties onbewerkt voedsel (zonnebloempitten, sorghum, gierst en gebroken maïs), minimaal bewerkt voedsel (geroosterde pinda's) en ultra bewerkt voedsel (pindakaas-eiwitrep) aan. We zagen dat op beide locaties meer vogels van het onbewerkte voedsel aten, wat een voorkeur voor natuurlijk of bekend voedsel suggereert. De campusvogels aten meer pindakaas-eiwitrep en geroosterde pinda's dan de vogels in het reservaat. De resultaten suggereren dat de vogels natuurlijk of bekend voedsel prefereren, maar toch ook (ultra) bewerkt voedsel niet schuwen. Ons onderzoek biedt een leidraad voor toekomstig onderzoek naar veranderingen van het foerageergedrag van vogels als er antropogeen voedsel beschikbaar komt.

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SUPPLEMENTARY MATERIAL

Table S1. Ingredients, protein and fat content of food options. Processing level based on NOVA guidelines.

Food	Processing level	Ingredients	Protein (per 100 g)	Fat (per 100 g)
Companion® Wild Basic Bird Mix	Unprocessed	Milo, cracked corn, millet, sunflower seeds	11.5 g	9.0 g
Planters® Dry roasted peanuts	Minimally processed	Peanuts	25.0 g	50.0 g
Clif® crunchy peanut butter protein bar	Ultraprocessed	Rolled oats, brown rice syrup, soy rice crisps (soy protein isolate, rice flour, barley malt extract), tapioca syrup, cane syrup, peanut butter, peanuts, peanut flour, chicory fiber, roasted soybeans, soy flour, natural flavors, salt	16.2 g	11.8 g

Table S2. Species observed during study. We report first the number of scans when a bird of that species was seen at a food option during the moment of the scan. Next, we report the number of individual visits to either of the processed food options (dry roasted peanuts or peanut butter protein bar), which occurred at any point within the observation periods, not just at the moment of the scan. There were too many unique visits to the unprocessed bird seed to accurately record the total number of individual visits.

Species	Total number of scans when present at any food		Total number of individual visits to processed foods	
	Campus	Sanctuary	Campus	Sanctuary
House Sparrow <i>Passer domesticus</i>	72	32	334	13
Mourning Dove <i>Zenaida macroura</i>	51	32	8	5
Brown-headed Cowbird <i>Molothrus ater</i>	13	2	0	0
House Finch <i>Haemorhous mexicanus</i>	4	11	0	9
Blue Jay <i>Cyanocitta cristata</i>	10	1	22	0
Eastern Wood-pewee <i>Contopus virens</i>	0	9	0	0
Northern Cardinal <i>Cardinalis cardinalis</i>	4	3	6	13
Common Grackle <i>Quiscalus quiscula</i>	5	0	7	0
Red-winged Blackbird <i>Agelaius phoeniceus</i>	3	0	1	0
Common Starling <i>Sturnus vulgaris</i>	1	0	0	0
Song Sparrow <i>Melospiza melodia</i>	0	0	2	1