Original Manuscript

AVIAN BIOLOGY RESEARCH

Avian Biology Research
2022, Vol. 0(0) 1–11

DOI: 10.1177/17581559221110107
journals.sagepub.com/home/avb
SAGE

Effects of urban sugar water feeding on bird body condition and avian diseases

Daria A Erastova[1], Josie A Galbraith[2], Kristal E Cain[1], Yolanda van Heezik[3], Ellen A Hume[1,4] and Margaret C Stanley[1]

Abstract

Garden bird sugar water feeding is increasingly popular worldwide, but little is known about its effects on bird health and associated diseases. There is a concern that feeding stations can accumulate pathogens and facilitate pathogen transmission between individuals, resulting in adverse effects on body condition of visiting birds. We tested the effects of sugar water feeding in urban New Zealand backyards by sampling target species for multiple infections and comparing bird body condition. For this, we compared backyards with and without sugar water feeders and again compared existing sugar water feeders with various sugar concentrations in two cities and in two seasons. Birds caught in gardens with sugar water feeders had poorer body condition; however, birds had better body condition in the city with the warmer climate (Auckland), during summer, and in gardens with high (≥20%) sugar concentration in sugar water feeders in winter. All screening tests for *Chlamydia psittaci* and *Salmonella spp.* returned negative results. Avian poxvirus prevalence in tauhou (*Zosterops lateralis*) was four times higher in the city with a warmer climate. The likelihood of lice infection in tauhou was lower in gardens with feeders, in the warmer city, in summer, and at feeders with higher sugar concentrations. In tūī (*Prosthemadera novaeseelandiae*), the likelihood of lice infection decreased with an increase in sugar concentration. Coccidia infection was 4.25 times higher in tauhou in gardens with feeders. Despite the identified risks associated with sugar water feeding, there appear to be potential benefits for native nectarivorous birds, specifically in winter.

Keywords

garden birds, avian diseases, supplementary feeding, urban ecology, nectarivorous species

Introduction

While deliberate wild bird feeding is a popular pastime in urban areas around the world, the impact of this human activity on avian communities remains poorly understood.[1–7] Supplementary food can benefit visiting individuals by mitigating the stress related to food shortage, especially in harsh winters, when a reduction in immunity makes birds more susceptible to disease.[8–10] However, there are concerns that supplementary feeding may lead to negative effects on bird health, such as poor body condition or disease outbreaks.[5,6,11–13]

Urbanization can be associated with an increase in urban bird densities, especially around supplementary feeders, which in turn results in a higher chance of avian parasite transmission and disease outbreaks.[14–22] In particular, more frequent feeder visits can lead to increased transmission of avian viruses and ectoparasites through direct body contact, and gastrointestinal parasites through accumulation of contaminated feces.[4,6,15,22–27] There is also the potential for *Salmonella enterica*, the agent of salmonellosis infection, transmission to humans via bird feeding.[10,21,28] Other infections associated with bird feeding can cause considerable avian mortality leading to downstream impacts on urban ecosystems since birds provide many ecosystem services and feature in human recreational activities.[29–31]

Bread and seed are the most commonly offered supplementary foods,[3,32,33] and the most studied context for examining how supplementary feeding contributes to avian pathogen prevalence.[23,24] Avian diseases in species associated with grain-based feeders include coccidiosis,[34] trichomoniasis,[19,35] mycoplasmal conjunctivitis,[17,36,37] chlamydiosis,[38] and avian poxvirus (Lawson et al., 2014). Meat-based feeders for red kites (*Milvus milvus*) have been linked to a higher prevalence of endoparasites (coccidia and helminths) in birds at feeders, compared to conspecifics consuming primarily wild prey.[25]

Urban sugar water feeding is aimed at providing nectarivorous birds (i.e., species that include flower nectar in their diet) with a sugar water solution as a substitute for natural sources of nectar. Despite its popularity in many countries where nectarivorous bird assemblages are part of urban ecosystems, information on pathogen and parasite

[1]School of Biological Sciences, University of Auckland, Auckland, New Zealand
[2]Auckland War Memorial Museum, Auckland, New Zealand
[3]Department of Zoology, University of Otago, Dunedin, New Zealand
[4]Te Pūnaha Matatini, University of Auckland, Auckland, New Zealand

Corresponding author:
Daria A Erastova, School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland 1142, New Zealand.
Email: dera076@aucklanduni.ac.nz

prevalence associated with sugar water feeding is lacking.[23,39,40] One of the main concerns is that this carbohydrate media is highly suitable for bacterial growth, especially in hot climates or warmer seasons.[41,42] In addition, the low concentrations of sugar solution usually used for bird feeding[43–45] have been shown to stimulate bacterial and yeast growth.[46] Furthermore, when opportunistic species visit sugar water feeders,[43] there is a higher risk of pathogen and parasite transmission to nectarivorous birds and humans.[47,48]

Infection prevalence has been studied in birds at sugar water feeders used as a conservation tool in New Zealand, to support endangered populations in protected natural areas.[42,49] Aspergillosis (a respiratory disease caused by the fungal agent *Aspergillus* sp.), coccidiosis, and salmonellosis were detected in populations of endemic nectarivorous hihi (stitchbird, *Notiomystis cincta*) which used sugar water feeders.[42,50]

Given the increasing popularity of sugar water feeding in New Zealand backyards to attract native bird species—tūī (tui, *Prosthemadera novaeseelandiae*), korimako (New Zealand bellbird, *Anthornis melanura*; absent in Auckland), and tauhou (silvereye, *Zosterops lateralis*)[43]—understanding the disease dynamics in visiting populations and the potential for infection transmission at feeders is essential.[34] Our goal was to identify how supplementary backyard sugar water feeding affects body condition and infection prevalence in birds associated with sugar water feeding in urban areas in New Zealand. We sampled a range of pathogens and parasites identified in previous report for birds at urban bread and seed feeders[47]: *Salmonella* spp. and *Chlamydia psittaci*; avian poxvirus infection; chewing feather lice (Phthiraptera); and coccidia (*Eimeria* spp. and *Isospora* spp.). We determined (1) how sugar water feeder presence and sugar concentration affect body condition and pathogen and parasite prevalence; (2) seasonal and climatic trends in common avian infections dynamics; and (3) risk of *Salmonella* spp. transmission among birds via feeders in urban gardens. We predicted (1) poorer bird body condition in winter when birds are more likely to be susceptible to diseases,[51] but better body condition in gardens with high sugar concentration feeders that may help birds meet their energetic requirements; and (2) higher infection detectability in colder winter months when birds use feeders more often and increased visitations may enhance the likelihood of infection transmission.[43]

Methods

Study sites

We sampled birds in two types of private urban backyards: (1) gardens with existing sugar water feeders (feeding gardens) and (2) gardens with no previous sugar water feeding history (non-feeding gardens). We recruited participating households by word-of-mouth through the study's website (sugarfeederproject.wixsite.com/sugarfeeder) and social media (Facebook and Twitter), mainly targeting scientific research and community conservation organizations. All properties offered for the study (n = 30) were visited before recruitment to assess suitability. Suitability criteria included sufficient vegetation (trees or shrubs) at least 1.5 m high on at least one boundary of the property as a suitable habitat for native birds. Other criteria were lawn/open backyard area of a minimum 20 m^2 for mist netting and property being situated at least 100 m away from any roads with a lot of traffic that could disturb birds. All study properties were at least 500 m apart to reduce the probability of capturing the same residential individuals that are likely to dominate access to feeders (based on.[52]

Gardens with pre-existing feeders. To understand the effects of climate, season, and sugar concentration on avian pathogen and parasite prevalence and body condition, we recruited gardens with feeders that had been in place for a minimum of 3 months in central Dunedin (n = 8) and in central Auckland (n = 8), New Zealand (Figure 1), and sampled them between November 2018 and September 2019. The two cities were chosen as climatic extremes of urban centers in New Zealand. Auckland (36°50′54″S, 174°45′48″E) is the largest city in North Island with a population density of 2400/km^2 in 2020 (New Zealand Census data, www.stats.govt.nz). Auckland has an oceanic, warm temperate climate, with a mean annual temperature of 15.5°C; Tmax = 22.9°C in February and Tmin = 9.5°C in July; and mean annual precipitation of around 1114 mm (https://en.climate-data.org). Dunedin (45°52′27″S, 170°30′13″E) is the second-largest city in South Island with a population density of 420/km^2 in 2020 (New Zealand Census data, www.stats.govt.nz). Dunedin has an oceanic mild temperate climate with a mean annual temperature of 9.7°C; Tmax = 17.7°C in January and Tmin = 2.5°C in July; and mean annual precipitation of around 806 mm (https://en.climate-data.org).

Gardens with no previous feeding history. We sampled birds captured in Auckland gardens with no previous sugar water feeding history before and after installment of feeders (n = 14; Figure 1) between June and November 2019, but only in Auckland. Then we compared results from these gardens before the installing of feeders to results from Auckland gardens with pre-existing feeders only in winter months as low temperatures and seasonal food shortage have been linked to stress-induced immunosuppression in birds.[53] On this basis, we assumed increased detectability of avian infections in colder months.

Avian species sampled

We sampled three native nectarivorous species: tūī, korimako, and tauhou. All species have been previously observed drinking from urban sugar water feeders.[43] We examined each bird for clinical signs of avian poxvirus, sampled for the presence of pathogens or parasites, and assessed its body condition. We additionally sampled one primarily granivorous introduced species, house sparrow (*Passer domesticus*), for avian poxvirus and body condition.

Bird capture and sampling overview

We caught birds via mist netting for sampling in recruited gardens over a total of 30 days. We only processed target species, while non-target species were released without processing (Supplementary 1). In gardens with pre-existing feeders, we conducted pathogen sampling once in summer

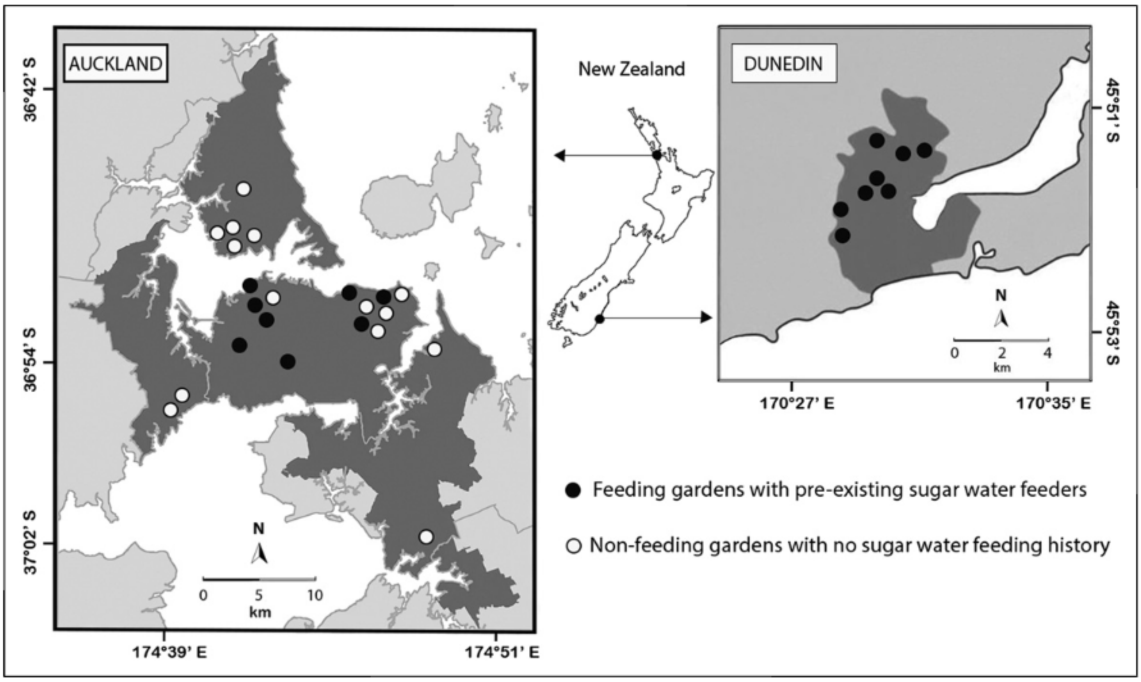

Figure 1. Map of study gardens in Auckland and Dunedin, New Zealand. The urban–rural boundary is shown, with the urban areas shaded in dark gray, and the rural areas shaded in light gray. The white color on the map represents the water. Reference coordinates are expressed as latitude and longitude (WGS84).

(2018/2019) and once in winter (2019) for each garden in Auckland and Dunedin. In Auckland gardens with no previous feeding history, we conducted sampling once in winter (2019).

After extraction from a net, we placed captured birds in cotton holding bags that had been washed with Trigene® (MediChem International, Kent, UK). All individuals were banded with numbered metal bands issued by the New Zealand Department of Conservation Bird Banding Office. We weighed each bird, recorded standard morphometric measurements, and recorded the fat score to assess body condition.

Infection sampling

Salmonella spp. sampling. We sampled target species in Auckland and Dunedin gardens with pre-existing feeders. We took cloacal swab samples using sterile transport swabs and placed them in a clean tube with enrichment growth media for Gram-negative bacteria (Copan, Italy). We also swabbed each sugar water feeder twice: once in winter and once in summer. After swabbing, we immediately placed samples on ice for transportation. We refrigerated all samples at 2–4°C as soon as possible after collection. Samples were sent for laboratory screening within 7 days. All screening was conducted at Gribbles Veterinary Pathology, Auckland or Dunedin, New Zealand. See Supplementary 2 for the full screening method description.

Chlamydia psittaci sampling. We swabbed the conjunctiva, choana, and cloaca of target individuals (in that order) with sterile dry swabs (Copan, Italy). We placed samples in clean plastic tubes (Axygen®). The screening was performed using PCR at Massey Equine Parentage and Animal Genetic Services Centre, Palmerston North, New Zealand. See Supplementary 3 for screening method description.

Avian poxvirus sampling. We visually screened target individuals for signs of avian poxvirus in the form of pox-like lesions indicative of this infection.[54] We defined poxvirus presence as visible skin lumps on feet, toes, around bills, and eye areas (following.[47]

Lice sampling. We examined wing primary and secondary feathers, tail rectrices, and body feathers of target individuals for evidence of avian chewing lice using the visual screening method, the least invasive and the most accurate of all the existing methods.[55]

Coccidia sampling. We screened target individuals for the presence of endoparasite coccidia infection using fecal samples. We used a clean toothpick to scrape fecal samples into a 2 mL Eppendorf® tube either directly from the defecating bird or holding bags. We placed each sample on ice and refrigerated them at 2–4°C as soon as possible after collection. We used the fecal floatation method to assess parasite presence[47]; Supplementary 4).

Body condition

Scaled mass index. We used the scaled mass index (SMI) to assess bird body condition, which corrects mass for body size.[56] The SMI is a better predictor than other condition indices because it accounts for allometric relationships between morphological measurements.[57] To calculate the SMI, we used maximum tarsal length for each target species as this had the strongest correlation with the mass on a log–log scale.[56] The formula for the SMIs calculated for each sampled individual was

$$Mp = Mi\left[\frac{Lo}{Li}\right]^{SMA}$$

where M_i and L_i are the mass and linear body measurement of an individual; L_0 is the sample mean observed for L; SMA is the scaling exponent estimated by the standardized major axis regression of ln (M) on ln (L); and M_p is the predicted body mass for individual i, where the linear body size is scaled to L_0. We calculated the standardized major axis regression slope (for the scaling exponent, SMA) using the software RMA v 1.21.[58] The SMA for house sparrow = 1.72; korimako = 4.38; tauhou = 2.16; and tūī = 2.02.

Fat score. We assessed furculum fat deposits in target individuals using a visual method. Fat is the primary energy reserve in small passerines and indicates overall body condition.[59] We scored the amount of visible subcutaneous fat in the furculum of the clavicle (tracheal pit) as follows: 0 = no visible fat, 1 = furculum <33% full, 2 = furculum 33%–66% full, 3 = furculum filled, 4= outward bulging fat in furculum, and 5 = fat deposits extending over the pectoral muscle (following.[47,59,60]

Statistical analysis

All statistical analyses were performed in R 4.1.0 and results were visualized using the *ggplot2* package.[61]

Auckland gardens in winter. We used a mixed-effects model to test the effect of sugar water feeder presence on each health response variable (body condition, fat score, and infection presence) in the target species. Each full model included the fixed effect of the feeder (present/absent) and the random effect of location (garden ID).

Gardens with pre-existing feeders. We tested the effects of climate, season, and sugar concentration on each health response variable (body condition, fat score, and infection presence) in the target species. Each full model included the fixed effects of climate (Auckland/Dunedin), season (summer/winter), and sugar concentration (ranging in feeding gardens from 3.6% to 25% w/v, as reported by volunteer households), and included all 2- and 3-way interactions. Location (garden ID) was also added as a random effect.

Model selection was done through ANOVA comparison using AIC and chi-square tests to determine the most parsimonious model. The random effect of location was removed where there was zero variance attributed, and the model was over-fitting. In all models, bird identity was not included in the random effects because the recapture rate was negligible (<1%) and we did not sample the same bird twice for the same infection.

For analysis of the response variables of avian poxvirus, lice, and coccidia prevalence (binary response: 0 = not infected and 1 = infected), we used generalized linear mixed-effects models (family = binomial). The models were fitted by maximum likelihood-based on Laplace approximation in the *lme4* package.[62] If the random effect of location (garden ID) was removed from the model, we analyzed it as a generalized linear model (family = binomial) fitted by iteratively reweighted least squares in the *stats* package. For analyzing the SMI response (body condition, continuous variable), we used linear mixed-effects models fitted by restricted maximum likelihood (family = Gaussian) in the *lmerTest* package with t-tests of significance using Satterthwaite's method. If location was removed from the model, we analyzed it as a multiple linear regression model in the *stats* package. To analyze the ordinal response variable of the fat score, we used cumulative link mixed-effects models fitted by Laplace approximation (link = logit) in the *ordinal* package. If location was removed from the model, we analyzed it as a cumulative link model in the same package. To estimate the error for modeled means, the 95% confidence intervals were calculated for significant effects.

We did not model *Chlamydia psittaci* and *Salmonella* spp. data for the tested species as all the sample tests returned negative. For some tests on the effect of city, season, or sugar concentration, we did not include data in the modeling if the obtained sample size was minimal (e.g., fecal samples for some low-capture rate species) or there was no variation in the response variable (e.g., fat score in tūī).

Results

Pathogen prevalence

Over summer 2018/2019, we caught and sampled 86 individual birds (Supplementary 5), primarily tauhou (79%), for the presence of *Salmonella* spp. and *Chlamydia psittaci*. No individuals tested positive for these pathogens. In addition, *Salmonella* spp. was not detected in any of the samples taken directly from feeders (n = 44).

Avian poxvirus infection

Over summer 2018/2019, we caught and inspected 393 individual birds for signs of avian poxvirus (Supplementary 5). No pox-like lesions were detected in captured korimako and tūī; however, the sample sizes for these species were small (n = 11 and n = 25, respectively). Pox-like lesions were detected in house sparrows in Auckland (n = 76 birds sampled) feeding and non-feeding gardens, but not in Dunedin (n = 17 birds sampled).

There was no evidence that avian poxvirus prevalence in tauhou (n = 264 birds sampled) differed in response to sugar water feeder presence (Table 1). For feeding gardens, only the city affected poxvirus prevalence in tauhou (Table 2), with the probability of infection being four times higher in Auckland, the city with the warmer climate. However, the likelihood of testing positive was still very low (Auckland = 0.086 (95% CI: 0.037–0.185); Dunedin = 0.022 (95% CI: 0.005–0.089)).

Feather chewing lice

We sampled three nectarivorous species (n = 272) for the presence of feather chewing lice (Supplementary 5). Feeder status (feeding vs. non-feeding) affected lice prevalence only in tauhou: birds in feeding gardens were 2.25 times less likely to have lice infections (feeding = 0.27 probability, 95% CI:

Table 1. Summary of terms from the most parsimonious models testing the effect of sugar water feeding (feeding vs. non-feeding gardens) on pathogen prevalence and body condition of house sparrow and tauhou in winter in Auckland urban gardens, New Zealand.

Health response variable	Host	MES	Intercept (feeding)			Feeding status		
			ß	SE	p	ß	SE	p
Avian poxvirus	Tauhou	B	**−2.201**	**0.50**	**<0.001*** ***	−1.454	1.18	0.217
Lice	Tauhou	B	**−0.973**	**0.28**	**<0.001*** ***	**1.453**	**0.45**	**0.001** **
Coccidia	Tauhou	B	**−0.661**	**0.31**	**<0.001*** ***	**−1.781**	**0.80**	**0.026***
SMI	House sparrow	N	**24.237**	**1.10**	**<0.001*** ***	**5.711**	**1.39**	**0.006** **
	Tauhou	N	**10.799**	**0.75**	**<0.001*** ***	**3.496**	**0.96**	**0.003** **
Fat score (0–5)	House sparrow	M				1.389	0.86	0.105
	Tauhou	M				0.535	0.63	0.393

Significant parameter estimates are highlighted in bold.
Parameter estimates (β) are presented for each model, with reference levels stated for the intercept in brackets.
p < 0.10; *, p < 0.05; **, p < 0.01; and ***, p <0.001.
Model error structure (MES): B = binomial, M = multinomial, and N = normal.

Table 2. Summary of terms from the most parsimonious models testing the effects of climate (Auckland and Dunedin), season (summer and winter), and sugar concentration on pathogen prevalence and body condition of korimako, house sparrow, tauhou, and tūī in gardens feeding with sugar water, New Zealand. Parameter estimates (β) are presented for each model, with reference levels stated for the intercept in brackets.

Health response variable	Host	MES	Intercept (Auckland, summer)		Concentration		City		Season		Concentration x season	
			ß	SE	ß	SE	ß	SE	ß	SE	ß	SE
Pox	Tauhou	B	**−2.363**	**0.45**			**−1.414**	**0.74**				
Lice	Tauhou	B	−1.041	0.90	**−0.159**	**0.08**	**1.318**	**0.46**	−0.399	1.03	**0.207**	**0.08**
	Tūī	B	**8.490**	**3.77**	**−0.349**	**0.17**	−2.283	1.54				
SMI	Korimako	N	**68.510**	**12.46**	**−2.674**	**0.95**			**−49.325**	**12.91**	**3.356**	**0.97**
	House sparrow	N	**25.087**	**1.33**	0.136	0.08	**−2.639**	**1.17**				
	Tauhou	N	**12.326**	**0.26**			−0.493	0.27	**−0.946**	**0.24**		
	Tūī	N	**144.983**	**11.888**	−0.453	0.75	**−17.721**	**6.75**	−29.457	16.66	2.183	1.10
Fat score (0–4)	House sparrow	M							**−1.984**	**0.78**		
	Tauhou	M			−0.077	0.05	**−1.454**	**0.57**	**−3.247**	**0.80**	**0.147**	**0.05**

Significant parameter estimates are highlighted in bold.
p < 0.10; *, p < 0.05; **, p < 0.01; and ***, p < 0.001.
Health response variable: Pox = Avian pox, Lice = feather chewing lice, SMI = scale mass index. Model error structure (MES): B = binomial, M = multinomial, and N = normal.

0.18–0.40; non-feeding = 0.62 probability, 95% CI: 0.40–0.80; Table 1). In feeding gardens, there was an effect of city on lice infection in tauhou (Table 2): the probability of lice infection was higher in Dunedin than in Auckland (mean probabilities of 0.52 and 0.22, respectively). There was also a significant interaction between sugar concentration and season: the probability of lice infection in tauhou increased in response to increased sugar concentration in winter compared with summer (Figure 2(a)). In tūī, sugar concentration was the only significant factor (Table 2), with the probability of lice prevalence decreasing with increased sugar concentration (Figure 2(b)).

Coccidia

We sampled tūī (n = 14) and tauhou (n = 221) for the presence of coccidia infection (Supplementary 5). Feeder status affected coccidia prevalence only in tauhou: birds in feeding gardens were 4.25 times more likely to have a coccidia infection than those in non-feeding gardens (feeding = 0.34 probability, 95% CI: 0.22–0.49; non-feeding = 0.08 probability, 95% CI: 0.02–0.29; Table 1). In feeding gardens, coccidia prevalence in sampled tauhou was highly variable across seasons and cities, and as such, the models and their explanatory variables (city, season, and sugar concentration) did not significantly explain the data.

Body condition

Scaled mass index. Feeding status affected SMI in house sparrow and tauhou (Table 1 and Figure 3(a) and (b)); both species had lower SMI in gardens with feeders (modeled means for house sparrow: feeding = 24.24, non-feeding = 29.95; for tauhou: feeding = 10.80, non-feeding = 14.29). In gardens with feeders there was a significant effect of city on SMI in house sparrow and tūī (Table 2 and Figure 3(c) and (d)), with SMI being higher in Auckland than Dunedin (modeled means for house sparrow: Auckland = 27.05 and Dunedin = 24.42; for tūī: Auckland =138.98 and Dunedin = 121.26). The season significantly affected tauhou (Figure 3(e)): SMI was higher in summer than in winter (modeled means: summer = 12.06 and winter = 11.12). The interaction between sugar concentration and season was associated with korimako SMI (Table 2 and Figure 3(f)): in winter, increased sugar concentration was associated with increased SMI, with the opposite trend in summer.

Fat score. There was no significant effect of feeder presence on the fat score in feeding versus non-feeding gardens (Table 1). In gardens with feeders, there was no variance in fat scores in korimako and tūī, with all observations scoring 0. Tauhou captured in Auckland gardens were 4.3 times more likely to have one level higher fat score than tauhou in Dunedin (95% CI: 1.4–13.5; Table 2). The seasonal effect was more remarkable: the likelihood of tauhou having one level higher fat score in summer was 25.7 times more (95% CI: 5.3–123.5) than in winter (Table 2). The interactive effect of sugar concentration and the season was significant: for every one-unit increase in sugar water concentration value, individuals were 1.16 times more likely to have one level higher fat score for tauhou in winter than summer. For the house sparrow, the likelihood of capturing a bird with one level higher fat score was 7.2 times higher (CI: 1.6–33.7) in summer, but the sample sizes were too low to detect any other trends.

Discussion

Effects of sugar water feeding

Although sugar water feeders in New Zealand urban gardens were associated with a lower probability of lice infection in tauhou, feeders were also associated with lower SMI and a higher chance of coccidia infection in this species. Unfortunately, the small sample size for tūī and the absence of korimako in Auckland precluded detection of the effects of feeder presence on health response variables in these species. All the *Salmonella* spp. and *Chlamydia psittaci* tests from birds in this study returned negative. Similar research on bread and seed feeding in Auckland detected the presence of *Salmonella* spp. in 1.4% of all tested house sparrows, and *Chlamydia psittaci* in one spotted dove (*Streptopelia chinensis*) found dead at a feeder.[47,63] Our result suggests that sugar water feeding may be safer for birds in terms of pathogen (*Salmonella* spp. and *Chlamydia* spp.) transmission risks than bread and seed feeding. However, it is possible that the sample size was too small, and the applied screening methods were not sensitive enough to reveal the actual abundance of these pathogens.

This is the first study to report avian infections and body condition indices for species associated explicitly with sugar water feeding.[23,39,40] Our finding of higher prevalence of coccidia infection associated with sugar water feeding in one species, tauhou, is likely linked to the clustering of this nectarivorous bird around feeders, which does not happen in non-feeding gardens.

A reduced probability of lice infection in tauhou in gardens with sugar water feeders is not consistent with the results from Galbraith et al.,[47] which showed that house sparrows were more likely to have lice in gardens with bread and seed feeders. There are many factors not measured in our study that could have contributed to lice abundance, such as habitat, nest types used by birds, bird physiology, parasite species virulence and even lice breeding strategies.[64–66] We also showed that the probability of lice infection in tauhou increased in response to increased sugar concentration in winter. Overall, birds used feeders with higher sugar concentrations in winter more often, and were more aggressive than at feeders with lower sugar concentrations (Erastova et al., *unpubl.*). As lice are transmitted from living birds or shed feathers through direct body contact,[55] tauhou congregating in groups at high concentration feeders, along with increased direct aggression, may increase the potential for lice transfer.

Our results indicate that house sparrows and tauhou had lower SMI in gardens with sugar water feeders. This result is consistent with studies on bread and seed feeding that found poorer body condition in house sparrows in gardens with feeders present,[47] and in house finch (*Haemorhous mexicanus*) at sites with higher feeder densities.[67] Galbraith et al.,[47] reported a mixed effect of feeding status and season, with SMI being lower in house sparrows and tauhou in spring than autumn. Aberle[67] found that house finches had to spend more time waiting for their turn in foraging at high-density feeder areas, which, in turn, increased the risk of infection transmission. In contrast, the differences in bird body condition we observed are likely to be dependent on the presence of parasite infections (e.g., increased chance of coccidia infection in feeding gardens which harms bird health) and associated host-parasite interactions[68]; the seasonal factor may also play a role. There was a month time gap in sampling feeding and non-feeding gardens in this study, which may have had a subtle effect on SMI.

While there was no effect of sugar water feeder presence on birds' fat scores in this study, Galbraith et al.,[47] found that tauhou, but not house sparrow, had higher fat scores in gardens with bread and seed feeders. Given that in small passerines the fat repository can significantly vary in size within a short period (a few days or even hours) in response to food availability, ambient temperatures, physiological condition (molt and breeding), and stress,[69–71] SMI appears to be a better body condition predictor.[56,57]

Effects of sugar concentration, city, and season

There were mixed effects of sugar concentration in relation to the season: (1) the probability of lice infection in tauhou increased in response to increased sugar concentration in winter compared to summer; (2) korimako SMI was higher in winter at feeders with higher sugar concentrations but lower in summer; and (3) higher sugar water concentrations were associated with increased fat scores for tauhou in winter compared to summer. Overall, the primary trend was increased body condition indices (SMI, fat score) at high concentration feeders in winter for at least two bird species. The consumption of the higher concentration sugar water likely meets birds' energetic needs more efficiently compared to lower concentration solutions, and this improves body condition.

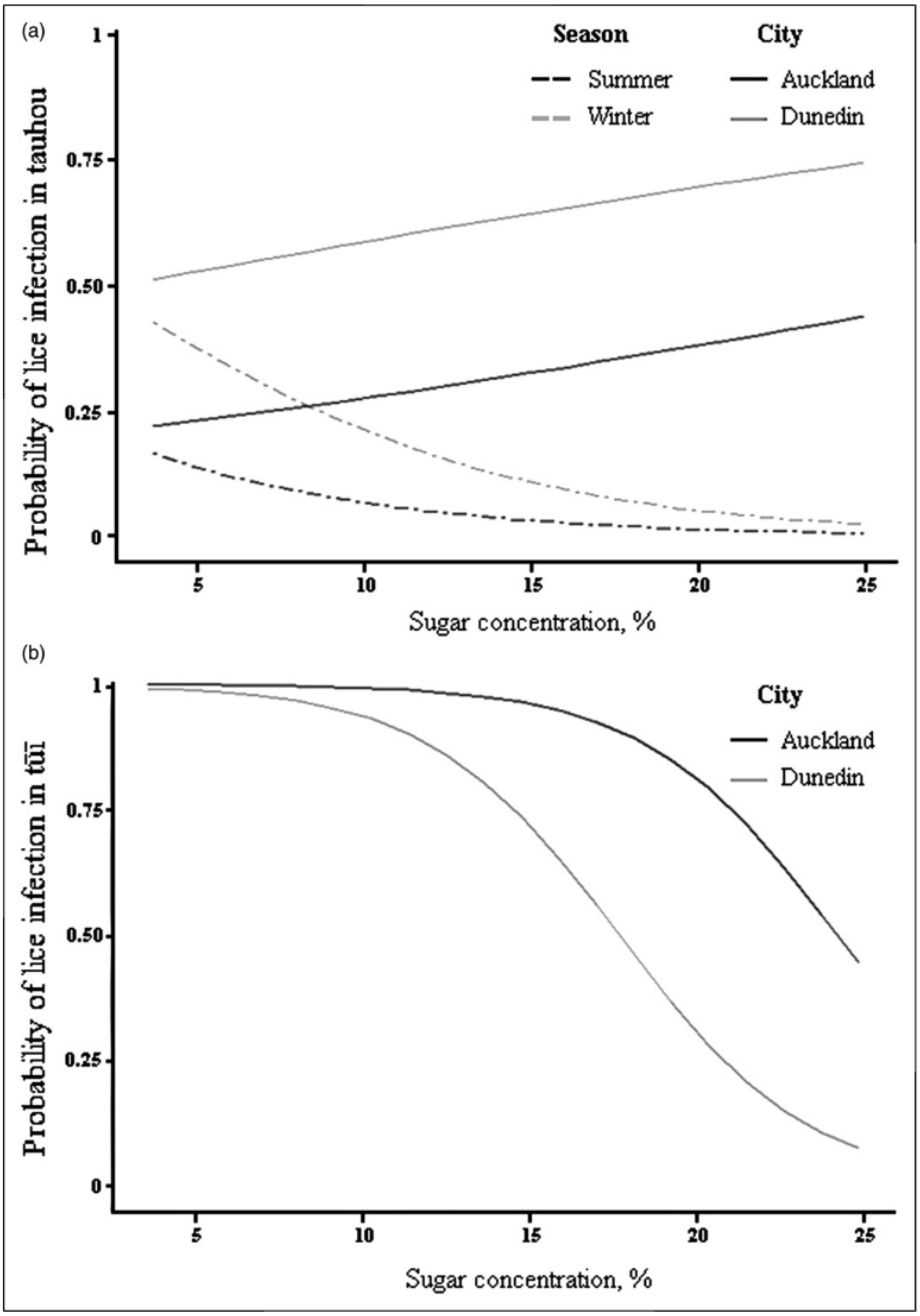

Figure 2. Generalized linear model results for the effects of climate (Auckland and Dunedin), season (summer and winter), and sugar concentration on the probability of feather chewing lice infection in birds at feeding gardens in Dunedin and Auckland, New Zealand. (*A*) Lice presence probability in tauhou. (*B*) Lice presence probability in tūī.

Season affected tauhou's body condition, with both SMI and fat scores being higher in summer than winter. Physiological stress caused by increased energetic requirements at low winter temperatures and seasonal food shortages has been linked to poorer body condition in granivorous birds.[51,72–76] Results from this study suggest that there is a similar trend for at least one urban species in New Zealand, tauhou: poorer body condition in winter when nectar and fruit are generally less available.

City was an important factor associated with feeder effects on parasite prevalence and bird body conditions: (1) the likelihood of detecting pox-like lesions was higher in Auckland, a city with a warmer climate; (2) tauhou had a higher probability of lice infection in Dunedin, a city with a colder climate; (3) house sparrow and tūī had higher SMI in Auckland; and (4) tauhou had a higher fat score in Auckland. Overall, there were lower parasite infections and higher body condition indices in the city with the warmer climate. Studies of granivorous birds associated with bread and seed feeders have found lower parasite prevalence in tropics compared to colder temperate climates.[77–80] Lower parasite loads and a milder climate may contribute to the increased body indices

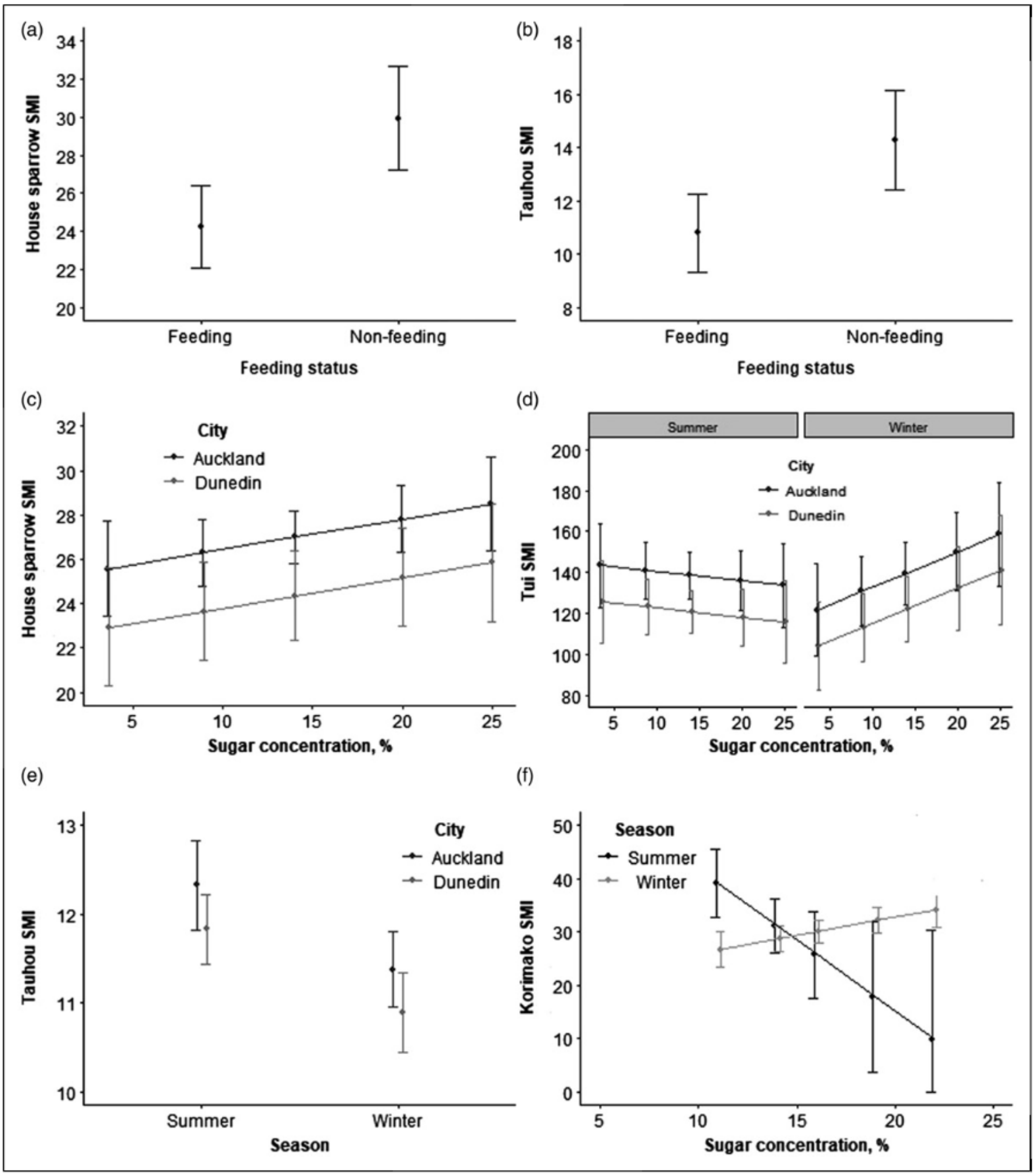

Figure 3. Linear regression and mixed-effects model results for scaled mass index (SMI). A, B in gardens with and without feeders in Auckland in winter; C–F in gardens with feeders in Dunedin and Auckland, New Zealand. (*A*) feeder presence effect on house sparrow SMI; (*B*) feeder presence effect on tauhou SMI; (*C*) sugar concentration x city effect on house sparrow SMI; (*D*) city x season x sugar concentration effect on tūī SMI; (*E*) city x season effect on tauhou SMI; (*F*) season x sugar concentration effect on korimako SMI. Error bars represent 95% confidence intervals.

observed in Auckland birds. It is also possible that other characteristics of the two cities, such as population density, might have affected our results, but these were out of the scope of this study.

Feeders as a source of pathogens

We found no evidence for the presence of *Salmonella* spp. on sugar water feeders themselves. Although some studies have not detected this pathogen on urban bread and seed feeders,[81,82] a New Zealand study (Auckland) showed that up to 7% of sampled feeders were positive for *Salmonella* spp.[16] One of the most common bread and seed feeder visitors in that study was the house sparrow, which also was shown to carry *Salmonella* spp.[47,48] Given that house sparrows use sugar water feeders, this may threaten native nectarivorous species due to the potential transmission of novel diseases or strains from bread and seed feeders to sugar water feeders.[43] However, the low frequency with which house sparrow use the feeders may have contributed to the absence of positive *Salmonella* spp. samples. It is important to note that acute diseases such as salmonellosis often lead to rapid death away from feeders, decreasing the probability of catching an infected individual.[83]

Given this study was conducted in the same city and had a sample size comparable to that of Galbraith et al.,[47] we conclude that the overall risk of *Salmonella* spp. transmission via sugar water feeders is low. However, attention should be paid to the feeder type used for sugar water feeding and its hygiene. The restricted design of some commercially available feeders, aimed at nectarivorous species, prevents feces contamination of the sugar solution and feeder itself.[43] In addition, studies related to the hygiene of urban bread and seed feeders show that there were lower rates of detecting *Salmonella* spp. and coccidia infections at feeding stations where feces accumulation was prevented by regular cleaning.[23,82]

Does sugar water feeding pose a risk to native birds?. Although there was no evidence of highly pathogenic *Salmonella* spp. presence in birds and on sugar water feeders, we found that supplementary sugar water feeding is associated with slightly poorer bird body condition and higher coccidia prevalence in urban New Zealand gardens. Based on this, we conclude that sugar water feeding poses some, although low, risks to native birds' health, and sugar water feeding practices should be used with caution. However, obtaining a large enough sample size of captured individuals poses a problem in monitoring disease dynamics,[84] and unfortunately the larger nectarivorous target species, korimako and tūī, proved very difficult to catch in the urban environment. As a result, the sample size for these species was too low to detect trends in pathogen and parasite prevalence, and the majority of conclusions from this study are made for a single nectarivorous species, tauhou. At the same time, high sugar concentration was associated with better bird body condition in winter.

To mitigate the identified risks, we recommend using specialized sugar water feeders, restricting feeding to cold winter months, regularly cleaning feeders, and always using fresh sugar solutions to prevent the growth of potentially pathogenic microbes.[85]

Future directions

There was no consistency in cleaning methods applied by our participating volunteers to maintain sugar water feeder hygiene (Supplementary 6). We recommend future investigations focusing on cleaning methods to develop a justified guideline for the public to mitigate the risks identified in this study. Additional studies are needed to explore whether sugar water feeding is associated with transmission of pathogens specific to carbohydrate media, for example, *Aspergillus* spp. or other yeasts, and whether generalist sugar water feeder types are more prone to bacteria accumulations than specialized feeders.

Acknowledgments

We are grateful for all the private household volunteers who participated in this survey. We thank Alan Fredy, Alex and Mary Kaliukin, Antoine Filion, Casey Patmore, Cathy Nottingham, Meg Spittal, Rosie Gerolemou, Roisin Normanly, and Sandra Andersen, for help with conducting the fieldwork. The University of Auckland Animal Ethics Committee (approval No. 002100) approved the research.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Forest and Bird [2018 J S Watson Trust fund]; Birds New Zealand [2018 Research Fund]; Centre for Biodiversity and Biosecurity [Project Fund 2018, Publication stipend 2021]; the University of Auckland [University of Auckland Doctoral Scholarship].

Data availability statement

Original datasets are available at: https://doi.org/10.6084/m9.figshare.17291774; and https://doi.org/10.6084/m9.figshare.17291984.

ORCID iDs

Daria A Erastova https://orcid.org/0000-0003-1947-2123
Josie A Galbraith https://orcid.org/0000-0003-3869-7977
Kristal E Cain https://orcid.org/0000-0002-6908-7015
Yolandavan Heezik https://orcid.org/0000-0003-0494-5311
Ellen A Hume https://orcid.org/0000-0001-8287-6433

Supplemental Material

Supplemental material for this article is available online.

References

1. Jones D. *The Birds at My Table. Why We Feed Birds and Why it Matters*. Ithaca, New York: Cornell University, 2018, p. 327.
2. Fischer JD and Miller JR. Direct and indirect effects of anthropogenic bird food on population dynamics of a songbird. *Acta Oecol* 2015; 69: 46–51.
3. Galbraith JA, Beggs JR, Jones DN, et al. Risks and drivers of wild bird feeding in urban areas of New Zealand. *Biol Conserv* 2014; 180: 64–74.
4. Galbraith JA, Beggs JR, Jones DN, et al. Supplementary feeding restructures urban bird communities. *PNAS USA* 2015; 112: E2648–E2657.
5. Jones DN and Reynolds SJ. Feeding birds in our towns and cities: a global research opportunity. *J Avian Biol* 2008; 39: 265–271.
6. Robb GN, McDonald RA, Chamberlain DE, et al. Food for thought: supplementary feeding as a driver of ecological change in avian populations. *Front Ecol Environ* 2008; 6: 476–484.
7. Ishigame G and Baxter GS. Practice and attitudes of suburban and rural dwellers to feeding wild birds in Southeast Queensland, Australia. *Ornithol Sci* 2007; 6: 11–19.
8. Knutie SA. Food supplementation affects gut microbiota and immunological resistance to parasites in a wild bird species. *J Appl Ecol* 2020; 57: 536–547.
9. Chamberlain DE, Vickery JA, Glue DE, et al. Annual and seasonal trends in the use of garden feeders by birds in winter. *Ibis* 2005; 147: 563–575.
10. Brittingham MC and Temple SA. Impacts of supplemental feeding on survival rates of black-capped chickadees. *Ecology* 1988b; 69: 581–589.

11. Lawson B, Robinson RA, Toms MP, et al. Health hazards to wild birds and risk factors associated with anthropogenic food provisioning. *Philos Trans R Soc B* 2018; 373: 20170091.
12. Wilcoxen TE, Horn DJ, Hogan BM, et al. Effects of bird-feeding activities on the health of wild birds. *Conserv Physiol* 2015; 3(1): cov058. DOI: 10.1093/conphys/cov1058
13. Ruffino L, Salo P, Koivisto E, et al. Reproductive responses of birds to experimental food supplementation: a meta-analysis. *Front Zool* 2014; 11: 80.
14. Stephens CRA, McAmmond BM, Van Hamme JD, et al. Analysis of bacterial communities associated with Mountain Chickadees (Poecile gambeli) across urban and rural habitats. *Can J Microbiol* 2021; 67: 572–583.
15. Moyers SC, Adelman JS, Farine DR, et al. Feeder density enhances house finch disease transmission in experimental epidemics. *Philos Trans R Soc B* 2018; 373: 20170090.
16. Galbraith JA, Stanley MC, Jones DN, et al. Experimental feeding regime influences urban bird disease dynamics. *J Avian Biol* 2016; 48: 700–713.
17. Adelman JS, Moyers SC, Farine DR, et al. Feeder use predicts both acquisition and transmission of a contagious pathogen in a North American songbird. *Proc R Soc Lond B Biol Sci* 2015; 282: 20151429. DOI: 10.1098/rspb.2015.1429
18. Lawson B, de Pinna E, Horton RA, et al. Epidemiological evidence that garden birds are a source of human salmonellosis in England and Wales. *PLoS ONE* 2014; 9: e88968.
19. Lawson B, Lachish S, Colvile KM, et al. Emergence of a novel avian pox disease in British tit species. *PLoS ONE* 2012; 7: e40176.
20. Schoener ER. *Gastrointestinal Parasites in Endemic, Native and Introduced New Zealand Passerines with Special Focus on Coccidia*. MSc Thesis. New Zealand: Massey University, 2010.
21. Pennycott TW, Cinderey RN, Park A, et al. Further monitoring for Salmonella species and *Escherichia* coli O86 at a bird table in south-west Scotland. *Vet Rec* 2005; 157: 477–480.
22. Lepczyk CA, Mertig AG and Liu J. Assessing landowner activities related to birds across rural-to-urban landscapes. *Environ Manage* 2004; 33: 110–125.
23. Schaper L, Hutton P and McGraw KJ. Bird-feeder cleaning lowers disease severity in rural but not urban birds. *Sci Rep* 2021; 11: 12835.
24. Aberle MA, Langwig KE, Adelman JS, et al. Effects of bird feeder density on the foraging behaviors of a backyard songbird (the House Finch, *Haemorhous mexicanus*) subject to seasonal disease outbreaks. *Can J Zool* 2020; 98: 611–621. DOI: 10.1139/cjz-2019-0282
25. Blanco G, Cardells J and Garijo-Toledo MM. Supplementary feeding and endoparasites in threatened avian scavengers: coprologic evidence from red kites in their wintering stronghold. *Environ Res* 2017; 155: 22–30.
26. Greig EI, Wood EM and Bonter DN. Winter range expansion of a hummingbird is associated with urbanization and supplementary feeding. *Proc R Soc B* 2017; 284: 20170256.
27. Fuller RA, Warren PH, Armstrong PR, et al. Garden bird feeding predicts the structure of urban avian assemblages. *Divers* 2008; 14: 131–137.
28. Alley MR, Connolly JH, Fenwick SG, et al. An epidemic of salmonellosis caused by *Salmonella Typhimurium* DT160 in wild birds and humans in New Zealand. *N Z Vet J* 2002; 50: 170–176.
29. Clark DN, Darryl JN and Reynolds SJ. Exploring the motivations for garden bird feeding in south-east England. *Ecol* 2019; 24: 26.
30. Cox DTC and Gaston KJ. Urban bird feeding: connecting people with nature. *PLoS ONE* 2016; 11: e0158717.
31. Jones D. An appetite for connection: why we need to understand the effect and value of feeding wild birds. *Emu* 2011; 111: i–vii.
32. Burt SA, Vos CJ, Buijs JA, et al. Nutritional implications of feeding free-living birds in public urban areas. *J Anim Physiol Anim Nutr* 2020; 105: 385–393.
33. Chace JF and Walsh JJ. Urban effects on native avifauna: a review. *Landsc Urban Plan* 2006; 74: 46–69.
34. Robinson RA, Lawson B, Toms MP, et al. Emerging infectious disease leads to rapid population declines of common British birds. *PLoS One* 2010; 5: e12215.
35. Forzán MJ, Vanderstichel R, Melekhovets YF, et al. Trichomoniasis in finches from the Canadian Maritime provinces — An emerging disease. *Can Vet J* 2010; 51: 391–396.
36. Adelman JS, Carter AW, Hopkins WA, et al. Deposition of pathogenic *Mycoplasma gallisepticum* onto bird feeders: host pathology is more important than temperature-driven increases in food intake. *Biol Lett* 2013; 9: 20130594.
37. Dhondt AA, Dhondt KV, Hawley DM, et al. Experimental evidence for transmission of *Mycoplasma gallisepticum* in house finches by fomites. *Avian Pathol* 2007; 36: 205–208.
38. Kaleta EF and Taday EMA. Avian host range of *Chlamydophila* spp. based on isolation, antigen detection and serology. *Avian Pathol* 2003; 32: 435–462.
39. Feliciano LM, Underwood TJ and Aruscavage DF. The effectiveness of bird feeder cleaning methods with and without debris. *Wilson J Ornithol* 2018; 130: 313–320.
40. Pierce RA, II and Denkler S. Attracting hummingbirds to your property. In: *Agricultural Guides*. Columbia: University of Missouri-Columbia Extension, 2016, p. 9419.
41. El Kasmi F, Horvath D and Lahaye T. Microbial effectors and the role of water and sugar in the infection battle ground. *Curr Opin Plant Biol* 2018; 44: 98–107.
42. Alley MR., Castro I and Hunter JEB. Aspergillosis in hihi (*Notiomystis cincta*) on Mokoia Island. *N Z Vet J* 1999; 47: 88–91.
43. Erastova DA, Galbraith JA, Cain KE, et al. Sugar water feeding practices are associated with bird species composition in urban backyards. *J Urban Ecol* 2021; 7: 1–9.
44. Chalcoff VR, Aizen MA and Galetto L. Sugar preferences of the Green-Backed Firecrown hummingbird (*Sephanoides sephanoides*): a field experiment. *The Auck* 2008; 125: 60–66.
45. Fleming PA, Xie S, Napier K, et al. Nectar concentration affects sugar preferences in two Australian honeyeaters and a lorikeet. *Funct Ecol* 2008; 22: 599–605.
46. Mizzi L, Maniscalco D, Gaspari S, et al. Assessing the individual microbial inhibitory capacity of different sugars against pathogens commonly found in food systems. *Lett Appl Microbiol* 2020; 71: 251–258.
47. Galbraith JA, Jones DN, Beggs JR, et al. Urban bird feeders dominated by a few species and individuals. *Front Ecol Evol* 2017; 5: 1–15.
48. Rouffaer LO, Strubbe D, Teyssier A, et al. Effects of urbanization on host-pathogen interactions, using *Yersinia* in house sparrows as a model. *PLoS ONE* 2017; 12: e0189509.

49. Alley MR. Avian wildlife diseases in New Zealand: current issues and achievements. *N Z Vet J* 2002; 50: 118–120.
50. Ewen JG, Thorogood R, Nicol C, et al. *Salmonella Typhimurium* in Hihi, New Zealand. *Emerg Infect Dis* 2007; 13: 788–790.
51. Brittingham MC and Temple SA. Avian disease and winter bird feeding. *The Passenger Pigeon* 1988a; 50: 195–203.
52. Bergquist CAL and Craig JL. Competitive asymmetries, status, and breeding success of tui (Meliphagidae) at an established feeding station. *New Zealand J Zoolog* 1988; 15: 369–380.
53. Owen JC, Landwerlen HR, Dupuis AP, II, et al. Reservoir hosts experiencing food stress alter transmission dynamics for a zoonotic pathogen. *Proc R Soc B* 2021; 288: 20210881.
54. Lachish S, Lawson B, Cunningham AA, et al. Epidemiology of the emergent disease Paridae pox in an intensively studied wild bird population. *PLoS ONE* 2012; 7: e38316.
55. Clayton DH and Drown DM. Critical evaluation of five methods for quantifying chewing lice (Insecta: Phthiraptera). *J Parasitol Res* 2001; 87: 1291–1300.
56. Peig J and Green AJ. New perspectives for estimating body condition from mass/length data: the scaled mass index as an alternative method. *Oikos* 2009; 118: 1883–1891.
57. Peig J and Green AJ. The paradigm of body condition: a critical reappraisal of current methods based on mass and length. *Funct Ecol* 2010; 24: 1323–1332.
58. Bohanak A and van der Linde K. RMA: software for reduced major axis regression, Java version, http://kimvdlinde.com/professional/rma.html (2004, accessed 21 September 2021).
59. Gosler AG. Environmental and social determinants of winter fat storage in the great tit. *Parus Major. J Anim Ecol* 1996; 65: 1–17.
60. Hartup BK, Bickal JM, Dhondt AA, et al. Dynamics of conjunctivitis and *Mycoplasma gallisepticum* infections in house finches. *The Auk* 2001; 118: 327–333.
61. Wickham H. *ggplot2* – Elegant graphics for data analysis (2nd edition). *J Stat Softw* 2017: 77. DOI: 10.18637/jss.v077.b02
62. Bates D, Maechler M, Bolker B, et al. *lme4*: linear mixed-effects models using Eigen and S4. *R Package Version 1.1-5*. https://cran.r-project.org/package=lme4. (2014, accessed 21 September 2021).
63. Galbraith JA. *Ecological Impacts of Supplementary Feeding on Urban Bird Communities in New Zealand*, PhD Thesis. New Zealand: the University of Auckland, 2016.
64. Byrd FN. *Effects of Urbanization on Arthropod Communities in Carolina Wren (Thryothorus ludovicianus) Nests: A Comparative Study between Urban and Rural Habitats in Walker County, Texas*. M.Sc Thesis. US: Sam Houston State University, 2019.
65. Janiga M. Different coevolutionary breeding strategies of Ischnoceran lice on *Prunella collaris* and *P. modularis* in High Mountains. *Pol J Ecol* 2018; 66: 182–193.
66. Clayton DH and Tompkins DM. Ectoparasite virulence is linked to mode of transmission. *Proc R Soc B* 1994; 256: 211–217. DOI: 10.1098/rspb.1994.0072
67. Aberle MA. *Effects of Bird Feeder Density on the Behavior and Ecology of a Feeder-dependent Songbird: Patterns and Implications for Disease Transmission*. M.Sc Thesis. US: Virginia Polytechnic Institute and State University, 2018.
68. Minias P. Contrasting patterns of *Campylobacter* and *Salmonella* distribution in wild birds: a comparative analysis. *J Avian Biol* 2020; 51: jav.02426. DOI: 10.1111/jav.02426
69. Bergstrom BJ, Johnson MD, Harris JC, et al. Effects of habitat, season, and age on winter fat storage by migrant and resident birds in Jamaica. *J Field Ornithol* 2019; 90: 162–175.
70. Rojas TN, Vergara-Tabares DL, Valdez DJ, et al. Food supplementation by an invasive fleshy-fruited shrub sustains body condition of a native frugivorous bird during winter. *Integr Zool* 2019; 14: 259–269.
71. Bonier F, Martin PR, Small TW, et al. Energetic costs and strategies of post juvenal molt in an Equatorial birds, the Rufous-collared Sparrow (*Zonotrichia capensis*). *Ornitol Neotrop* 2018; 29: S19–S28.
72. Arne P, Risco-Castillo V, Jouvion G, et al. Aspergillosis in Wild Birds. *J Fungi* 2021; 7: 241.
73. Tryjanowski P, Pape Møller A, Morelli F, et al. Food preferences by birds using bird-feeders in winter: a large-scale experiment. *Avian Res* 2018; 9: 16.
74. Hosseini PR, Dhondt AA and Dobson A. Seasonality and wildlife disease: how seasonal birth, aggregation and variation in immunity affect the dynamics of *Mycoplasma gallisepticum* in house finches. *Proc R Soc B* 2004; 271: 2569–2577.
75. Pravosudov VV, Kitaysky AS, Wingfield JC, et al.. Long-term unpredictable foraging conditions and physiological stress response in Mountain Chickadees (*Poecile gambeli*). *Gen Comp Endocrinol* 2001; 123: 324–331.
76. Brittingham MC and Temple SA. A survey of avian mortality at winter feeders. *Wildl Soc Bull* 1986; 14: 445–450.
77. Legault S, Wittische J, Cusson M, et al. Landscape-scale population connectivity in two parasitoid species associated with the spruce budworm: testing the birdfeeder effect using genetic data. *Mol Ecol* 2021; 30: 5658–5673. DOI: 10.1111/mec.16160
78. Clark NJ, Drovetski SV and Voelker G. Robust geographical determinants of infection prevalence and a contrasting latitudinal diversity gradient for haemosporidian parasites in Western palearctic birds. *Mol Ecol* 2020; 29: 3131–3143.
79. Soares L, Latta SC and Ricklefs RE. Neotropical migratory and resident birds occurring in sympatry during winter have distinct haemosporidian parasite assemblages. *J Biogeogr* 2019; 47: 748–759.
80. Martin LB, Pless MI and Wikelski MC. Greater seasonal variation in blood and ectoparasite infections in a temperate than a tropical population of house sparrows passer domesticus in North America. *Ibis* 2007; 149: 419–423.
81. Frątczak M, Indykiewicz P, Dulisz B, et al. Lack of evidence that bird feeders are a source of salmonellosis during winter in Poland. *Animals* 2021; 11: 1831.
82. Prescott JF, Hunter DB and Campbell GD. Hygiene at winter bird feeders in a southwestern Ontario city. *Can Vet J* 2000; 41: 695–698.
83. Brittingham MC, Temple SA and Duncan RM. A survey of the prevalence of selected bacteria in wild birds. *J Wildl Dis* 1988; 24: 299–307.
84. Jovani R and Tella JL. Parasite prevalence and sample size: misconceptions and solutions. *Trends Parasitol* 2006; 22: 214–218.
85. Lee C, Tell LA, Hilfer T, et al. Microbial communities in hummingbird feeders are distinct from floral nectar and influenced by bird visitation. *Proc R Soc B* 2019; 286: 20182295.