


Sugar water feeding practices are associated with bird species composition in urban backyards

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Submitted: 18 January 2021; Received (in revised form): 10 June 2021. Accepted: 12 June 2021

Abstract

Feeding backyard birds with sugar water is increasingly popular in urban areas, but it has poorly understood effects on bird assemblages. In New Zealand, ca. 20% of households engaged in feeding wild birds use sugar water, often in an attempt to attract native, nectarivorous birds. Developing best practices for sugar water feeding could be a powerful tool for attracting these species in urban areas. However, it is currently unclear whether these feeders actually support native species, and, if so, which feeding practices are most effective in increasing visitation. We surveyed New Zealanders who provide sugar water to birds about their feeding practices via an online questionnaire. The aim of our research was to understand existing practices and their effect on attracting native species, as well as the motivations and social factors behind urban sugar water bird feeding. Our results show that this practice is popular throughout the country with the majority of households successful in attracting native nectarivorous species to their gardens. Sugar water feeder type had the largest effect on reported species richness at feeders in comparison to other factors (e.g. sugar concentration). Feeders specifically designed for nectarivorous birds, namely the Tui Nectar Feeder™, are more successful at attracting natives in comparison to other commonly used feeder types. Thus, individual householder decisions around feeder use can have important consequences for bird species composition in urban gardens. Future research is needed to understand the consequences of sugar water feeding for bird communities and individual bird health.

Key words: avian ecology, garden birds, human–wildlife interaction, supplementary feeding, urban ecology

Introduction

Backyard bird feeding has become a popular activity over the past few decades (Robb et al. 2008). Almost half of households in the USA feed birds on a regular basis (Martinson and Flashpolder 2003; Rogers 2002), while in the UK, as many as 75% of households engage in this practice (Davies et al. 2012; Goddard et al. 2013). Despite its growing popularity and some evidence of benefits for urban bird communities, such as higher winter survival rates, population densities, breeding success and even improved health (Crick et al. 2002; Bonnington et al.

2014; Wilcoxon et al. 2015), there are a number of concerns associated with bird feeding. Large numbers of birds present at a feeder could enhance disease transmission if feeding stations serve as bird pathogen reservoirs (Dhondt et al. 2007; Blanco et al. 2017; Galbraith et al. 2017). Supplementary food can also lead to imbalances in birds' diets (Nicolson and Fleming 2003b; Schaefer et al. 2003). Other authors have suggested that dependency on supplementary food and risk of predation are additional potential costs for small birds (Nyffeler et al. 2017; Carr and Golinski 2021). However, other studies failed to find similar relationships (Dunn and Tessaglia 1994; Ballantyne and Hughes

2006; Jones 2018). Unsurprisingly, this conflicting evidence leads to opposing stances towards bird feeding. For example, in some Australian states, wildlife and conservation agencies strongly discourage all forms of wildlife feeding (Seipen and Stanley 1996; Petrie et al. 2003). In contrast, many Northern European and American organisations actively promote urban wildlife feeding as a conservation activity (Jones and Reynolds, 2008). This inconsistency in attitudes is probably due to some feeding practices being harmful, while others are helpful.

Research has mainly focused on bread and seed feeding rather than sugar water feeding, probably because bread and seed is the most common food provided for granivorous species, which are common natives in the North America and Europe (Cowie and Hinsley 1988; Orams 2002; Rollinson et al. 2003; Chace and Walsh 2006; Galbraith et al. 2014). For example, householders in the USA and the UK purchase 500 000 tonnes of birdseed annually (O’Leary and Jones 2006) and mixed seed is the number one food provided by householders in Canada (Prescott et al. 2000). However, in USA and Canada, 73% of survey participants from both urban and rural areas provide sugar water as well as seeds (Horn and Johansen 2013), primarily to support/attract hummingbirds (Trochilidae; Graves 2013; Sonne et al. 2016; Greig et al. 2017). Data on sugar water feeding practices are scarce, and the effects of different aspects of the practices are still greatly understudied worldwide. A recent study exploring the effect of presence of nectar feeders in a rural area revealed important differences in behavioural patterns in hummingbirds (Nuñez-Rosas and Arizmendi 2019). However, despite the popularity of hummingbird feeders, the advantages and disadvantages of supplementary sugar water feeding have rarely been explored (Bandivadekar et al. 2018). One of the few studies to do so found the presence of sugar water feeders in Cape Town (South Africa) gardens increased both the diversity and the abundance of nectarivorous birds compared to gardens without feeders (Coetzee et al. 2018). Another South African study showed that sugar concentration, total duration of feeding and frequency of feeding did not affect bird species diversity, but the presence of feeders increased breeding success in sunbirds and sugarbirds (Coetzee et al. 2021). In Australia, despite the abundance of nectarivorous honeyeaters, recent studies have been limited to controlled laboratory experiments on bird preferences for sugar types or concentrations (Downs 1997; Fleming et al. 2008; Napier et al. 2013), or the effects of various sugar concentrations on metabolism and foraging rates (Mitchell and Paton 1990; Armstrong 1992; Nicolson and Fleming 2003a). The effects on Australian species assemblages and behaviour are unknown.

In New Zealand, about half of households feed birds in residential gardens; most people feed bread and seed, consistent with practices elsewhere, but almost 20% provide sugar water (Galbraith et al. 2014). The New Zealand ecological context differs from many other countries because of the high proportion of introduced bird species within avifaunal communities (nationally 41 species, or 16.5% of all species; Duncan, Blackburn, and Cassey 2006; Sol and Lefebvre 2000). This is of particular concern in urban areas, where introduced birds are often the majority of both species richness and abundance (van Heezik et al. 2008; Heggie-Gracie et al. 2020). Furthermore, most of these introduced species are granivorous or omnivorous. In contrast, several of the native and endemic birds are nectar feeding, and none are primarily granivorous (Gill et al. 2010). Sugar water feeding could be used as a tool to enhance endemic honeyeater populations, such as tūi (*Prosthemadera novaeseelandiae*) and korimako (bellbird, *Anthornis melanura*), and the native omnivorous

tauhō (silveryeye, *Zosterops lateralis*). All of these species are tolerant to urbanisation to some extent due to the adaptations in breeding behaviour, the ability to travel long distances in search for scarce food sources and feeding on nectar of introduced plant species (Heggie-Gracie et al. 2020; Palacio 2020; van Heezik and Hight 2017). Recent work has shown that the predominant feeding practices using bread and seed have negative impacts on native New Zealand urban bird communities, by increasing the number of introduced birds in the area and negatively affecting the abundance of at least one endemic bird species (Galbraith et al. 2015, 2017). Galbraith et al. (2014) suggested that sugar water might serve as a feeding alternative because it specifically benefits native species, and may help birds to survive during the austral winter when natural food is scarce (Gravatt 1970; Craig et al. 1981; Galbraith et al. 2014).

Given the increasing popularity of attracting birds to backyards via sugar water feeders, and the potential of using feeders as a conservation tool, it is important to understand the impact of sugar feeders on urban ecology (Shaw et al. 2008; Jones 2011; Reynolds et al. 2017). Little is known about how various aspects of this practice might affect birds and there are concerns that it could result in behavioural changes and jeopardise bird health. Detailed knowledge of sugar feeding practices would help identify risks and potential directions for research. Hence, the goal of this first study of urban sugar water feeding practices was to understand the diversity of practices employed in New Zealand and their effect on native urban birds. We used a questionnaire to survey households throughout New Zealand about their current feeding practices and determine the extent to which sugar water feeding could be useful as a conservation strategy directed at native species. Specifically, we aimed to determine: (i) the most prevalent feeding practices; (ii) the effectiveness of different individual feeding choices in attracting native bird species into urban gardens; and (iii) the motivations of respondents feeding birds sugar water.

Methods

Survey method

An online questionnaire was developed using Survey Monkey (www.surveymonkey.com) and opened for responses from 11 October to 26 November 2018. Any individual who lived in New Zealand and was over 16 years of age was able to participate. The invitation to participate in a sugar water feeding survey was disseminated through social media (targeted Facebook bird groups and Twitter followers), printed flyers disseminated at garden shops and Auckland Botanical garden, networks and organisations involved in scientific research, bird, community conservation and nature NGOs and/or conservation (e.g. University of Auckland, University of Otago, Manaaki Whenua—Landcare Research, Department of Conservation, Forest & Bird, Birds New Zealand), word-of-mouth, and the study’s website (sugarfeederproject.wixsite.com/sugarfeeder). An accompanying letter informed participants of the study’s purpose and highlighted the importance of participating. A prize draw (NZD\$100 voucher) was used as an incentive for participation. Participants were self-selected and likely biased toward those that feed sugar water to birds in their backyard and/or individuals with an interest in wildlife, biodiversity and conservation. However, it is understanding the behaviour of enthusiasts in particular which is most critical, as it is their activities and attitudes which are likely to have the proportionally largest

impact on native bird species. Overall, almost a thousand people responded ($N=990$).

Questionnaire

The survey consisted of a questionnaire with 25 questions, including whether or not people fed birds with sugar water, the feeder types they used, the frequency of sugar water provisioning, sugar concentrations, and cleaning method and frequency, as well as motivations to feed (Erastova et al. 2010; Supplementary Table A1). We also asked which birds visited participants' feeders, which bird species participants would like to attract, and some demographic information. To minimise misidentification by respondents, some of the questions were accompanied by images of bird species and feeder type (Supplementary Figs. A1 and A2). Most responses were categorical options; however, the question why people feed sugar water was open-ended. The survey took approximately 10 min to complete. Although other factors may also influence bird communities (e.g. garden size, distance from bush patches), we restricted our questions to those we deemed more important to our primary question to keep the survey short and maximise participation.

Data treatment and selection

Incomplete surveys were not included in our data analysis. We also removed responses that had IP addresses originating from outside of New Zealand ($n=6$). To classify open-ended questions, we assigned each response a particular theme category following Galbraith et al. (2014) (with some modifications, Supplementary Table A2). The majority of responses concerning reasons why householders used a particular cleaning method were straightforward, and we placed them into three categories: benefits for people (personal convenience, personal hygiene), benefits for birds (bird safety, hygiene efficiency) and other reasons (common sense, follow advice, no reason; Supplementary Table A2.1). The responses on motivations to feed were more ambiguous and in most of the cases included more than one theme. We divided all motivation open-end responses into three categories: benefits for birds (includes aiding survival and population growth, providing additional food source, conservation), benefits for people (includes pleasure, birdwatching, photography, education) and ecological benefits (includes attracting birds to control pest insects; Supplementary Table A2.2).

A possible source of bias in our dataset was the potential for people to report large and conspicuous birds at their feeders, such as tūi, more often than smaller birds, which are more difficult to identify. Given the potential bias, we created a binomial response variable 'presence of native birds at the feeders'. Then we called such presence a successful attraction (regardless of species type) and compared it to all the observed at the feeders species, including introduced ones. Prior to analysis, we excluded all the observations with missing or multiple values (e.g. more than one feeder at the property in order to estimate the effect of specific feeder types, $N=603$). For socio-demographic analyses we excluded observations with no responses. In total, we analysed 387 individual questionnaire responses.

Our dataset included several variables with multiple categories, which we described as follows: (i) Feeder types popular and/or available in New Zealand (Supplementary Fig. A2): the Tui Nectar Feeder™ (as the most commonly used type it was chosen as the reference feeder for analyses), rodent water feeder, Topflite Nectar Nutra feeder™, commercial bottle feeder, open dish feeder, bird water dispenser, self-constructed

feeder; (ii) sugar concentration: low (less than one cup of sugar per litre of water), medium (one cup) and high (two or more cups); (iii) duration of feeding: <6, 6–12 and >12 months; and (iv) presence of vegetation planted by householder for birds (presence/absence).

For the analysis of socio-demographic factors, we divided sugar water feeder types into two groups: (i) specific or designed for nectarivorous species and (ii) generic or those that might be more inclusive for introduced birds. For the analysis, we chose the two most commonly used feeder types representing both groups: the Tui Nectar Feeder™ (reference level) and the open dish. We tested the following independent variables as factors: (i) gender: male, female, (ii) income (NZ\$): <60K, 60–100K, <150K; (iii) age: 16–29, 30–60, >60; (iv) education: high school, specialist diploma, graduate diploma; and (v) involvement in conservation-related field: involved, not involved.

Statistical analysis

We used Bayesian Multilevel Modelling (BMM) to understand the probability of success of various feeding choices in attracting native bird species, as well as the effect of selected socio-demographic factors in influencing feeder-type selection. BMM was chosen to allow better flexibility when dealing with categorical response variables and better estimation of the effect size. Analyses were conducted in R 3.6.2 (R Development Core Team 2019). Each model was built with priors obtained from the *get prior* function in brms package (Bürkner 2017) and with four chains of 4000 iterations (2000 for warmup, 2000 for sampling). First, we built a set of models to test each independent variable separately. If a variable had confidence intervals that did not include zero we considered it as significant, otherwise the variable was removed from further analysis. Second, we combined all significant variables into more complex models and used model averaging (pseudo-BMA weighting and stacking criterion) to determine which model best explained the variation of our response variable. We checked that every variable in the model converged using the RHAT indicator (at convergence, RHAT is equal to 1). Furthermore, to investigate a possible effect of latitudinal gradient caused by considerable variation in climate across New Zealand islands, especially winter low temperatures, on the proportion of native species at feeders, we included latitude (continuum of coordinates) as a fixed effect in our model.

Results

Survey response

Overall, 566 (57%) participants from a total 990 responses from 100 New Zealand towns and cities (Fig. 1) confirmed they fed sugar water to wild birds. The most common respondent who fed sugar water to birds was female (64%) New Zealand European (91%), aged 50–69 years (45%), with a tertiary-level qualification (56%; Supplementary Table A3). Given the respondents were self-selected, we report results but do not provide inferences regarding demographic groups or locality.

Prevalent sugar water feeding practices

Of those respondents who fed sugar water the majority had done so for more than a year and had only one feeder at the time of the survey. The most popular feeder types were the Tui Nectar Feeder™ (33% of respondents), open dish (29%) and commercial bottle feeder (25%; Supplementary Table A4). Most participants used either half (41%) or one cup (32%) of sugar per litre of water

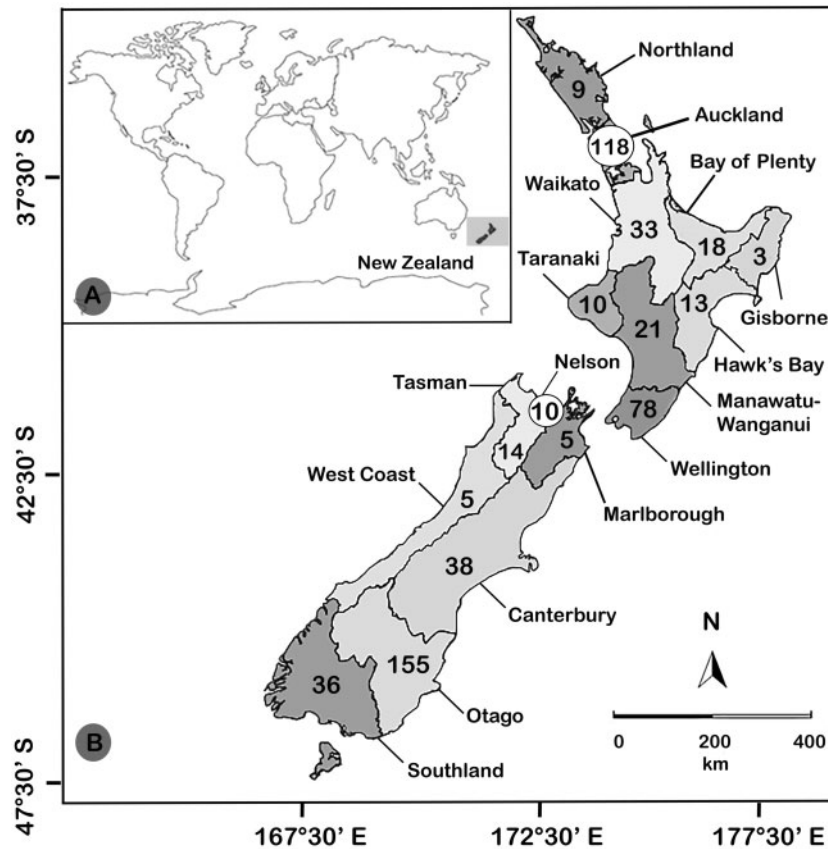


Figure 1: A, New Zealand on the world map. B, Response map from 2018 online survey investigating urban sugar water feeding practices in New Zealand. Numbers are the number of responses from each given region.

(Supplementary Table A4). Most respondents (82%) did not add any extras to their sugar water; of those who did the most common additive was food colouring (12% of all respondents). Most of the respondents cleaned their feeders every 2–3 days (29%) or weekly (25%) using hot water and/or a scrubbing brush (Supplementary Table A4). Personal convenience (35%) and bird safety (34%) were the most commonly cited reasons for cleaning method choices (Supplementary Table A2.1). Also, most of the respondents had planted vegetation (73%) and about half offered supplementary fruit (50%) and a water bath (48%) in order to attract birds into their garden (Supplementary Table A4). Respondents were mainly interested in attracting native and/or endemic species into their gardens: tūi, tauhou and korimako. However, 30.3% had no preferences regarding native vs. introduced species. The species that were the most often observed consuming sugar water were tūi (85% of all responses) and tauhou (70%), followed by korimako (47%), and house sparrow (*Passer domesticus*; 34%), a primarily granivorous bird (Supplementary Table A4). Other birds observed at feeders included native species such as kākā (*Nestor meridionalis*; 4%), kererū (New Zealand pigeon, *Hemiphaga novaeseelandiae*; 3%), kākāriki (*Cyanoramphus* sp.; 1%) and introduced species such as common starling (*Sturnus vulgaris*; 7%), common myna (*Acridotheres tristis*; 2%) and eastern rosella (*Platycercus eximius*; 1%).

The effectiveness of different feeders in attracting native bird species

The best model explaining variation in observations of native species visiting feeders was the one, comprising feeder type and

latitude (stacking weight: 0.878, pseudo-BMA weight: 0.861), when compared to the individual effect of those variables alone (Table 1). Feeder types designed for nectar feeding birds that were functionally similar to the reference Tui Nectar Feeder™ did not differ significantly in attracting native bird species (Fig. 2). However, generalist feeder types had significantly lower native bird sighting rates compared to the overall pool of observed species (Fig. 2). There was no other significant effect of the other tested variables, such as sugar concentration, duration of feeding, and presence of garden vegetation (Table 2, Supplementary Table A5). We also found that latitude had a significant, albeit small, negative effect on native bird sightings (effect size = -0.08 , SE = 0.03; Fig. 3).

The best model explaining choice of feeder provided by respondents contained only 'age classes' (Table 2). While middle-aged respondents (30–59) did not significantly differ from the younger class (<30) in choosing the generalist open

Table 1: Estimate and credible interval bounds for each variables investigated in 2018 New Zealand online survey investigating urban sugar water bird feeding practices: model averaging score for each tested combination of variables in attracting native nectarivorous species using model averaging score

Tested variables	Stacking score	Pseudo-BMA score
Latitude	0.000	0.112
Type of feeders	0.122	0.027
Latitude + Type of feeders	0.878	0.861

dish feeder (effect size = 0.70, SE = 0.98), we found that people over 60 largely preferred this type (effect size = 1.75, SE = 0.98; Fig. 4). No other socio-demographic variable was able to explain differences in feeder-type preferences (Table 2).

Motivations for sugar water feeding

Most of the respondents reported several reasons why they fed wild urban birds with sugar water. The main motives were benefits for people such as 'bird-watching or photography as a pastime' (41% of respondents) and 'appreciation of birds and the environment' (31%). Other popular reasons were benefits for birds: 'survival aid' (23%),

'providing reliable food source' (18%), 'encouraging population growth/maintenance' (17%) and 'encouraging bird diversity' (14%). Nine percent of respondents used sugar water feeding as a conservation tool to protect native birds. Other motivations were less common (Supplementary Table A2.2).

Discussion

Our results show that the most commonly used sugar water feeder types were the Tui Nectar Feeder™ and open dish. The majority of participants used concentrations of either half or one cup sugar per litre of water and cleaned their feeders twice a week. We also show that feeder types specifically designed for nectarivorous species, such as the Tui Nectar Feeder™ and functionally similar feeders, are significantly more effective at attracting native birds to gardens in comparison to generalist feeders. We did not detect any impact of other factors, such as sugar concentration, on the presence of native birds at the feeder. The main motivations for sugar water feeding were human-centred benefits, with bird-watching or photography, and appreciation of the environment, being the two most commonly stated motivations.

Sugar water bird-feeding practices

Most of our respondents used the Tui Nectar Feeder™. This feeder type is specifically designed for sugar water feeding and is available in most New Zealand hardware and garden shops. Other types are distributed via more specialised pet stores. The second-most popular type of feeder was an open dish. This may be because existing dishes can be re-purposed for bird feeding by householders without extra cost. We could not find similar studies from other countries describing popular sugar water feeder types. Most studies in Australia, Costa Rica and USA focused on experimental set ups for honeyeaters or hummingbirds and authors either do not give details on which feeder type they chose (Broom 1976; Armstrong 1992; Avalos et al. 2012; Buecher and Sidner 2013; Graves 2013; Sonne et al. 2016), or used a single standardised type (Harris-Haller and Harris 1991; Chalcoff et al. 2008; Davis and Jackson 2008; Lee et al. 2019).

In our study, we found considerable variation in the concentrations of sugar water provided. In New Zealand, some commercial bird feeders come with instructions on how to make a

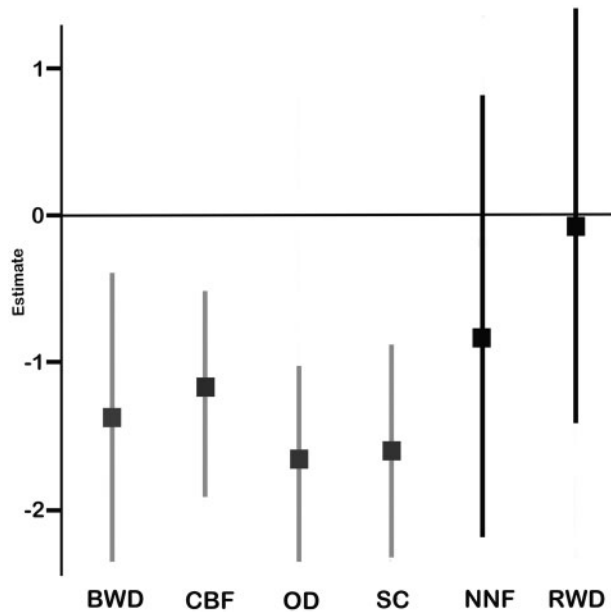


Figure 2: Success in attracting native bird species by the seven sugar water feeder types used in New Zealand. The estimated effect is corrected for the effect of latitude. The Tui Nectar Feeder™ was used as the reference level (estimate = 0). Error lines represent 95% confidence intervals. X axis represents compared feeder types. Generalist feeder types are shown in grey; specific feeders are shown in black. BWD = Bird water dispenser; CBF = Commercial bottle feeder; OD = open dish; SC = self-constructed feeder; NNF = Topflite Nectar Nutra feeder™; RWD = rodent water dispenser.

Table 2: Estimate and 95% credible interval bounds for each variable investigated in 2018 New Zealand online survey investigating urban sugar water bird feeding practices

Variable tested	Best model selected	Tested variables	Estimate	Lower credible interval	Upper credible interval
Proportion of native birds	Latitude + feeders type (reference level = Tui feeder)	Latitude	-0.08	-0.13	-0.03
		Bird water dispenser	-1.26	-2.22	-0.28
		Commercial bottle feeder	-1.13	-1.79	-0.50
		Commercial Nectar NutraFeeder	-0.87	-2.16	0.69
		Open dish	-1.56	-2.20	-0.96
		Rodent water dispenser	-0.04	-1.31	1.50
Choice of feeder	Sex (reference level = female) Income (reference level = low income) Age (reference level = young)	Sex	0.05	-0.58	0.69
		Income mid	0.29	-0.57	1.09
		Income high	-0.38	-1.16	0.39
		Age mid	0.66	-1.00	2.59
		Age old	1.75	0.01	3.68

We considered that an effect was relevant if the credible interval did not overlap with 0.

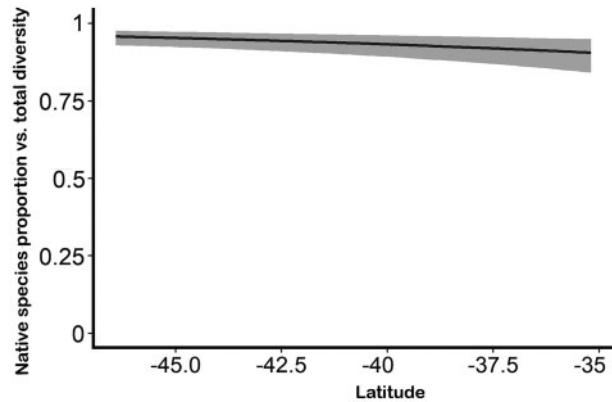


Figure 3: Effect of latitudinal gradient on proportion of native bird species versus total species richness at feeders, shown with 0–1 scale. The regression estimate is conditional to the Tui Nectar Feeder™. Error lines represent 95% confidence intervals.

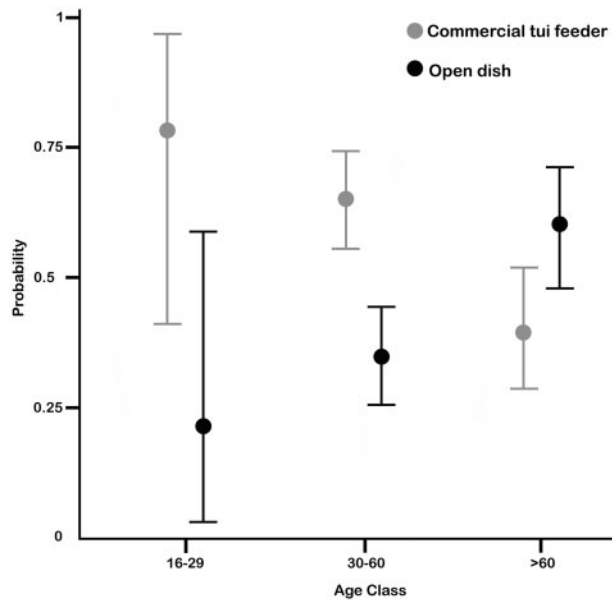


Figure 4: Probability of choosing one of the two most popular in New Zealand specific and generalist sugar water feeder types by various age groups of respondents. Error lines represent 95% confidence intervals.

sugar solution and several New Zealand organisations also provide advice on recommended sugar concentrations. Forest and Bird (www.forestandbird.org.nz) and the Banks Peninsula Conservation Trust (www.bpct.org.nz) recommend half cup per litre of water, while Manaaki Whenua—Landcare Research (www.landcareresearch.co.nz) suggests one cup per litre ratio. These concentrations (one cup sugar per litre of water = 20% sugar solution) are comparable to the available data on sugar concentrations in natural food sources used by New Zealand nectarivorous birds: 20.4% for the nectar of some introduced plants (Pyke 1991), 21% for nectar of New Zealand mistletoes (Loranthaceae; Ladley et al. 1997) and 21–76% for beech honeydew (Gaze and Clout 1983). We could not find information on the sugar concentrations that are commonly used by feeding participants in other countries. Data available from the few experimental studies on sugar concentration preferences in hummingbirds show high variation (9–66% solutions; Broom 1976;

Harris-Haller and Harris 1991; Lopez-Calleja et al. 1997; Chalcoff et al. 2008; Sonne et al. 2016; Lee et al. 2019).

Previous work has found that sugar water feeders can accumulate pathogenic bacteria and parasites (Marquez-Luna et al. 2016; Lee et al. 2019), thus feeder hygiene is a very important aspect of the practice. On average, our respondents cleaned sugar water feeders more often than previous studies report cleaning bread and seed feeding stations (Horn and Johansen 2013; Galbraith et al. 2014). New Zealand conservation organisations (e.g. Forest and Bird, Manaaki Whenua—Landcare Research) recommend cleaning sugar water feeders every 2–3 days and emphasise the importance of cleanliness to prevent bacterial growth. However, these instructions are vague in comparison to very detailed hummingbird feeder guidelines (e.g. <https://www.thespruce.com/how-to-clean-a-hummingbird-feeder-386610>).

The effectiveness of different practices in attracting native bird species

Most respondents intentionally used sugar water feeders to attract native nectarivorous birds, with most successful in doing so in that they observed several native species, including tūi, tauhou, and korimako. There may have been a bias in species observations as conspicuous birds, such as tūi, are more noticeable. On the other hand, a species such as korimako could have a low sighting rate because it is absent or rare in some populated New Zealand areas, such as Northland and Auckland (Scofield and Stephenson 2013). The observations of native species at feeders also slightly depended on latitude, with respondents in southern regions observing more native species. The latter can be explained by the difference in natural history of each bird species such as bird alpha-diversity (e.g. presence/absence of korimako) and/or the natural occurring differences in abundance and distribution of exotic species that can outcompete with native birds for resources (e.g. common myna, Cohen et al. 2019; Parkes and Avarua 2006). Both factors can have large influences on the human wildlife feeding behaviour and vice versa (Galbraith et al. 2015).

Feeder type had the most explanatory power in predicting the proportion of native bird species at a sugar water feeder. It is possible that all sugar water feeder types could be divided into two groups, ‘specific’, and ‘generalist’, in terms of species able to access them. Specific feeders (e.g. Tui Nectar Feeder™ and Topflite Nectar Nutra feeder™) contain the sugar water solution within a covered vessel and bear special holes intended to prevent access by undesirable birds (e.g. common myna or common starling). Generalist feeders (e.g. open dish, inverted bottle and bird water dispenser) lack any features to exclude non-nectarivorous species, hence sugar water is easily accessible to virtually any bird capable of encountering the feeder, including introduced species. Specific feeders were significantly more effective in attracting native species. Similarly, previous work found that more specialised squirrel-proof seed feeders were significantly less contaminated with faeces than less specialised feeder types (Prescott et al. 2000). Thus, we see potential benefits of using specific feeder types for sugar water feeding in having fewer visiting species, and less opportunity for debris accumulation, and as a result, lower contamination risk and better hygiene. Open dish was the least effective feeder type in terms of attracting native species and potentially the most prone to accumulating faeces and other debris, and thus predicted to have higher contamination risk in comparison to specific feeders. Feliciano et al. (2018) showed that feeders with debris accumulation had significantly higher levels of *Salmonella*

spp. even after cleaning and recommended a combination of cleaning methods for such feeders. However, further research is needed.

We also found that latitude had a significant negative effect on native bird sightings. The need to consider latitudinal effects is founded on the prediction that supplementary feeding may have a greater benefit to birds using this resource in colder environments due to greater energetic requirements for survival (Dunn and Tessaglia 1994; Prescott et al. 2000; Martinson and Flaspohler 2003). While a differential benefit has not been demonstrated, there is latitudinal differences in the proportion of people feeding birds specifically in autumn and winter—increases as you go south (Galbraith et al. 2014). So people may be altering their behaviour based on the assumption winter feeding is more beneficial. However, in our case, the observed differences in sightings could be explained primarily by the absence of korimako in some regions.

The motivations of sugar water feeding

Our results support other recent work showing that humans are often motivated by benefits they receive, rather than benefits directly to wildlife, when making decisions around interactions with wild birds (Horn and Johansen 2013; Galbraith et al. 2014; Howard and Jones 2004). However, in our survey, the number of respondents who reported bird watching or bird photography as the main reasons for feeding was noticeably higher (41% vs. 5%) in comparison to a recent similar on bread and seed wildlife feeding (Galbraith et al. 2014). At least one-third of our respondents fed because they appreciated birds and the environment; a motivation stated ten times more often than by respondents engaged in bread and seed feeding (31% vs. 3%; Galbraith et al. 2014). Another difference is that in our study more respondents stated wildlife-centred or conservation-oriented motivations to feed sugar water as compared to a similar study of bread and seed feeding (Galbraith et al. 2014). For example, 'survival aid' was mentioned three times (23% vs. 7%) and 'encouraging population growth/maintenance' was mentioned six times (17% vs. 3%) more often. Nine percent of our respondents specifically stated they want to assist in the conservation of native species.

Implications for urban ecology

It has been suggested that provisioning of sugar water for wild birds in lieu of bread and seed may benefit native species (Galbraith et al. 2017). Indeed, most of our respondents who fed sugar water wanted to support populations of native nectarivorous birds. However, potentially harmful consequences of sugar water feeding can include changes in behaviour (e.g. dependency, increased aggression), dietary imbalances, and increased disease transmission (Bradley and Altizer 2007), though this has yet to be explored in New Zealand. The lack of knowledge about the possible positive and negative ecological consequences of sugar water feeding, along with a lack of explicit, fulsome feeding guidelines, can lead to negative impacts on urban birds (Galbraith et al. 2014). While a number of studies in other countries reveal some patterns in sugar concentration preferences and the effects of this practice on bird foraging behaviour in some hummingbird and honeyeater species (Broom 1976; Harris-Haller and Harris 1991; Armstrong 1992; Lopez-Calleja et al. 1997; Avalos et al. 2012; Buecher and Sidner 2013; Chalcoff et al. 2008; Graves 2013; Sonne et al. 2016), little is known about how various individual feeding choices affect social behaviour and pathogen accumulation. Further research should focus on

impacts of the most common sugar water feeding practices on bird assemblages, for example, whether feeders with higher sugar concentrations accumulate more microbes (Lee et al. 2019).

In general, urban wildlife management of New Zealand native birds needs a holistic approach, as these species are vulnerable to a number of threats, primarily predation by introduced mammalian pests and habitat loss (Moorhouse et al. 2003; Duncan and Blackburn 2004; Morgan et al. 2009; Innes et al. 2010). Recent community-led predator control initiatives have led to increasing numbers of private households engaging in trapping (e.g. <https://www.doc.govt.nz/predator-free-2050>; <https://predatorfreenz.org/>). Our survey results also reflect this trend: five percent of our respondents stated they used predator control as a tool to protect birds they have attracted into their gardens and to boost their numbers. Recent studies also identify the need for urban habitat restoration to support native biodiversity in New Zealand (Sullivan et al. 2009; van Heezik and Seddon 2018).

Our research provides insights into typical wildlife feeding practices and can be used to develop and test hypotheses for future research into the critically understudied area of sugar water feeding. The majority of studies from North and South America, and South Africa have been vital in shedding light on how sugar water feeders alter species diversity (Armstrong 1992; Greig et al. 2017; Bandivadekar et al. 2018; Coetzee et al. 2018). However, still to be determined is how sugar water feeding alters birds' welfare and conservation success (Nuñez-Rosas and Arizmendi 2019; Coetzee et al. 2021). Our results show that householders' choices of feeder type is strongly related to observed bird species composition in urban backyards. Identifying which sugar water feeding parameters are more effective at attracting certain bird species globally will help inform our understanding of the potential scope of management applications of this practice (Brown et al. 2008) and enable the development of best practice feeding guidelines for private households and conservation.

Acknowledgements

We are grateful for the hundreds of New Zealanders who participated in the survey. We thank New Zealand Birds online (www.nzbirdsonline.org.nz) for bird photos used in the survey. We thank three anonymous reviewers for their useful comments on the manuscript. The survey was approved by the University of Auckland Human Participants Ethics Committee (approval No. 022202).

Funding

This research was supported by the University of Auckland (University of Auckland Doctoral Scholarship).

Conflict of interest statement. None declared.

Data availability

Full original dataset from this urban bird sugar water feeding survey is available at https://figshare.com/articles/data_set/online_urban_bird_sugar_water_feeding_survey_from_New_Zealand_2018_xlsx/13356644.

Supplementary data

Supplementary data are available at JUECOL online.

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