Sweet support: Exploring supplementary feeder use by female Hihi (*Notiomystis cincta*) at Tarapuruhi Bushy Park, New Zealand

MSc Thesis

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June 2025
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Cover photo: Female hihi drinking from supplementary nestbox feeder © A.N. Pijpers

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Abstract

With the arrival of humans to Aotearoa New Zealand, the country's ecosystem changed permanently. The islands are home to many endangered species, some of which now rely on supplementary feeding for population sustainability. One such species is the hihi (*Notiomystis cincta*), a New Zealand passerine that once inhabited the entire the North Island. Nowadays, only a few populations remain, and all extant hihi populations depend on supplementary sugar water feeding for survival. However, the extent to which females benefit from this supplementary food source remains unclear, as they appear to use feeders less frequently than males. This study investigated the feeder use by female hihi at Tarapuruhi Bushy Park, an ecosanctuary near Whanganui, where the population is skewed toward males, an imbalance that can negatively impact breeding success. Two feeder types were assessed: general feeders, accessible to all individuals in the population, and supplementary nestbox feeders, placed within the territories of breeding pairs. The research determined whether male and female hihi differed in visit rate, visit duration, and drinking rate at both general and nestbox feeders. It also examined whether female hihi differed in drinking rate, visit duration, and harassment rate between the two feeder types. Results showed that females visited general feeders significantly less often than males, and no significant sex differences were found in visit rate at the nestbox feeders. Feeder type significantly influenced visit duration, though sex did not. Males exhibited a higher drinking rate at general feeders, while female drinking rates remained consistent across feeder types. Harassment of females by males occurred mainly at general feeders, with almost no such interactions at nestbox feeders. Overall, nestbox feeders appeared to reduce competition for female hihi compared to general feeders. This study offers new insights into female hihi feeder use and suggests that nestbox feeders may help support breeding females. Nonetheless, further individual-based research is needed to determine the long-term effects of nestbox feeders and whether they contribute to increase hihi population numbers.

Introduction

The world is undergoing a major biodiversity crisis, and a sixth mass extinction is likely already on its way (Ceballos et al., 2015). This biodiversity decline can be attributed to anthropogenic activities which cause habitat loss and fragmentation, climate change, the introduction of invasive species, overexploitation and pollution (Ceballos et al., 2015; Sala et al., 2000). Biodiversity loss is detrimental for ecological processes, as the health of the ecosystem depends on species interactions (Valiente-Banuet et al., 2014). Disruption of these biotic interactions by human activities may further accelerate species extinctions (Valiente-Banuet et al., 2014). In particular, island species face high levels of extinction due to their limited distribution, reduced predator escape response and certain physiological traits (Duncan & Blackburn, 2004). Islands often house a unique biodiversity with species not seen anywhere else in the world. One example is Aotearoa New Zealand which, having been isolated from the mainland for 80 million years, hosts a highly endemic biodiversity (Cooper & Millener, 1993; Winkworth et al., 2005).

Since humans arrived approximately 800 years ago, New Zealand has undergone drastic changes in its biodiversity. Together with the early Polynesian settlers, and later the European settlers, invasive predators made their way onto the land and had a significant impact on the native animal populations (Donnell et al., 2014). Before humans arrived, New Zealand housed no terrestrial mammals, which allowed for the evolution of many flightless and ground-dwelling birds, such as the North Island brown kiwi (*Apteryx mantelli)* and kākāpō (*Strigops habroptilus)* (Bull & Whitaker, 1975). Many bird species are highly susceptible to predation by introduced mammals (Dowding & Murphy, 2001). Invasive predators, like ship rats (*Rattus rattus)*, brown rats (*Rattus norvegicus)*, brushtail possums (*Trichosurus vulpecula)*, stoats (*Mustela erminea)*, feral cats *(Felis silvestris)* and European hedgehogs *(Erinaceus europaeus)* are still widespread all over New Zealand and impact forest, river and coastal habitats (Donnell et al., 2014). These predators prey on native wildlife and are responsible for the loss of approximately 26.6 million chicks and eggs of native birds each year (Russell et al., 2015). It is estimated that around 40% of New Zealand's bird species have gone extinct since the arrival of humans (Holdaway, 1989).

Through intense conservation efforts, New Zealand has been trying to keep its remaining native species from extinction, particularly through pest control on islands and translocations (Parker et al., 2023; Miskelly, 2013). Initiatives by the Department of Conservation, like Predator Free 2050, aim to protect New Zealand's native species by eradicating the most damaging predators (Department of Conservation, n.d). In 1999, New Zealand introduced many fenced ecosanctuaries to keep out predators and grazers such as red deer (*Cervus elaphus scoticus)* and rabbits *(Oryctolagus cuniculus)*. These ecosanctuaries are often isolated from unmanaged habitats like farmlands (Innes, 2019). Fenced sanctuaries allow vulnerable bird and lizard species to be reintroduced on the mainland (Burns et al., 2012).

For the most vulnerable species, additional support is required. Supplementary feeding (Ewen et al., 2015) is a valuable tool in the conservation of threatened species (Roper & Brunton, 2024). For avian scavengers, supplementary feeding supports individual survival and helps to maintain breeding populations (Cortes-Avizanda, 2016; Oro et al., 2008). Supplementary feeding can prevent rapid population declines, as was found in the case of the red-billed cough (Fenn et al, 2020). Supplementary feeding reduces aggression between siblings in the imperial eagle and fledging rate is increased in supplemented broods as compared to non-supplemented broods (Gonzalez et al, 2006). Supplementary feeding has been found to be positively correlated with the number of breeding pairs and fledglings in Eurasian griffons (Marinkovic et al., 2019). In buff-nest partridges and scrub-jays, supplementary feeding has shown an increase in breeding success (Yang et al., 2016; Schoech et al., 2008).

One New Zealand bird that heavily relies on supplementary feeding is the hihi *(Notiomystis cincta).* The hihi is a small forest passerine endemic to New Zealand, and the only member of its family

Notiomystidae. By the late 1800s, the bird had almost become extinct, except for a population on Te-Hauturu-o-Toi, or Little Barrier Island. The reason for this decline is not completely known, although it was likely due to habitat destruction and the introduction of mammalian predators. Hihi are cavity nesters, and a lack of suitable nest locations limits their reproduction. This nesting behaviour also makes them more susceptible to invasive predators (Perrott & Armstrong, 2000; Hare et al., 2019). Hihi are susceptible to respiratory diseases such as *Aspergillus fumigatus*, as shown by failed translocations on Mokoia Island (Perrott & Armstrong, 2011). From the population on Little Barrier Island, several translocations have been carried out to predator-free reserves (Brekke et al., 2010). These translocations initially faced multiple failures, but hihi populations established themselves successfully when supplementary feeding was introduced. This suggests that limitation in food resources in the young-growth forests to where hihi were translocated were a key challenge (Perrott & Armstrong, 2000; Hare et al., 2019). The original hihi population, which is not being monitored and is estimated at 600 to 6000 birds (Taylor et al., 2005), requires no supplementary feeding on their island of origin. However, all the translocated populations require supplementary feeding, as well as the provision of artificial nestboxes, and in the case of mainland translocations, predator control (Higgins et al., 2001).

New Zealand has seven islands and ecosanctuaries where hihi have been reintroduced from Little Barrier Island; 1) Tiritiri Matangi (Population: ~200 adult birds), 2) Rotokare Scenic Reserve (Population: ~ 80 adult birds, 3) Zealandia (Population: ~70 adult birds), 4) Maungatautari (Population: ~60 adult birds), 5) Kapiti Island (Population: ~100 adult birds), 6) Bushy Park Tarapuruhi (Population: ~50 adult birds). All reintroduced hihi populations are heavily managed and monitored by the Hihi Recovery Group, which aims to increase the number of hihi nationwide and increase the natural ecological setting of reintroduced populations through decreased provision of nestboxes and decreased supplementary feeding (Hihi conservation, n.d). On Te-Hauturu-O-Toi, hihi feed on nectar, fruit and insects, of which proportions and quantities vary throughout the year. Hihi forage mainly in trees and shrubs (Higgins, 2001). Reintroduced populations have a similar diet, with an addition of supplementary sugar water.

Hihi have an interesting mating system which can vary from monogamy to polygynandry (Castro et al., 1996), resulting in a high likelihood of extra-pair offspring. Hihi have one of the highest rates of extra-pair paternity in avian species; 35-46% of offspring in a nest are estimated to be of extra-pair paternity (Ewen et al., 1999; Castro et al., 2004). Extra-pair males have been found to be aggressive towards females and engage in many extra-pair copulations with forced mountings, known as face-to-face copulations (Castro et al., 1996; Ewen & Armstrong, 2002). Hihi are sexually dimorphic with the males characterised by a black head, white ear tufts and a yellow band on their shoulder. The females are olive-coloured, lack the ear tufts and are smaller than the males (Figure 1). The breeding season starts in October, around which time male hihi will look for suitable nesting locations and deposit some sticks in suitable places. Females will subsequently choose one of the locations and finish building the nest, which resembles a cup-like structure on a base of sticks. The males do not provide parental care during the nest-building and incubation process but will help feed the chicks once they have hatched and actively defend their territory (Ewen & Armstrong, 1999). Hihi pairs can raise up to two broods per breeding season, with one to five chicks per brood. The incubation period is approximately two weeks, and the chicks fledge about 30 days after hatching (Castro et al., 2003).

Figure 1: Female hihi (left) and male hihi (right)

During the breeding season, hihi consume large quantities of nectar (Low et al., 2012). This is also reflected in the high use of the supplementary feeding stations during this period (Brooke, 2024). In general, artificial feeders for birds often form a focal point for competitive behaviour, with more dominant individuals having increased access over subordinate individuals. In birds, whether males or females are dominant depends on the species and the season (Mostrom, 2003). Reintroduced hihi populations heavily rely on supplementary feeding, but its effects are not always positive. Other birds, like the korimako, are also able to use the feeders. Korimako are more dominant than hihi and often chase hihi away from the feeders (Roper & Brunton, 2024). Next to this interspecific competition, there is also intraspecific competition between male and female hihi. Male hihi have been found to be more dominant than female hihi (Roper & Brunton, 2024). This intraspecific dominance may affect feeder use by female hihi (Roper & Brunton, 2024), leading to lower use by females during the breeding season, and, consequently, lower breeding success (Doerr et al., 2016). If females cannot access supplementary feeders, the number of fledglings decreases (Chauvenet et al., 2012). One example comes from a sanctuary in Maungatatauri. In a study, it was hypothesised that the impact of feeders on fledgling production would be smaller in a mature forest like Maungatautari, than in a regenerating forest, since mature forests are expected to contain enough fruits and flowers to feed from. However, results showed that feeder-using females raised, on average, 1.8 more fledglings than non-feeder using females (Doerr et al, 2016). Therefore, females seem to also benefit from the sugar water feeders significantly, provided they can access them.

Male hihi have been found to be aggressive towards female hihi. As stated earlier, hihi have a complicated breeding system with high rates of extra-pair paternity and will forcibly mount female hihi (Castro et al., 1996; Ewen & Armstrong, 2002). Due to male harassment, female hihi can get injured, and their breeding behaviour can be altered (Ewen et al., 2011). Fertile female hihi are often chased by extra-pair males and forced into face-to-face copulations (Ewen et al., 2011). They resist these copulations with alarm calls, erratic flight behaviour and by looking for cover in vegetation (Low, 2005). Male harassment of females has been found to have costs, such as reduced paternal care for the chicks, laying gaps between clutches (Low, 2008), and injuries (Ewen et al., 2011). Harassment of females is often seen in male-biased adult sex ratios, as the competition for mates increases (Ewen et al., 2011). Females in a male-biased population produce fewer offspring than those in female-biased populations (Ewen et al., 2011). Harassment of females by male hihi can cause reduced feeder use by the females, which could have dramatic consequences for population sustainability. In threatened species and in small populations, which are both characteristics of hihi populations, male-biased populations are common (Dale, 2001; Donald, 2007; Morrison et al. 2016). Many female birds have

high energetic costs of egg-laying and chick-rearing and might thus respond negatively towards a lower abundance of resources (Morrison et al., 2016).

In Tarapuruhi Bushy Park, where the current study was conducted, such a male-biased sex ratio can be seen, with male hihi largely outnumbering female hihi (male hihi: n=29, female hihi: n = 14). A year after the translocation of 44 hihi to Tarapuruhi Bushy Park in 2013, a significant decline in females was observed, leaving a surplus of males. The reason for this decline has not been found (Frost, 2014). Over the years, this male surplus has remained, and it is important to investigate its effects on the remaining female hihi in Tarapuruhi Bushy Park, starting with whether females benefit from supplementary feeding stations. Like all ecosanctuaries that house hihi, Tarapuruhi Bushy Park uses supplementary feeding stations to sustain its hihi population. In addition to these supplementary feeding stations, hihi researcher Doug Armstrong and hihi contractor Erin Patterson decided to place extra feeders near nestboxes for the breeding season of 2024-2025, the year in which this study was conducted. These extra feeders were added to assist breeding hihi during chick-rearing. Understanding female behaviour at the feeder is important for the conservation of the hihi and increasing female access to supplementary feeders could be an important step in ensuring the long-term viability of this endangered species.

This study thus aims to determine female feeder use at Bushy Park Tarapuruhi, focusing on the relation between use by females of centrally placed feeders and male harassment. Additionally, I here examine whether placing additional feeders near nestboxes could improve female access and reduce competition, by exploring the dynamics of feeder use and its relationship with reproductive success. Specifically, I quantified the differences in feeder behaviour between male and female hihi in terms of feeder visit rate, feeder visit duration and feeder drinking rate. Moreover, I determined if the feeder visit rate, feeder visit duration, feeder drinking rate and the number of agonistic interactions towards females differ between females visiting nestbox feeders and general feeders. I hypothesised that females would visit the general feeders less often than males, as was found in a study by Roper and Brunton (2024). In addition, I explored if the visit duration of hihi differed among the sexes and was related to the rate of feeder visits. I also examined whether drinking rate differed among sexes, with the expectation that females would have a lower drinking rate because of higher vigilance. For the nestbox feeders, I expected similar visit rates between the male and female of the breeding pair whose territory included the feeder. I anticipated that the breeding pair would visit the nestbox feeder most often, with few other hihi using these feeders. Moreover, females were expected to visit these nestbox feeders more often compared to the general feeders, to spend more time at them, and to have a higher drinking rate, measured in seconds per drink. Finally, I predicted females to experience fewer agonistic interactions at the nestbox feeders compared to the general feeders.

Materials and methods

Study area and subjects

This study was conducted at Bushy Park Tarapuruhi, New Zealand (39°47′50.4″S 174°55′43″E) (Figure 2). Bushy Park Tarapuruhi is an 89-hectare fenced forest reserve, home to many different New Zealand native animal species. Birds such as kererū (*Hemiphaga novaeseelandiae)*, Toutouwai (*Petroica longipes)* and tīeke (*Philesturnus rufusater)*, but also native geckos, skinks and insects inhabit the ecosanctuary. The park is surrounded by two fences: the predator-proof fence (Xcluder™) which keeps possums, rats, stouts and other predators out of the reserve, and the larger outer fence, which keeps out grazers such as goats, deer and rabbits. The forest is a temperate lowland forest, with many mature trees and dense canopy, and has been generally unmodified. The forest's dominant trees are tawa (*Belschmiedia tawa)*, pukatea (*Laurelia novae-zelandiae)*, rimu (*Dacrydium cupressinum)* and nothern rātā (M*etrosideros robusta)* (Bushy Park Tarapuruhi, n.d.). The fence is actively managed by volunteers through trapping of pests, weeding, and pruning trees that risk growing over the fence.

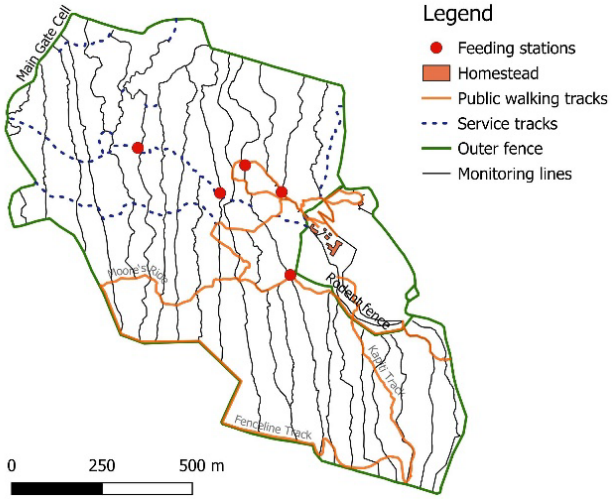

Figure 2: Tarapuruhi Bushy Park, New Zealand. The feeding stations are shown in red.

The current hihi population was translocated in 2013 from the scientific reserve island Tiritiri Matangi. 44 birds (21 females, 23 males) were released into Bushy Park Tarapuruhi. Today, the exact population numbers in Bushy Park Tarapuruhi are unknown, but according to a list of hihi seen since 2023, there are approximately 24 females, and 36 males present in the sanctuary, forming a total of about 50 birds. However, these numbers are not fully reliable as it is uncertain all individuals identified as females were actually females. Some were still in their juvenile plumage, which has a similar colouring to adult females and can lead to misidentification. Before this study began, a pre-breeding survey on the hihi was carried out by hihi contractor Erin Patterson, who recorded 26 males and four females. It is worth noting that females are more difficult to spot, as their plumage does not have outstanding colours. The birds are banded with colour bands (Figure 3), and most birds are banded with an RFID-PIT band (Radio frequency Identification). The RFID bands can be detected by a detection unit in the feeder which records which bird enters the feeder and at what time. These RFID bands are a non-invasive method of monitoring hihi populations, and tracking which birds use which feeding station. This method was developed and tested on Tiritiri Matangi, from which all mainland hihi populations are translocated. In Tarapuruhi Bushy Park, all adult males wear an RFID band, but not all adult females. Some females are not banded at all. Therefore, the RFID measurements are not an accurate representation of the population number and individuals in Tarapuruhi Bushy Park. All individuals in the population, except some females that are not banded at all, carry their own unique colour combinations, which is how they are identified. Since last year, problems with RFID-bands have been recorded. Some birds wearing them

have developed swollen and constricted legs. Therefore, the RFID project has been abandoned for the time being, and new hihi chicks are not banded with RFID-bands. At Bushy Park Tarapuruhi, the fledglings born in the breeding season of 2024-2025 have been banded with a colour-band and a metal band on the left leg, and two colour-bands on the right leg.

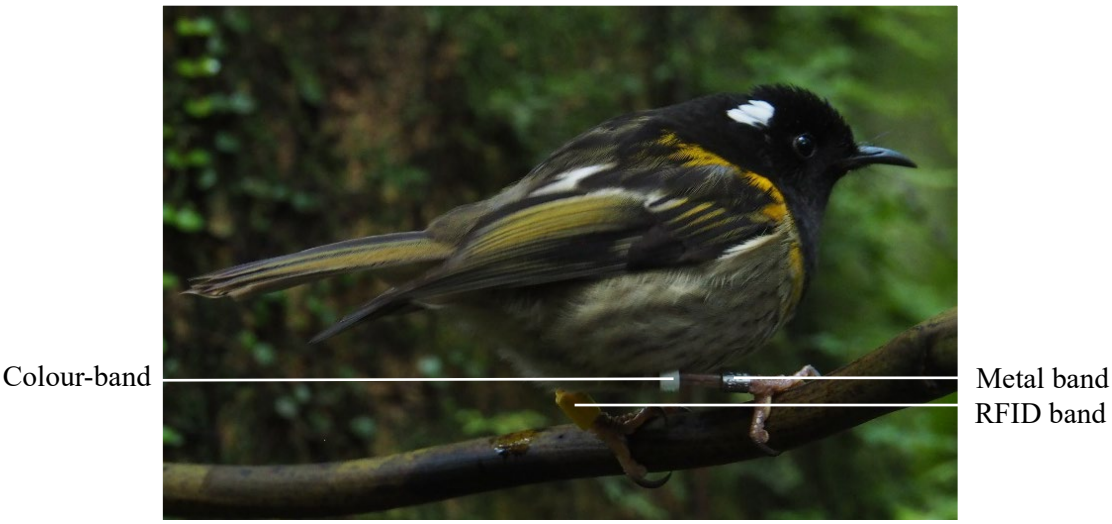

Figure 3: The combination of colour bands on a male hihi at Bushy Park Tarapuruhi. This male is identified as Y-W/M, referring to the colours of the bands and on which leg the bands are placed (**Y**ellow-**W**hite/**M**etal).

Feeding stations

The park has a total of five general sugar-water feeding stations, divided over a small area of the park (Figure 4). A total of approximately 5 litres of sugar water is divided over the feeders every three days, although the amount varies depending on how much sugar water is consumed. The amount usually increases as the breeding season progresses. The ratio of sugar and water is 1 cup of sugar per litre of water. The sugar water is poured into bottles attached to a drinking trough placed in the middle of the feeding station. These feeders have little holes from which the birds can drink (Figure 5). Two feeding stations were visited more often, number 2 and 5, so these feeding stations were equipped with a larger quantity of sugar water. Volunteers of Tarapuruhi Bushy Park replace the sugar water every three days, as the sugar water starts to ferment at this point. Excess sugar water is collected, and the amount is recorded. The used bottles are cleaned and sterilised thoroughly to prevent the spread of diseases.

Figure 4: Locations of the general feeding stations for hihi

Figure 5: Hihi feeding station, with sugar water placed in the middle of the station.

Feeders near nestbox

Bushy Park Taraparuhi has approximately 48 nestboxes divided over the sanctuary. These replicate the tree cavities in which hihi usually nest. The nestboxes are paired, meaning that two nestboxes are placed close to each other. This allows the female to lay another clutch in the second nestbox after using the first nestbox. After a nest has fledged, or died, the nestboxes are cleaned out thoroughly.

In the breeding season of 2024-2025, we placed feeders near nestboxes, at approximately 10 metres from the nestbox, similar to the nestbox feeder setup used at the Maungatautari Reserve (Doerr et al., 2016). The feeders were placed as soon as hihi chicks hatched and were removed once the chicks fledged. The feeder would not sit in a cage, but would be open, hung on a branch with ropes (Figure 6). Like the general feeders, the nestbox feeders were replaced every three days with new sugar water. We put about 500-700 ml sugar water in a nestbox feeder. A total of 10 nestbox feeders were installed, of which seven were observed. The reason some feeders were not observed, is because the chicks died soon after the nestbox feeders were put up, and thus the nestbox feeders were removed. The locations of all nestbox feeders can be seen in Figure 7.

Data collection and procedure

I conducted my study from mid-October 2024 to mid-January 2025, which covered a large part of the breeding season (usually from October to February). Over this period of three months, I observed the five general feeders and seven nestbox feeders. This was done between 9:00 and 19:00. An observation day consisted of observing all the feeders one after the other, with 40 minute-sessions per feeding station. During the observation sessions, I recorded the behaviour of male and female hihi at the feeder. I performed live observations in which I took voice recordings with my phone. I recorded the occurrences shown in Table 1.

Figure 6: Nestbox feeder, hung with ropes to a branch. A female hihi is seen next to the feeder.

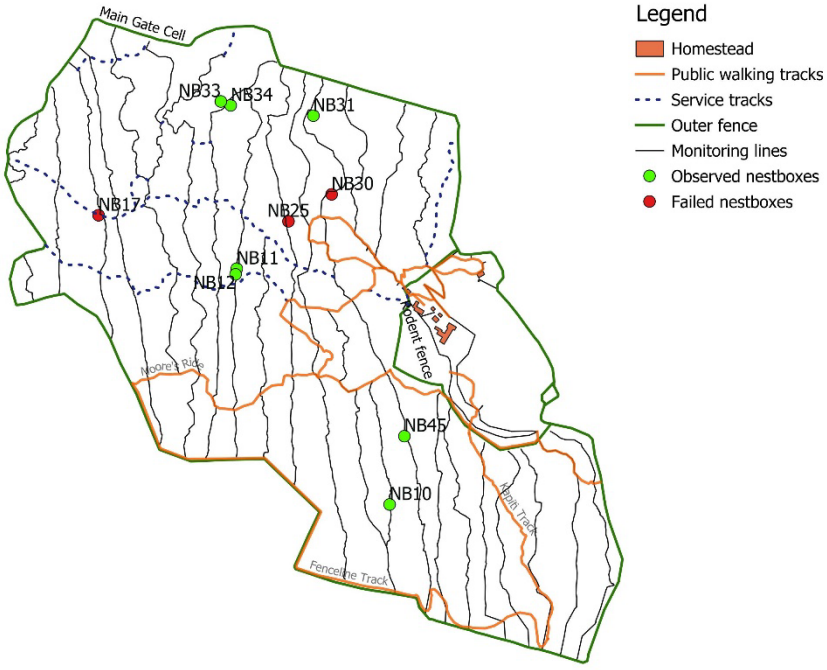

Figure 7: Map of all nestboxes where additional feeders were placed.

I recorded all the behaviours shown above as well as the individual that performed them, and if applicable, which bird was involved. I transcribed the voice recordings in Excel and noted down my observations in a quantitative manner. Per feeder, I spent 40 minutes performing all-occurrence sampling of the males and the females at the same time, as well as the presence of korimako if it was there. The feeder order was randomised every day. A bird was marked as visiting the feeder when it fully entered the feeder. I recorded if there were birds waiting outside the feeder as well. I spent a total of 113 hours observing the birds from 21 October 2024 to 15 January 2015. All the main feeders were observed an equal amount of time: 18 hours per main feeder. A table with the total number of hours observed per feeder is presented in the appendix (A-1).

Table 1: Behaviours and events recorded, based on the ethograms from the appendix (adapted from Higgins et al., 2001, and personal observations)

Behaviour/event	**Description**
Feeder entrance	When a bird entered the feeder
Partner presence	Whether the female's partner was present while she was feeding
Drinking rate	Number of sips a hihi took while in the feeder
Time spent in feeder	Duration from feeder entry to feeder exit
Aggressive encounters	Occurrences of chasing, pecking, and fighting; both the attacker and victim are recorded
Copulations	Conventional and face-to-face copulations, usually by extra-pair males
Territorial calls	High-pitched whistle-like calls emitted by males to mark territory (Distribution shown in figure C-1, appendix)
Warbling calls/Aggressive chat	Warbling sounds directed at other hihi, displays aggression
Other calls	Stitch calls, alarm calls, and high-pitched calls
Waiting to enter feeder	When a hihi waited to access the feeder due to another bird's presence

Female presence survey

To get an overview of how many females were present in the forest, I surveyed the nestboxes where full nests were built. Hihi build nests together, with the male choosing the nest sites by placing some sticks in the nestbox and the female finishing the process. A complete nest contains a base of sticks and a cuplike structure on top, lined with fern tree scales and feathers. I observed nestboxes with full nests for two weeks to determine which females were nesting.

Feeder visit rate females

For each observation session I used continuous all-occurrence sampling to monitor the behaviour of the females at the feeder. The birds were individually marked by their colour bands. I also identified the birds towards which behaviour was performed. The behaviours recorded for each female are presented in the ethogram in the appendix (Table B-1).

Data processing and analysis

The raw data of my fieldwork comes from voice recordings taken with the voice recorder app on a smartphone (Samsung A34). I transcribed these voice recordings into Excel to create a format suitable for data analysis. During my field observations, I recorded the date, start and end times of each session, the feeder number, the time each behaviour occurred, the individual bird performing it, the nature of the behaviour, whether the bird's partner was present (if applicable), and any interactions with other birds. I calculated the time a bird spent in the feeder by counting the seconds in the recording between the words "enters feeder" and "leaves feeder". I counted the number of times a bird drank from the feeder while in the feeder and calculated the drinking rate by dividing the duration by the number of drinks.

To allow for proper comparison between different situations, I created two separate datasets from the final dataset. One dataset consists of data collected when no nestbox feeders were present in the forest at all. This dataset consists of data collected from 21 October 2024 until 11 November and from 23 December 2024 until 6 January 2025. The second dataset consists of data collected when one or more nestbox feeders were present in the forest, in addition to the general feeders. This dataset includes data collected from 12 November 2024 until 18 December 2024 and from 7 January 2025 until 15 January 2025.

Statistical analysis

I analysed all data in Rstudio 4.3.2 (2023). I divided the data into two situations; one situation was when only general feeders were present in the forest, with no nestbox feeders; the other situation was when the nestbox feeders were also present in the forest. This allowed for a more balanced comparison. As the observation time varied between feeders, I divided the total number of specific behavioural occurrences by the observed time, which gave a number of these behaviours performed per hour. In case of the visit rate, I did not correct for the potential number of females and males that could have visited the feeder because these numbers would not be entirely reliable as the accurate number of females and males present in the forest is unknown. For the comparison of feeder entrances between males and females, I first looked at the general feeders, during the time that no nestbox feeders were present. First, I tested the data for normality with the Shapiro-Wilkinson test. As the data was not normally distributed, I used a Mann-Whitney U test to test for the difference in male and female entrances for the general feeders, when no nestbox feeders were present. For the data when nestbox feeders were present in the forest, I also used a Mann-Whitney U test to test for the difference in male and female data.

To compare the feeder visit rates of male and female hihi, I divided the observation sessions into two distinct periods. The first period included dates during which only general feeders were present. These feeders, which are available all year-round, were each observed for an equal amount of time: 7.3 hours per feeder. During this time, no nestbox feeders were present in the forest, as there were no breeding pairs with chicks. For the duration and drinking rate of the individuals, I divided the data into the same situations: No presence of nestbox feeders, and presence of nestbox feeders in the forest.

I performed a linear regression to test for the effect of sex and feeder type (nestbox vs. general) on the feeder duration and the drinking rate. I fitted a generalised linear model with gamma distribution. These models were only tested on the data for dates where nestboxes were present in the forest. I used the following models:

$$Drinking\ rate \sim Sex\ individual\ *\ Feeder\ type$$

Equation 1: Generalised linear model that correlates the drinking rate of each individual with its sex and the feeder type

$$Duration\ (s) \sim Sex\ individual\ *\ Feeder\ type$$

Equation 2: Generalised linear model that tests if the duration of drinking was explained by its sex and by the feeder type (central or 'own' feeder at nestbox)

Finally, I tested for the differences in harassment occurrences towards female hihi between the nestbox feeders and the general feeders, during the period when nestbox feeders were present in the forest. I filtered for the occurrences in which an agonistic behaviour such as pecking or chasing was performed towards a female hihi. As my observation times varied at each feeder, I corrected for this variation by dividing the number of harassment occurrences by the number of hours observed at each feeder. I performed a Mann-Whitney U test to test for differences in harassment occurrences towards female hihi at nestbox feeders and at general feeders. Based on this I also created a social network to visualise which individuals were attacking the female hihi. Each node is a separate hihi individual (or a korimako/bellbird) and the name of each individual is also displayed. All plots were created with the packages ggplot and ggplot2 and the social network was created with the package igraph.

Results

Feeder visits

In total, 471 feeder entrances were recorded during the period when no nestboxes were present. Of these, 449 entrances (95%) were made by males, while 22 entrances (5%) were made by females. A total of 29 different males and 5 different females were observed visiting the feeders. Since all males in the forest are known to visit the feeders, this represents the entire male population. In contrast, there were 14 known females in the forest at the time, meaning that only 36% of the female population was observed visiting the feeders. The remaining females, who were never observed at a feeder, were assigned a feeder visit rate of zero. Males visited the feeders significantly more often than females (Mann–Whitney U test, W = 56.5, p = 0.0003, Figure 8). Figure C-2 (appendix) shows all feeder entrances per feeder number and displays which individual female hihi visited each feeder.

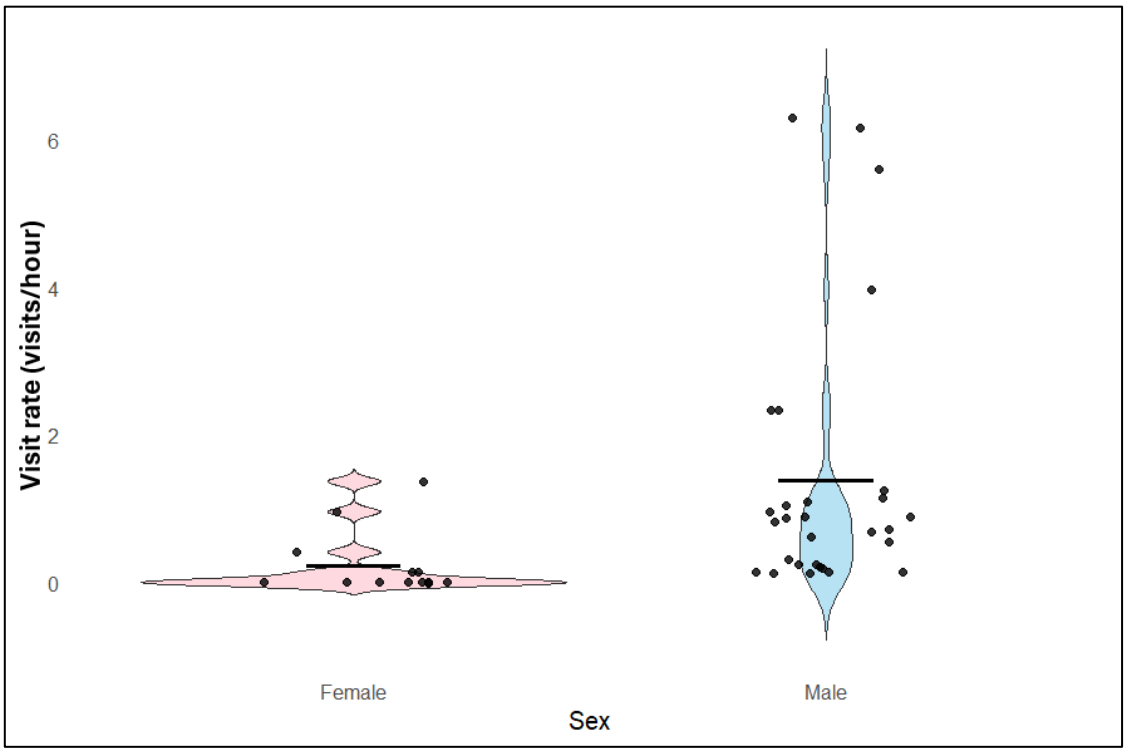

Figure 8: Feeder visit rate in the first period, when no nestbox feeders were present in the forest. These datapoints only consist of observations at the general feeder. Females that never visited the feeder were given a feeder visit rate of 0. Males: n = 29, Females, n = 14.

In the period when nestbox feeders were present in the forest, a total of 957 entrances were recorded at the general feeders, of which 817 (85%) were made by males, and 140 (15%) were made by females. For the nestbox feeders, a total of 321 feeder entrances was recorded, with 177 (55%) made by males, and 144 (45%) made by females. The plot shows that females have a higher average visit rate, which is due to these values being the absolute values, and not the relative values. Each nestbox feeder was observed a different number of hours, meaning that we should look at the mean feeder visit rate (visits corrected for number of hours observed). For the females, this number is 3.7, and for the males, 2.5. For the general feeder, a total of 29 unique males and 6 unique females visited the feeder. For the nestbox feeders, 13 unique males entered the feeder and 7 unique females. Males and females differed significantly in feeder visit rates (Mann-Whitney U test W = 72, p = 0.0001, Figure 9) for the general feeders during this period. Nestbox feeder visit rates during this period did not differ significantly between males and females (Mann-Whitney U test W = 69, p = 0.07, Figure 10). Figure C-3 (appendix),

shows the feeders entrances per feeder number, separated into nestbox feeders and general feeders, and displays which individual female hihi visited each feeder.

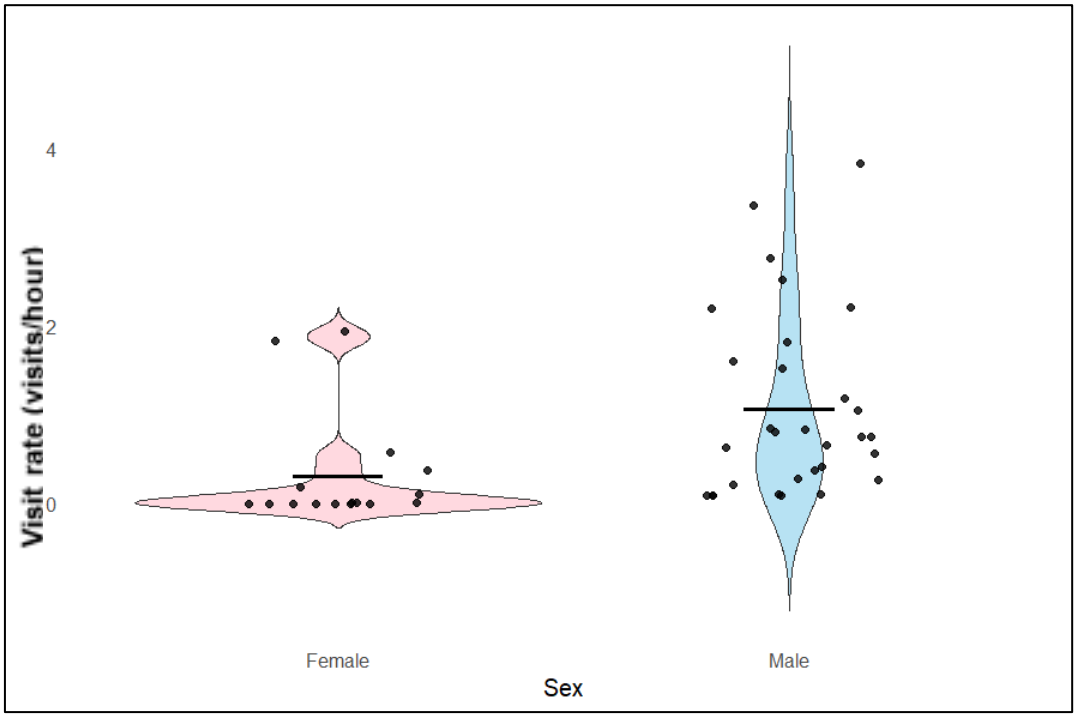

Figure 9: Feeder visit rate in the second period for the general feeders, when nestbox feeders were present in the forest. These datapoints only consist of observations at the general feeder. Females that never visited the feeder were given a feeder visit rate of 0. Males: n = 29, Females, n = 14.

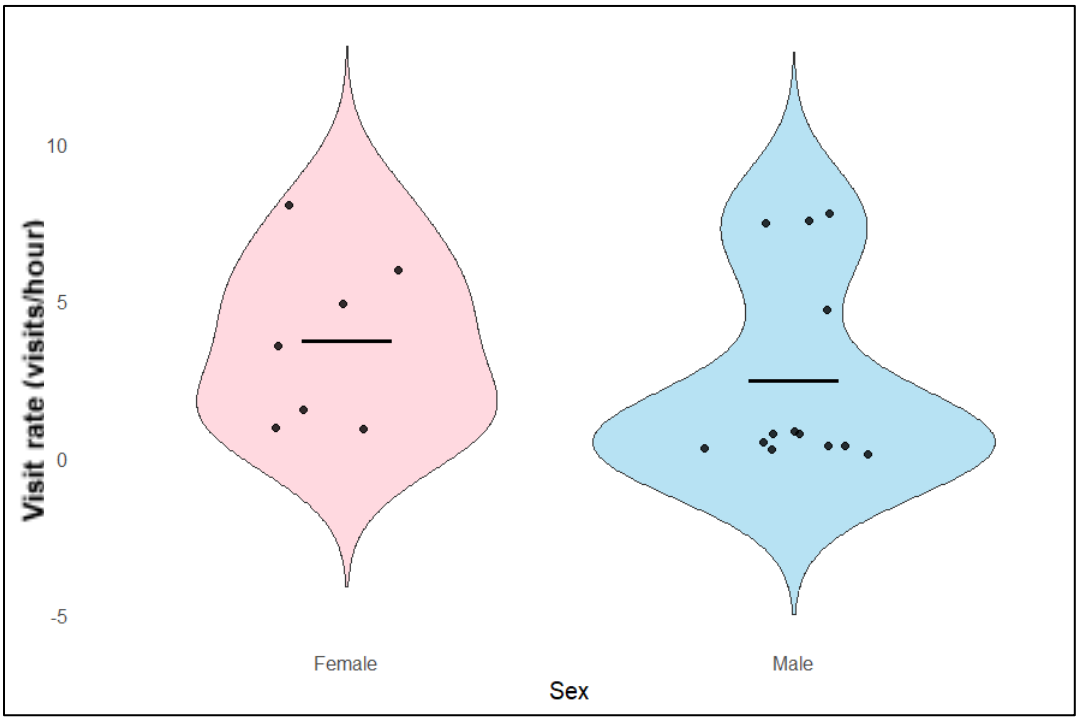

Figure 10: Feeder visit rate in the second period for the nestbox feeders, when these were present in the forest. These datapoints only consist of observations at the nestbox feeder. Males: n = 13, Females, n = 7.

Feeder visit duration

The GLM (Table 2) revealed that sex was not a significant predictor of feeder visit duration. However, there was a significant effect of feeder type on duration (Table 2, Figures 11 & 12).There was no significant effect of the interaction between sex and feeder type.

Table 2: Generalised linear model for the effects of Feeder type and Sex on Feeder visit duration

Term	Estimate	Std. Error	Pr(>|t|)
(Intercept)	0.0164851	0.0014857	<0.0001
Feeder type	0.0055210	0.0023421	0.02
Sex	0.0022838	0.0017283	0.19
Feeder type × Sex	0.0007651	0.0031135	0.81

Figure 11: Feeder visit duration of females in the second period for the general feeders and the nestbox feeders, when nestbox feeders were present in the forest. N = 14.

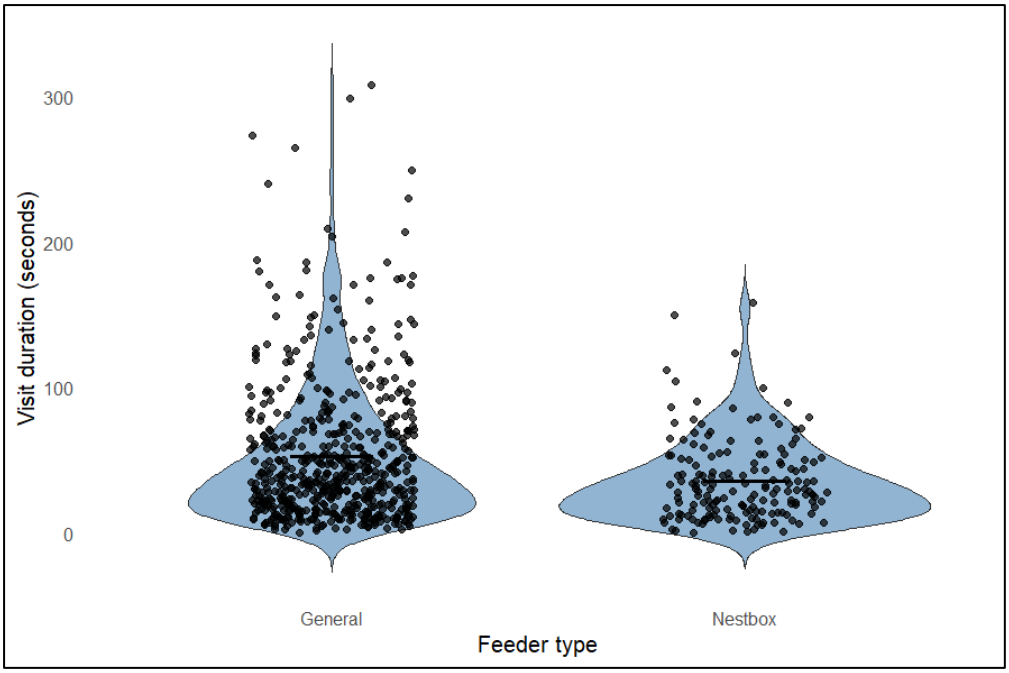

Figure 12: Feeder visit duration of males in the second period for the general feeders and the nestbox feeders, when nestbox feeders were present in the forest. N = 29

Drinking rate

The drinking rate at the feeders differed significantly between sexes, with males overall drinking more often than females (Table 3). Overall usage of both types of feeders did not differ, yet males drank significantly more at the general feeders than at the nestbox feeders, while the drinking rate did not differ for females at the two feeder types (Table 3, interaction term, Figure 13). Females had a mean drinking rate of 5.02s/drinking event at the general feeder and 4.66s/drinking event at the nestbox feeder. Males had a mean drinking rate of 6.24s/drinking event at the general feeder, and 4.23s/drinking event at the nestbox feeder.

Table 3: Generalised linear model for the effects of Feeder Type and Sex on Drinking rate

Term	**Estimate**	**Std. Error**	**Pr(>|t|)**
(Intercept)	0.19746	0.01152	< 0.0001
Feeder type	0.01722	0.01618	0.29
Sex	-0.03811	0.01258	0.003
Feeder type × Sex	0.05433	0.02023	0.007

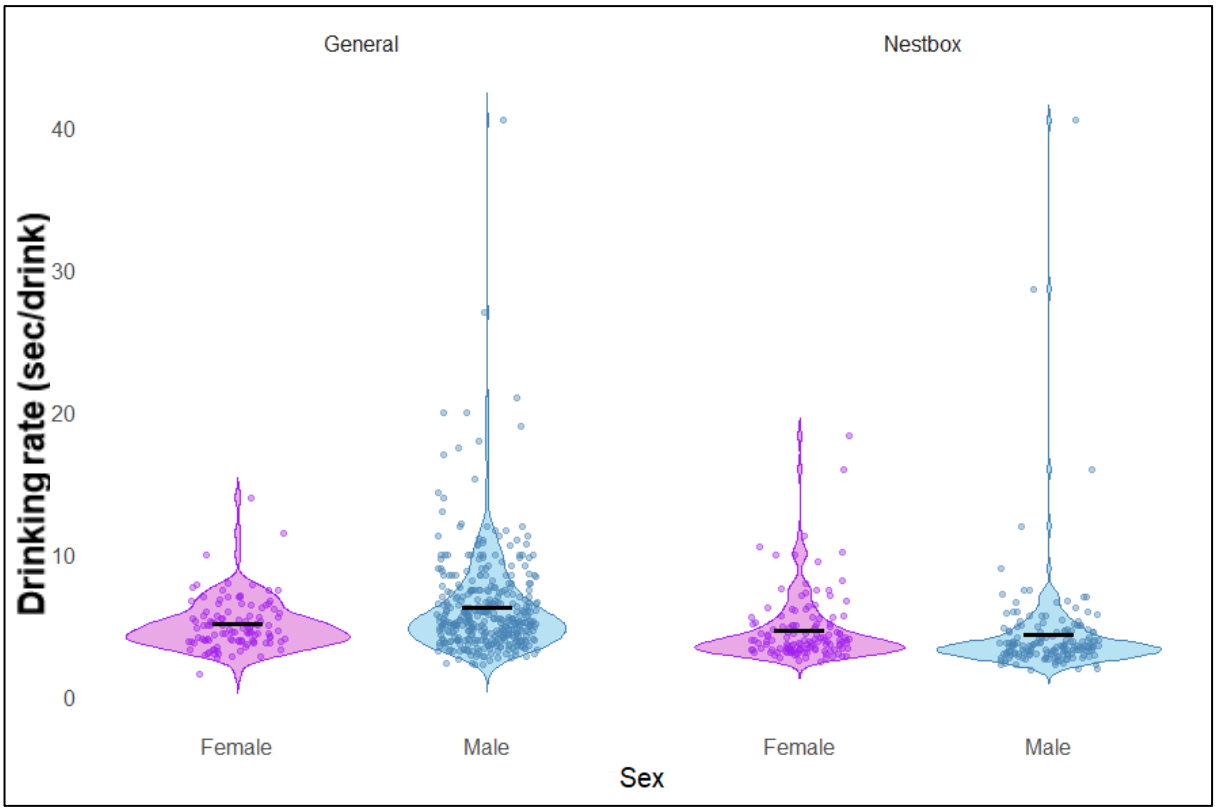

Figure 13: Drinking rate of male and female hihi in the second period for the general feeders and the nestbox feeders, when nestbox feeders were present in the forest. Males: n = 29, Females: n = 14.

Harassment rate

Harassment of females by males did not differ between feeder types (Mann-Whitney U test, W = 10, p = 0.27, Figure 14), yet females rarely visited the general feeders and extra-pair males rarely visited the nestbox feeders. Figure C-5 (appendix) reveals the harassment rate per feeder number and type. The harassment network for the general feeders shows that two specific females were attacked by many different male hihi, including bellbirds (korimako). The nestbox network does not reveal many such interactions (Figure 15). Females were only harassed at one of the seven nestbox feeders (appendix Figure C-4). The harassment network at the nestbox feeder shows that other hihi than the breeding pair visited and got harassed at this feeder. The breeding pair from this nestbox was DG/M-W (male) and LB/M-O (female). All breeding pairs from this season are shown in the appendix (Table A-1).

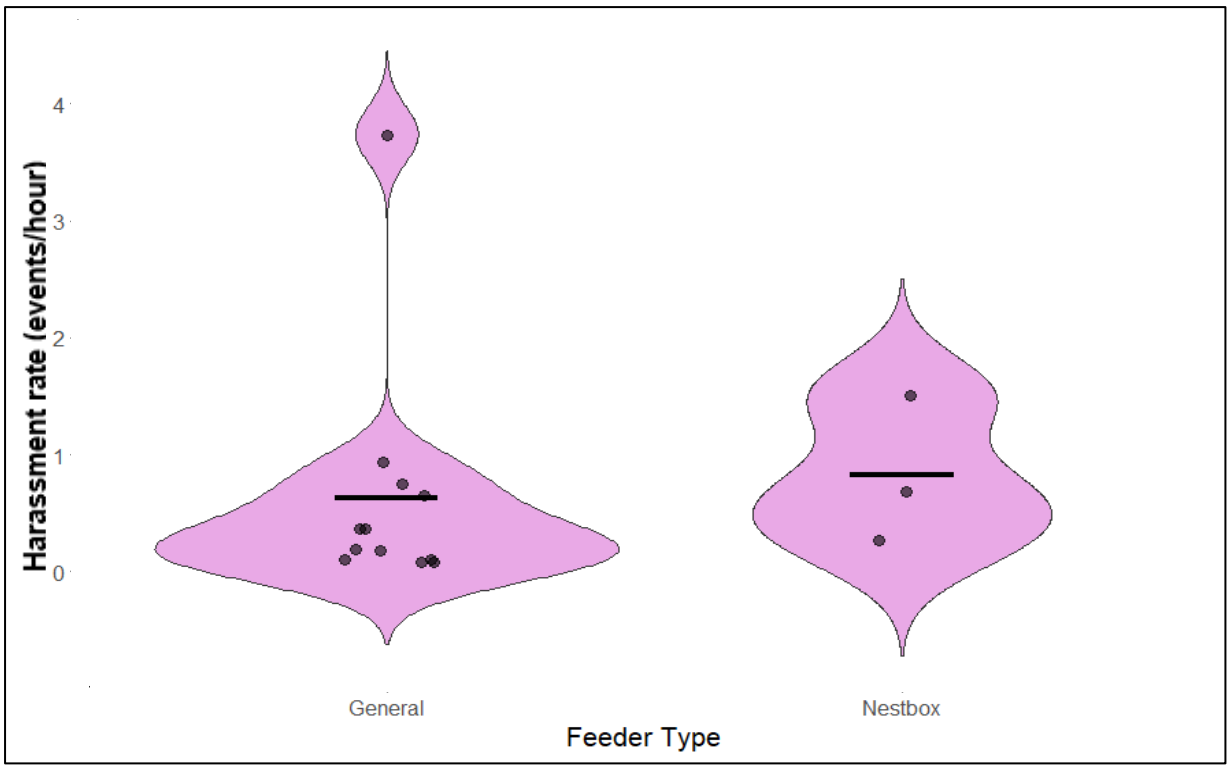

Figure 14: Harassment rate of females in the second period for the general feeders and the nestbox feeders, when nestbox feeders were present in the forest. Females: n = 7.

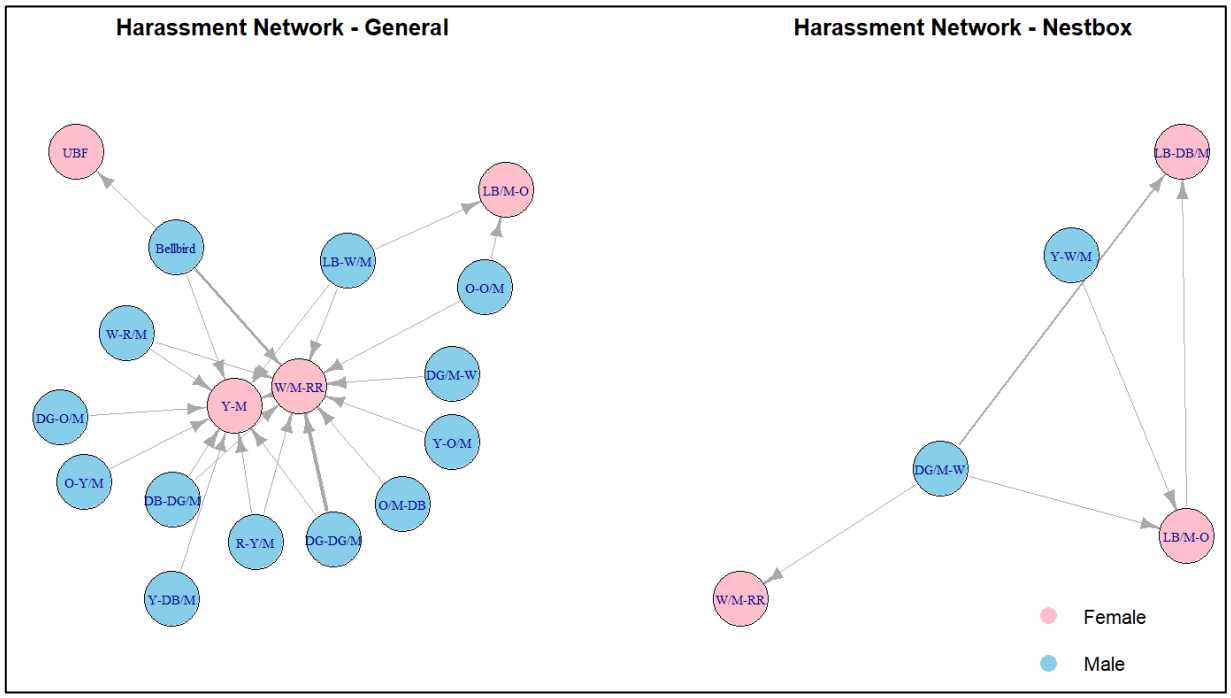

Figure 15: Social network of female harassment when nestbox feeders were present in the forest. Females: n = 7. A harassment event is visualised with an arrow from the attacker towards the victim. The thickness of the lines represents the number of times an individual attacked/was attacked.

Discussion

The results reveal that males visited the general feeders significantly more than females at times when there were no extra nestbox feeders present in the forest. During this period hardly any female was observed at these feeders. Yet, once we placed feeders at the individual nestboxes, females used these feeders as much as their mates, while almost no other birds used those feeders. These findings overall are in line with my predictions that female hihi would visit the hihi less often compared to male hihi, and that the primary cause could be male harassment at general feeders. These findings have wider implications for discussions on the use and placements of feeders as a conservation tool in a territorial species, as discussed below.

Feeder visit rate

The results on feeder visit rate indicated a significant difference in feeder entrance rate between males and females at the general feeders, prior to the period when nestbox feeders were introduced in the forest. Female hihi visited the general feeders less frequently than males, which is in line with my predictions. During the breeding season, feeder visits at the supplementary feeding stations increase rapidly (Roper & Brunton, 2024), but my results show that of most these visits are not made by female hihi, but by males. Hihi conservation reports from Tarapuruhi Bushy Park state that more sugar water is consumed by the birds during the breeding season (Brooke, 2024), and the same is true for other hihi populations, such as on Kapiti Island, where hihi are provided with increased sugar water supply during the breeding months (Correia, 2013). Roper and Brunton (2024) found that females visited the feeder more often than males outside of the breeding season. In contrast, they found that males visited the feeder more often than females during the breeding season. My study was conducted solely during months of the breeding season (October to January), thus the lower number of feeder visits by females and a high visit rate by males during this period is in line with the findings of Roper and Brunton (2024). Likewise, male hummingbirds visit feeders more often than females, and this difference is likely due to resource-guarding behaviour and trying to keep other males away from the feeders (Bandivadekar, 20

A comparable situation could occur at the hihi feeding stations, as hihi are territorial birds and the general feeders are placed in territories of certain individual males (Low, 2005). Therefore, it is highly likely that many feeder visits are paid by the dominant males at the feeders. The presence of territorial calls in certain territories indicates which males are dominant at particular feeders. Hihi emit calls to mark their territory, which are recognised by a three-note-whistle (Low, 2005). There were large differences in visit rates of hihi between the five general feeders. At one of the feeders, many different males emitted territorial calls, indicating no clear dominant male. This feeder was also the most visited by male hihi, and rarely by any female hihi. Other feeders had clear dominant males and were not often visited by other birds due to monopolisation of this feeder by the dominant male. One feeder was not dominated by a male hihi, but by a male korimako. Korimako are more dominant than hihi (Roper & Brunton, 2024) and are the only other species known to use the supplementary feeding stations at Tarapuruhi Bushy Park. Although this study does not focus on the presence of korimako, these birds have been found to sometimes exclude hihi from feeding stations, but they do not significantly prevent hihi from entering the feeding stations (Roper & Brunton, 2024). At the feeder dominated by korimako (feeder 1), and feeders where one male hihi dominated the feeder (Feeders 3, 4, and 5), females would sometimes visit. However, visit rates by female hihi were still very low at all general feeders. Female hihi might prefer to visit feeders that are dominated by one male, as total feeder visits are relatively low. To avoid harassment by males, these females might have more chance of successfully drinking at a general feeder if they only need to avoid one male, instead of aggregations of males at a feeder without a clear dominant male.

At the start of the breeding season, some females were building nests, laying eggs and incubating eggs, which are costly activities (Nilsson & Raberg, 2001; Mainwaring & Hartly, 2013; Nord & Williams, 2015). Therefore, visits to the general feeders would have provided them with energy to sustain

themselves, and feeder visits during this period could be beneficial for their reproduction. However, females barely visited the feeders during this period. It is possible that they found sufficient natural food sources to sustain themselves and the breeding activities, although other factors likely played a role such as intraspecific competition and harassment by male hihi, which is highest during the breeding season (Castro et al., 1996; Ewen & Armstrong, 2000).

In the second period of this study, when additional nestbox feeders were introduced in the forest, males again visited the general feeders significantly more often than females. Nestbox feeders were added once the chicks hatched to help the breeding pairs with chick rearing and increase the fledging success. They were placed in the territory of the breeding pair, close to the nestbox. Energetic costs are highest during the breeding season, also due to the energetic costs of chick rearing (Golet, 1998), and successful reproduction often depends on the availability of resources (Regular et al., 2014). Because of the nestbox feeders, breeding females with chicks had no need to visit the general feeders, as they could stay close by and drink from the nestbox feeders.

Six different females visited the general feeders during this period. The reason that there were visits by female hihi to the general feeders at all, even though females had access to nestbox feeders, is because sometimes the nestbox feeders would be empty, and the females would have to look for other sources of sugar water. In addition, the nestbox feeders were only hung up when the breeding pair had chicks, but when the chicks fledged, of before the chicks hatched, the females were also in need of sugar water for energy supply (Regular, 2014). Juvenile hihi are still cared for by the parents after hatching until they are a few weeks old (Higgins et al., 2001). The nestbox feeders were not hung up during the full breeding season, thus, to get sugar water, the females still had to visit the general feeders, if the nestbox feeders were empty, or not present at all. Results showed a significant difference in male and female visit rate at the general feeders in both situations. This indicates that during the whole breeding season, the females visited the feeders less than males, and some not at all. It might be beneficial for females be to hang the additional feeders as soon as a nest has been built and only remove the feeder a few weeks after the chicks have fledged. Usually, when a nest has been built, the chances of egg-laying and incubation are very high, which are costly activities (Mainwaring & Hartly, 2013; Nord & Williams, 2015; Ewen et al., 2018). In addition, as juvenile hihi are still cared for by the parents, the breeding pair might benefit from the nestbox feeders to rear the chicks until they are not dependent on them anymore. At two nestbox locations (NB11/12 and NB 33/34), the breeding pair produced two clutches, which both successfully produced fledglings. The year before, no second clutches were produced at all (Brooke, 2024), although hihi can make up to three clutches in a breeding season (Higgins et al., 2001). Whether this is caused by the additional nestbox feeders is too early to say as Doerr et al. (2017) found that feeder-using females did not necessarily attempt second clutches, whereas non-feeder using females did attempt second clutches after a first-clutch attempt. However, it would be interesting to see how the breeding success evolves in the hihi population at Tarapuruhi Bushy Park, due to the placements of additional nestbox feeders.

At the nestbox feeders, the results show that the feeder visit rate did not differ significantly between males and females. This was expected, as these feeders are placed near the nestbox of a breeding pair, around which the territory is usually built (Low, 2005). Only the breeding pair are expected to visit these feeders, and intruders are expected to be chased away (Low, 2005). The visits come mostly from the breeding pair. As these are both rearing the chicks (Low et al., 2012), the equal visit rate is not surprising, and even a slightly higher visit rate can be seen in the females, which is also in line with the parental care behaviour of hihi, where the females are the main caretakers of the chicks, and males visit the chicks less often (Higgins et al., 2001).

When looking at the individual female hihi that visited the feeders, two of them stick out. One female (LB/M-O) that nested in nestbox 11/12 often visited general feeder 3, which was located in the territory of a highly dominant male. Her visits usually occurred when her feeder at the nestbox was empty or

had tipped over. This female usually had access to general feeder 3, without the dominant male chasing her away. This male did chase away other females, and other male hihi. This is interesting because the dominant male from general feeder 3 is not the female's social partner. This dominant male was never spotted at the female's nestbox location during my observations.

Hihi have very complicated mating systems, with females and males mating with multiple partners (Castro et al., 1996). There is a possibility that this male allowed access to 'his' general feeder in exchange for extra-pair copulations. This behaviour is for example seen in the red-winged blackbird (*Agelaius phoeniceus)* (Gray, 1997). In this species, it was found that females that copulated with extra-pair males were allowed to feed in the extra-pair male's territory. However, for my study, I do not have evidence of this female hihi copulating with the male from feeder 3, nor do I have evidence that one or more of the chicks in her brood were genetically related to this male, as we did not perform any genetic testing. It would be highly interesting to see if this relationship between the female from nestbox 11/12 and the male from general feeder 3 will remain in future breeding seasons, whether there are copulations between these individuals and whether the chicks are related to this male.

Another female that had a relatively high general feeder visit rate was W/M-RR. This female had a natural nesting cavity, and did not nest in an artificial nestbox. No nestbox feeder was hung up at this nest because this female's nesting location was only found after the chicks had hatched, and this female seemed to have no problems entering the general feeder. This female was also seen at a nestbox feeder, placed in the territory of another breeding pair, thus this bird managed to drink from both general and nestbox feeders. It is however unclear whether her chicks survived as we did not see any evidence of chicks fledging. This female is an example of a female that managed to use the general feeders and kept using them throughout the breeding season.

I found a significantly higher feeder visit rate for males compared to females at the general feeders in both periods studied during my research, but no difference in feeder visit rate at the nestbox feeders. In this study, only the breeding females received extra nestbox feeders. However, there are many female hihi in the forest that were not observed at any feeder, neither at the general feeders nor at the nestbox feeders. It would therefore be interesting to determine what female hihi consume instead of sugar water during the breeding season, if they do not visit sugar water feeders. Hihi feed on nectar, which is mimicked by the supplemented sugar water, but they eat fruit and invertebrates as well. The sugar water serves only as a carbohydrate supplement and does not provide a complete diet (Walker et al., 2013). Tarapuruhi Bushy Park is a mature forest, and should contain enough food to sustain the population, even without the feeders. However, the breeding data of Tarapuruhi Bushy Park reveals that breeding success has been low for the past five years (Brooke, 2024). On Mokoia Island, it was found that females that made use of sugar water feeders increased clutch size and fledgling success (Castro et al., 2003). A similar result was found in an ecosanctuary in Maungatautari (Doerr et al., 2017). In addition, ecosanctuaries that try to reduce the amount of sugar water are met with declining hihi populations (Hihi Recovery Group). This suggests that females would benefit from sugar water feeders, and that a higher feeder visit by females would increase growth in the population.

The high dominance of certain hihi males at general feeders and avoidance by females reveal a potential limitation of using general feeding stations as a conservation tool. Because females have less access these feeders, likely due to male harassment, these feeding stations may not support the energetic needs of breeding females. Therefore, conservation efforts should consider the social dynamics of territorial species like the hihi and consider feeder placements that reduce competition and harassment, such as the supplementary feeders near nest sites used in this study. This approach can ensure that females have access to resources during energetically demanding periods, potentially improving breeding outcomes and population viability.

Feeder visit duration

Feeder visit duration did not differ between males and females, indicating that sex was not a significant predictor of the time a hihi spends at the feeder. There is limited literature on feeder duration in hihi, but feeder duration has been researched in other species that make use of supplementary feeders (Aichele et al, 2021; Bandivadekar, 2018; Francis et al., 2018). In hummingbirds, which are also nectar feeders, the females were found to stay for longer periods (Bandivadekar, 2018). In kākā, a New Zealand parrot, no significant difference in duration was found between the sexes (Aichele et al., 2021). However, a difference in duration per age group was found, with juvenile kākā spending the most time on the feeding platforms (Aichele et al., 2021). It would be interesting to investigate whether age affects feeder visit duration in the hihi population, particularly among females. Francis et al. (2018) found that heavier and more dominant bird species spent more time on supplementary feeding platforms in gardens, thus in hihi, dominancy and size might also have an influence on feeder visit duration.

However, I found that feeder type influenced the duration of feeder visits. For both males and females, the visit duration at the general feeder was found to be longer on average, compared to the nestbox feeder. Although I had expected that individuals would spend more time at the nestbox feeder, the results did not confirm this hypothesis. An explanation could be that there was no need for the breeding pair to spend a long time at the nestbox feeder, as this feeder is present in their territory. Although no significant correlation was found between feeder visit rate and feeder visit duration, there may be a trade-off between how long a hihi visits the feeder and how often it visits. Grab-and-go behaviour, where a bird takes for example a seed and consumes it elsewhere, could reduce predation risk and is seen in black-capped chickadees (Lima, 1985). I expected a similar behaviour by female hihi at general feeders to avoid harassment and thus expected them to spend less time at the general feeders compared to the nestbox feeders, where harassment risk is lower. However, if individuals travel longer distances to reach the general feeders, they need to consume enough sugar water to make the energy spent worth it, which is a possible explanation for the longer visit duration at the general feeders. As females were often observed to visit the feeder alone, it is possible that they scan the surroundings to make sure they will not be attacked before entering the feeder. This vigilance inside the feeder was investigated with the drinking rate, discussed in the next section.

The results on feeder visit duration of hihi show that feeder placement and type affect not only visitation rates but also how efficiently birds can use the feeders. Providing feeders in safer locations, such as near nestboxes, could reduce energy costs associated with vigilance and travel, which can increase the benefits of supplementary feeding. These results can be useful for optimising feeder design and placement to support female hihi during energetically demanding periods, such as the breeding season.

Drinking rate

When a hihi enters a feeder station, it immediately puts its beak in one of the holes of the feeder and starts drinking. Hihi have a long tongue with which they lick up the sugar water. They usually drink for a few seconds, and then they look up. They sometimes look around and then they start drinking again. During the process of drinking, the birds are not vigilant, as their heads are faced towards the ground. While foraging, birds and mammals often pause to scan their surroundings, not only as an anti-predator behaviour, but also to detect rivals or potential mates (Beauchamp, 2010). The supplementary feeding stations provide a location where many birds may aggregate (Robb et al., 2008). As hihi are highly territorial and competitive during the breeding season (Castro et al., 1996), an increase of vigilance by nondominant male and female hihi is expected. The drinking rate corresponded to the number of seconds a hihi approximately spent per drinking event. Sex was found to be a significant predictor of drinking rate, and feeder type was not a significant predictor of drinking rate. Both males and females had a lower drinking rate at the nestbox feeder compared to the general feeder. Males had a slightly higher drinking rate than females at the general feeders, which might be explained by some males being dominant at certain feeding stations, raising the mean drinking rate at the general feeders. More

dominant individuals reduce scanning events while in the presence of subordinate individuals (Pravosudov & Grubb, 1999). In general, female hihi are found to be less dominant than male hihi (Roper & Brunton, 2024), causing more scanning events and a lower drinking rate while feeding.

A possible explanation for the higher drinking rate at the general feeder for both sexes is that the males and females at the general feeder tried to increase food intake during each drinking event by decreasing scanning events. If they would look up repeatedly, they would miss out on resources (Olson et al., 2015). In addition, I observed that females often only entered the feeders when there were no other birds around the feeder. Sometimes I would observe a female entering the feeder and get chased away by a male hihi or male korimako. Then, the females would hide higher up in the canopy and only enter the feeder again once the male had left the feeder. Thus, from these observations it seemed that females time their visits to the feeder to avoid other birds. Scanning events are necessary when feeding to detects potential attacks (Lima, 1995). There is a possibility that females scan the surroundings more before entering the feeder, which relieves them from often scanning while in the feeders, although more research is needed on this. Another explanation for the higher drinking rate at general feeders is due to the metal cage surrounding the general feeder. The design of the feeding station excludes larger nectar feeders like tūī and kākā from the feeders (Ewen et al., 2018). Nestbox feeders were not placed in cages, making the drinking birds more vulnerable for competition from other, more dominant, birds. This might increase scanning events, leading to a lower drinking rate. In addition, in kākā, adult females were found to spend the longest time drinking on average (Aichele et al., 2021), with breathing pauses taken into account. In my study, I did not take breathing pauses into account, and I defined the beginning of a drinking event as a bird putting its beak in the hole of the feeder base, and the end as the bird looking up. It is however possible that the birds did not always look up out of vigilance, but simply to breathe. More research on hihi drinking behaviour of hihi at feeders is needed to understand why some individuals spend more time per drinking event than others.

The observed tendency of female hihi to scan more often and to time visits to avoid aggressive male hihi suggests that general feeders dominated by males may not provide optimal feeding conditions for females. It is challenging to reduce competition between male and female hihi at general feeders, but the design of the additional nestbox feeder can be considered to reduce competition from other nectar-feeders. The design of the general feeders, a bottle placed within a metal cage, reduces competition from larger nectar feeders and may allow for more efficient feeding. On the other hand, the more exposed nestbox feeders might increase vulnerability to competition, potentially affecting feeding efficiency. It should first be investigated whether other nectar-feeders are using these nestbox feeders. If this is the case, conservation efforts could explore nestbox feeder designs that improve accessibility for hihi while limiting access for competing species, ensuring that especially female hihi can safely and effectively use the supplementary nestbox feeders.

Harassment rate

Finally, the results showed no significant difference in the harassment rate of females between the general feeders and the nestbox feeders. This is likely due to the low number of harassment events found overall during this study. In general, females always arrived alone at the general feeders and often would only enter the feeder when there were no other birds present. Roper and Brunton (2024) speculated about this female avoidance of male hihi, stating that the females seemed to avoid male hihi during the breeding season. To fully understand the whole picture, it is necessary to find a way to quantify how often females avoid other birds. As the feeder visit rate indicated, females did not visit the general feeders often, so there were few opportunities for harassment. This leads back to the male-skewed sex ratio at Tarapuruhi Bushy Park, with about twice as many males as females. Nonbreeding males thus may try to intercept females while foraging at general feeders and force them into extra-pair copulations (Castro et al, 1996; Ewen et al, 2011). The fact that only one third of the known females at Tarapuruhi Bushy Park visited the feeders is in line with these considerations.

At the nestbox feeders, there were more female feeder visits, but still few harassment occurrences. A social network on the harassment events gives a more in-depth overview on which females were attacked and by which birds. First, it shows that especially two female hihi are attacked by many different male hihi at the general feeders, and also by korimako. These females are Y-M and W/M-RR. W/M-RR did not have a nestbox feeder, and the only way for her to get sugar water was to visit the general feeders. This meant that there were more occasions for her to be attacked. Y-M was also harassed by many male hihi, and the individual feeder visit rates show that she has visited all general feeders at least once. These visits likely occurred at times when she was not actively rearing chicks, and no nestbox feeder was present in her territory.

At the nestbox feeder, multiple individuals were attacked. The breeding female of this nestbox (LB/M-O) was attacked by an outsider male (Y-W/M). There are also two other females visiting this nestbox feeder, W/M-RR and LB-DB/M. W/M-RR was harassed by the social male of this nestbox (DG/M-W), and LB-DB/M was harassed both by the male and female of this nestbox. This was expected because these females were drinking from a feeder in another bird's territory. Male hihi are known to be aggressive towards females, especially extra-pair males (Ewen et al., 2011). These extra-pair males use a forceful method of mating with females, called face-to-face copulations. I only saw this behaviour twice during my study, and thus I cannot state that this behaviour is a large problem in the hihi population at Tarapuruhi Bushy Park. However, there is a decline of females, and a male-biased sex ratio. In a study on the effects on female survival of hihi in a male-biased population on Tiritiri Matangi, no clear evidence was found that a male-biased sex ratio, and thus an increased harassment rate of males towards females, caused a decline of the females and thus extinction of the population (Ewen et al., 2011). The same study did find that less fledglings per female were produced but also found that more females were willing to breed in a population with a male-biased sex ratio. A possible explanation is the ad-libitum sugar water feeding, provided to all populations of hihi. This supplementary feeding may have given the females the opportunity to raise young despite the harassments from males (Ewen et al., 2011). It is possible that the low number of females in Tarapuruhi Bushy Park is sufficient to prevent population extinction, as long as the birds are fed ad-libitum sugar water. However, this study found that not all known females use the supplementary feeding stations, thus further research on the feeding patterns of the female hihi in Tarapuruhi Bushy Park is warranted. Although overall few harassment events towards female hihi were observed, almost none occurred at the nestbox feeders. This suggests that these nestbox feeders could be a positive addition for breeding pairs, and especially for female hihi to aid in chick rearing without the risks associated with visiting the general feeders. Females showed interesting behaviours, such as visiting feeders alone and timing visits to avoid males, likely to mitigate aggressive interactions, especially at the general feeders. The male-biased sex ratio at Tarapuruhi Bushy Park potentially limits female access to the general feeders and increases stress. For conservation, this means that placing nestbox feeders, situated within territories, may provide a safer location for females to feed.

Conclusion and implications for conservation

This study explored the feeder patterns in a population of hihi in Tarapuruhi Bushy Park, with a particular focus on female hihi. Female hihi are in the minority in this population, and the causes of this male-biased sex ratio are largely unknown. The hihi are fed ad libitum sugar water at supplementary feeding stations located at five locations in the forest. During the breeding season of the year this study was conducted (2024-2025), additional supplementary feeders were placed in the territories of breeding pairs that produced hachlings to aid in chick rearing. Since little is known about female hihi in general, this study aimed to provide deeper insights into their feeder behaviour patterns.

The findings from this study show that female hihi visit general feeders less often than males and could benefit from nestbox feeders, which may reduce competition and harassment. While the Hihi Recovery Group aims to eventually phase out the supplementary feeding in reintroduced hihi populations, these results emphasise a potential strategy to specifically support female hihi. Therefore, the Hihi Recovery Group might consider implementing additional nestbox feeders, either as a replacement for or alongside the general feeders, in populations where females are in the minority, such as at Tarapuruhi Bushy Park.

It is important to note that this was the first year Tarapuruhi Bushy Park placed feeders near nestboxes to aid chick-rearing. While the results indicate that females benefit from these nestbox feeders, their long-term viability remains uncertain. It is possible that the observed benefits are partly due to other birds being unaware of the nestbox feeders, as they are a new addition. Additionally, since nestbox feeders are not placed year-round but only during the breeding season for birds that need them, this limited availability may reduce habituation by other birds than the breeding pair. Nonetheless, if these nestbox feeders are implemented, it will be essential to continue monitoring their use over the coming years to determine whether other birds, such as nectar-feeding species like korimako or tūī, in addition to the hihi breeding pairs, begin to use them.

The hihi population in Tarapuruhi is relatively small, particularly the number of females, which could provide an opportunity for a more individual-based research approach. Almost all females carry bands with a unique colour combination, making it easy to identify them. By closely examining the feeder visitation patterns of individual females, explicitly noting which ones do or do not use the feeder, valuable insights can be gained into their specific needs and energetic requirements. Additionally, understanding the types of food hihi parents provide to their chicks could be helpful for ecological restoration efforts, such as planting those specific plant species that the hihi are known to feed on. It would also be interesting to investigate potential differences in breeding success between females that use nestbox feeders and those that do not.

In conclusion, the results indicate that nestbox feeders could benefit females in chick rearing by providing better access and reducing harassment. However, further research is needed to assess the practicalities of implementing nestbox feeders, including the increased vulnerability to predators in open nestbox feeders, the effort required to manage them, and when and for how long the additional nestbox feeders are placed near nestboxes. At the moment, it is too soon to determine their long-term effectiveness for the population. Additional trials will be necessary to evaluate whether this approach can help to increase the hihi population at Tarapuruhi Bushy Park. Overall, this study lays important groundwork for understanding the supplementary feeding use of female hihi in ecosanctuaries and opens the door for further research in this area.

Acknowledgements

I would like to sincerely thank everyone who has helped me throughout this research project. First, I am grateful to my supervisor, Prof. Dr. Marc Naguib, for his guidance during the entire process.I greatly appreciated his knowledge and supervision, and a highlight was that he came to visit us in Tarapuruhi Bushy Park. I am grateful that he made this experience in New Zealand possible for both Amber and me. A very special thanks goes out to Amber Buijsen, with whom I travelled to New Zealand and who researched this special bird with me. We had an incredible experience together and she made those months abroad so much easier. I want to thank her for all her support and all the fun times we spent together. I thoroughly enjoyed our entire journey to the other side of the world.

I would like to thank Mandy Brooke, former manager of Tarapuruhi Bushy Park, for the incredibly warm welcome and a great introduction to Bushy Park and providing us with everything we needed to begin our work. She left an incredible impact on Tarapuruhi Bushy Park and her passion and positivity is inspiring. Many thanks also go out to Rosi Merz, sanctuary manager of Tarapuruhi Bushy Park. It was amazing getting to know her and working together with her. I wish her all the best in the future in managing this beautiful sanctuary. I am also grateful to Doug Armstrong and Erin Patterson for their valuable guidance in monitoring the hihi breeding season. Their expertise and dedication greatly improved our understanding and efforts of monitoring this special bird. Sincere thanks to Dale Pullen and John Nielsen for being great hosts and facilitating our stay at Tarapuruhi Bushy Park. It was a pleasure to get to know them. I am extremely thankful to Doug and Sharon Maclean, neighbours of Tarapuruhi Bushy Park, whom we were so lucky to meet and get to know. Their love for the birds in Bushy Park is heartwarming and we loved sharing all the stories of our research with them.

I would also like to express my deep appreciation to all the volunteers of Tarapuruhi Bushy Park. They made our stay a wonderful experience and their efforts and dedication to the forest are truly admirable. The hihi is a very special bird and I really loved getting to know so many individuals in Tarapuruhi Bushy Park. I grew extremely attached to these birds and I miss them dearly. It makes me happy that they are cared for so well by all the amazing volunteers, whom I also miss so much. I will cherish the memories I made there for the rest of my life.

Finally, I want to thank my family for all their support during my journey to New Zealand. I am incredibly grateful that they always encourage me to follow my dreams, even when these send me so far from home. I especially want to thank my partner, Nathan, who has offered me constant support and care throughout this entire experience. I could not have wished for a more supportive partner.

AI statement

I hereby state that I used AI (ChatGPT 3.5, May 2025) to improve phrasing in parts of my written work to improve word flow and clarity. I also used ChatGPT 3.5, May 2025 to help with data analysis in Rstudio for troubleshooting and solving errors in the code.

References

Aichele, A., Seddon, P., & van Heezik, Y. (2021). Intake of sugar water by kākā in Orokonui Eco-sanctuary. *New Zealand Journal of Ecology*, *45*(1), 1–5.

Armstrong, D. P., & Perrott, J. K. (2000). An experiment testing whether condition and survival are limited by food supply in a reintroduced hihi population. *Conservation Biology*, *14*(4), 1171-1181.

Bandivadekar, R. R., Pandit, P. S., Sollmann, R., Thomas, M. J., Logan, S. M., Brown, J. C., Klimley, A. P., & Tell, L. A. (2018). Use of RFID technology to characterize feeder visitations and contact network of hummingbirds in urban habitats. *PLOS ONE*, *13*(12), e0208057. https://doi.org/10.1371/journal.pone.0208057

Beauchamp, G. (2010). A comparative analysis of vigilance in birds. *Evolutionary Ecology*, *24*(5), 1267–1276. https://doi.org/10.1007/s10682-010-9358-5

Bull PC, Whitaker AH 1975. The amphibians, reptiles, birds and mammals. In: Kuschel G ed. Biogeography and ecology in New Zealand. The Hague, Dr W. Junk. Pp. 231–276. Buller WL 1874. On the ornithology of New Zealand.

Brekke, P., Cassey, P., Ariani, C., & Ewen, J. G. (2013). Evolution of extreme-mating behaviour: Patterns of extrapair paternity in a species with forced extrapair copulation. *Behavioral Ecology and Sociobiology*, *67*(6), 963–972. https://doi.org/10.1007/s00265-013-1522-9

Brooke, M. (2024). Hihi report for Tarapuruhi Bushy Park 2023-2024.

Burns, B., Innes, J., & Day, T. (2011). The use and potential of pest-proof fencing for ecosystem restoration and fauna conservation in New Zealand. *Fencing for conservation: restriction of evolutionary potential or a riposte to threatening processes?*, 65-90.

Castro, I., Minot, E. O., Fordham, R. A., & Birkhead, T. R. (1996). Polygynandry, face-to-face copulation and sperm competition in the Hihi *Notiomystis cincta* (Aves: Meliphagidae). *Ibis*, *138*(4), 765–771. https://doi.org/10.1111/j.1474-919X.1996.tb08834.x

Castro, I., Brunton, D. H., Mason, K. M., Ebert, B., & Griffiths, R. (2003). Life history traits and food supplementation affect productivity in a translocated population of the endangered Hihi (Stitchbird, *Notiomystis cincta*). *Biological Conservation*, *114*(2), 271–280. https://doi.org/10.1016/S0006-3207(03)00046-6

Castro, I., Mason, K. M., Armstrong, D. P., & Lambert, D. M. (2004). Effect of Extra-Pair Paternity on Effective Population Size in a Reintroduced Population of the Endangered Hihi, and Potential for Behavioural Management. *Conservation Genetics*, *5*(3), 381–393. https://doi.org/10.1023/B:COGE.0000031146.51681.b0

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M., & Palmer, T. M. (2015). Accelerated modern human–induced species losses: Entering the sixth mass extinction. *Science Advances*, *1*(5), e1400253. https://doi.org/10.1126/sciadv.1400253

Chauvenet, A. L. M., Ewen, J. G., Armstrong, D. P., Coulson, T., Blackburn, T. M., Adams, L., Walker, L. K., & Pettorelli, N. (2012). Does supplemental feeding affect the viability of translocated populations? The example of the hihi. *Animal Conservation*, *15*(4), 337–350. https://doi.org/10.1111/j.1469-1795.2012.00522.x

Cooper, R. A., & Millener, P. R. (1993). The New Zealand biota: Historical background and new research. *Trends in Ecology & Evolution*, *8*(12), 429–433. https://doi.org/10.1016/0169-5347(93)90004-9

Correia, D. L. P. (2013). *The Role of Supplementary Feeding in Conservation: The Example of the Hihi (Notiomystis Cincta)* (Doctoral dissertation, Department of Life Sciences, Silwood Park, Imperial College London).

Cortés-Avizanda, A., Blanco, G., DeVault, T. L., Markandya, A., Virani, M. Z., Brandt, J., & Donázar, J. A. (2016). Supplementary feeding and endangered avian scavengers: Benefits, caveats, and controversies. *Frontiers in Ecology and the Environment*, *14*(4), 191–199. https://doi.org/10.1002/fee.1257

Dale, S. (2001). Female-biased dispersal, low female recruitment, unpaired males, and the extinction of small and isolated bird populations. *Oikos*, *92*(2), 344–356. https://doi.org/10.1034/j.1600-0706.2001.920217.x

Doerr, L. R., Richardson, K. M., Ewen, J. G., & Armstrong, D. P. (2017). Effect of supplementary feeding on reproductive success of hihi (stitchbird, Notiomystis cincta) at a mature forest reintroduction site. *New Zealand Journal of Ecology*, *41*(1), 34-40.

Donald, P. F. (2007). Adult sex ratios in wild bird populations. *IBIS*, *149*(4), 671–692. https://doi.org/10.1111/j.1474-919X.2007.00724.x

Dowding, J. E., & Murphy, E. C. (2001). The impact of predation by introduced mammals on endemic shorebirds in New Zealand: A conservation perspective. *Biological Conservation*, *99*(1), 47–64. https://doi.org/10.1016/S0006-3207(00)00187-7

Duncan, R. P., & Blackburn, T. M. (2004). Extinction and endemism in the New Zealand avifauna. *Global Ecology and Biogeography*, *13*(6), 509–517. https://doi.org/10.1111/j.1466-822X.2004.00132.x

Ewen, J.G.; Armstrong, D.P.; McInnes, K.; Parker, K.A.; Richardson, K.M.; Walker, L.K.; Makan, T.D.; McCready, M. 2018: Hihi best practice guide. Department of Conservation, Wellington, New Zealand. 127 p.

Ewen, J. G., & Armstrong, D. P. (2002). Unusual sexual behaviour in the stitchbird (or hihi) Notiomystis cincta. *Ibis*, *144*(3), 530-531.

Ewen, J. G., & Armstrong, D. P. (2000). Male provisioning is negatively correlated with attempted extrapair copulation frequency in the stitchbird (or hihi). *Animal Behaviour*, *60*(4), 429–433. https://doi.org/10.1006/anbe.2000.1485

Ewen, J. G., Thorogood, R., & Armstrong, D. P. (2011). Demographic consequences of adult sex ratio in a reintroduced hihi population. *Journal of Animal Ecology*, *80*(2), 448–455. https://doi.org/10.1111/j.1365-2656.2010.01774.x

Ewen, J. G., Walker, L., Canessa, S., & Groombridge, J. J. (2015). Improving supplementary feeding in species conservation. *Conservation Biology*, *29*(2), 341-349.

Fenn, S. R., Bignal, E. M., Trask, A. E., McCracken, D. I., Monaghan, P., & Reid, J. M. (2020). Collateral benefits of targeted supplementary feeding on demography and growth rate of a threatened population. *Journal of Applied Ecology*, *57*(11), 2212–2221. https://doi.org/10.1111/1365-2664.13721

FOREST – Bushy Park Tarapuruhi. (n.d.). https://bushypark.nz/forest/#forest-sanctuary

Francis, M. L., Plummer, K. E., Lythgoe, B. A., Macallan, C., Currie, T. E., & Blount, J. D. (2018). Effects of supplementary feeding on interspecific dominance hierarchies in garden birds. *PLOS ONE*, *13*(9), e0202152. https://doi.org/10.1371/journal.pone.0202152

Golet, G. H., Irons, D. B., & Estes, J. A. (1998). Survival costs of chick rearing in black-legged kittiwakes. *Journal of Animal Ecology*, *67*(5), 827–841. https://doi.org/10.1046/j.1365-2656.1998.00233.x

Gonzalez, L. M., Margalida, A., Sanchez, R., & Oria, J. (2006). Supplementary feeding as an effective tool for improving breeding success in the Spanish imperial eagle (Aquila adalberti). *Biological Conservation*, *129*(4), 477-486.

Gray, E. M. (1997). Female red-winged blackbirds accrue material benefits from copulating with extra-pair males. *Animal Behaviour*, *53*(3), 625–639. https://doi.org/10.1006/anbe.1996.0336

Grethen, K. J., Gómez, Y., & Toscano, M. J. (2023). Coup in the coop: Rank changes in chicken dominance hierarchies over maturation. *Behavioural Processes*, *210*, 104904. https://doi.org/10.1016/j.beproc.2023.104904

Hare, K. M., Borrelle, S. B., Buckley, H. L., Collier, K. J., Constantine, R., Perrott, J. K., Watts, C. H., & Towns, D. R. (2019). Intractable: Species in New Zealand that continue to decline despite conservation efforts. *Journal of the Royal Society of New Zealand*, *49*(3), 301–319. https://doi.org/10.1080/03036758.2019.1599967

Higgins, P. J. (2001). *Handbook of Australian, New Zealand & Antarctic birds. Vol. 5, tyrant-flycatchers to chats*. Oxford University Press.

Hihi Recovery Group (2023). Hihi Conservation Annual Report 2023. https://www.hihiconservation.com/media-coverage/hihi-conservation-annual-report-2023/

Holdaway, R. N. (1989). New Zealand's Pre-Human Avifauna and Its Vulnerability. *New Zealand Journal of Ecology*, *12*, 11–25.

Hughes, E. J., Mady, R. P., & Bonter, D. N. (2021). Evaluating the accuracy and biological meaning of visits to RFID-enabled bird feeders using video. *Ecology and Evolution*, *11*(23), 17132–17141. https://doi.org/10.1002/ece3.8352

Innes J, Fitzgerald N, Binny R, Byrom A, Pech R, Watts C, Gillies C, Maitland M, Campbell-Hunt C, Burns B 2019. New Zealand ecosanctuaries: types, attributes and outcomes. Journal of the Royal Society of New Zealand 49: 370-393H

Lima, S. L. (1985). Maximizing feeding efficiency and minimizing time exposed to predators: a trade-off in the black-capped chickadee. *Oecologia*, *66*, 60-67.

Lima, S. L. (1995). Back to the basics of anti-predatory vigilance: The group-size effect. *Animal Behaviour*, *49*(1), 11–20. https://doi.org/10.1016/0003-3472(95)80149-9

Low, M. (2005). Factors influencing mate guarding and territory defence in the stitchbird (hihi) Notiomystis cincta. *New Zealand Journal of Ecology*, *29*(2), 231–242.

Low, M. (2008). Laying gaps in the New Zealand Stitchbird are correlated with female harassment by extra-pair males. *Emu - Austral Ornithology*, *108*(1), 28–34. https://doi.org/10.1071/MU07037

Low, M., Makan, T., & Castro, I. (2012). Food availability and offspring demand influence sex-specific patterns and repeatability of parental provisioning. *Behavioral Ecology*, *23*(1), 25–34. https://doi.org/10.1093/beheco/arr145

Makan, T., Castro, I., Robertson, A. W., Joy, M. K., & Low, M. (2014). Habitat complexity and management intensity positively influence fledging success in the endangered hihi (Notiomystis cincta). *New Zealand journal of ecology*, 53-63.

Mainwaring, M. C., & Hartley, I. R. (2013). The energetic costs of nest building in birds. *Avian biology research*, *6*(1), 12-17.

Management Plan – HIHI Conservation. (n.d.). Retrieved December 10, 2024, from https://www.hihiconservation.com/about/management-plan/

Marinković, S., Hribšek, I., Tatalović, N., & Skorić, S. (2021). A long-term population study of the Eurasian griffon (Gyps fulvus) in Serbia before and following the establishment of a supplementary feeding program. *Ethology Ecology & Evolution*, *33*(2), 137-155.

Miskelly, C. M., & Powlesland, R. G. (2013). Conservation translocations of New Zealand birds, 1863–2012. *Notornis*, *60*(1), 3-28.

Morrison, C. A., Robinson, R. A., Clark, J. A., & Gill, J. A. (2016). Causes and consequences of spatial variation in sex ratios in a declining bird species. *Journal of Animal Ecology*, *85*(5), 1298–1306. https://doi.org/10.1111/1365-2656.12556

Mostrom, A. M. (2003). Chapter 22—Competitive Behavior of Birds at Feeders. In B. J. Ploger & K. Yasukawa (Eds.), *Exploring Animal Behavior in Laboratory and Field* (pp. 247–256). Academic Press. https://doi.org/10.1016/B978-012558330-5/50024-8

Nilsson, J.-Å., & Råberg, L. (2001). The resting metabolic cost of egg laying and nestling feeding in great tits. *Oecologia*, *128*(2), 187–192. https://doi.org/10.1007/s004420100653

Nord, A., & Williams, J. B. (2015). The energetic costs of incubation. *Nests, eggs, and incubation: new ideas about avian reproduction*, 152-170.

O'Donnell, C. F., Clapperton, B. K., & Monks, J. M. (2015). Impacts of introduced mammalian predators on indigenous birds of freshwater wetlands in New Zealand. *New Zealand Journal of Ecology*, *39*(1), 19-33.

Olson, R. S., Haley, P. B., Dyer, F. C., & Adami, C. (2015). Exploring the evolution of a trade-off between vigilance and foraging in group-living organisms. *Royal Society Open Science*, *2*(9), 150135. https://doi.org/10.1098/rsos.150135

Oro, D., Margalida, A., Carrete, M., Heredia, R., & Donázar, J. A. (2008). Testing the goodness of supplementary feeding to enhance population viability in an endangered vulture. *PLoS ONE*, *3*(12), e4084. https://doi.org/10.1371/journal.pone.0004084

Parker, K. A., Ewen, J. G., Weiser, E. L., Rayne, A., Steeves, T., Seddon, P. J., ... & Maitland, M. (2020). Conservation translocations of fauna in Aotearoa New Zealand: a review.

Perrott, J. K., & Armstrong, D. P. (2000). Vegetation composition and phenology of Mokoia Island, and implications for the reintroduced hihi population. *New Zealand Journal of Ecology*, *24*(1), 19–30.

Perrott, J. K., & Armstrong, D. P. (2011). Aspergillus fumigatus Densities in Relation to Forest Succession and Edge Effects: Implications for Wildlife Health in Modified Environments. *EcoHealth*, *8*(3), 290–300. https://doi.org/10.1007/s10393-011-0716-8

Pizzari, T. (2003). Food, vigilance, and sperm: the role of male direct benefits in the evolution of female preference in a polygamous bird. *Behavioral Ecology*, *14*(5), 593-601.

Pravosudov, V. V., & Grubb, T. C. (1999). Effects of Dominance on Vigilance in Avian Social Groups. *The Auk*, *116*(1), 241–246. https://doi.org/10.2307/4089473

Regular, P. M., Hedd, A., Montevecchi, W. A., Robertson, G. J., Storey, A. E., & Walsh, C. J. (2014). Why timing is everything: Energetic costs and reproductive consequences of resource mismatch for a chick-rearing seabird. *Ecosphere*, *5*(12), art155. https://doi.org/10.1890/ES14-00182.1

Robb, G. N., McDonald, R. A., Chamberlain, D. E., & Bearhop, S. (2008). Food for thought: Supplementary feeding as a driver of ecological change in avian populations. *Frontiers in Ecology and the Environment*, *6*(9), 476–484. https://doi.org/10.1890/060152

Roper, M. M., & Brunton, D. H. (2024). Do hihi lose access to supplemental feeders because of the presence of korimako?. *New Zealand Journal of Zoology*, *51*(2), 317-333.

Russell, J. C., Innes, J. G., Brown, P. H., & Byrom, A. E. (2015). Predator-Free New Zealand: Conservation Country. *BioScience*, *65*(5), 520–525. https://doi.org/10.1093/biosci/biv012

Sala, O. E., Stuart Chapin, F., III, Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L. F., Jackson, R. B., Kinzig, A., Leemans, R., Lodge, D. M., Mooney, H. A., Oesterheld, M., Poff, N. L., Sykes, M. T., Walker, B. H., Walker, M., & Wall, D. H. (2000). Global Biodiversity Scenarios for the Year 2100. *Science*, *287*(5459), 1770–1774. https://doi.org/10.1126/science.287.5459.1770

Schoech, S. J., Bridge, E. S., Boughton, R. K., Reynolds, S. J., Atwell, J. W., & Bowman, R. (2008). Food supplementation: A tool to increase reproductive output? A case study in the threatened Florida Scrub-Jay. *Biological Conservation*, *141*(1), 162-173.

Taylor, S., Castro, I. C., & Griffiths, R. (2005). *Hihi/stitchbird (Notiomystis Cincta) Recovery Plan, 2004-09*. Department of Conservation.

Valiente-Banuet, A., Aizen, M. A., Alcántara, J. M., Arroyo, J., Cocucci, A., Galetti, M., García, M. B., García, D., Gómez, J. M., Jordano, P., Medel, R., Navarro, L., Obeso, J. R., Oviedo, R., Ramírez, N., Rey, P. J., Traveset, A., Verdú, M., & Zamora, R. (2015). Beyond species loss: The extinction of ecological interactions in a changing world. *Functional Ecology*, *29*(3), 299–307. https://doi.org/10.1111/1365-2435.12356

Walker, L. K., Armstrong, D. P., Brekke, P., Chauvenet, A. L. M., Kilner, R. M., & Ewen, J. G. (2013). Giving hihi a helping hand: assessment of alternative rearing diets in food supplemented populations of an endangered bird. *Animal Conservation*, *16*(5), 538-545.

Winkworth, R. C., Wagstaff, S. J., Glenny, D., & Lockhart, P. J. (2005). Evolution of the New Zealand mountain flora: Origins, diversification and dispersal. *Organisms Diversity & Evolution*, *5*(3), 237–247. https://doi.org/10.1016/j.ode.2004.12.001

Yang, N., Moermond, T. C., Lloyd, H., Xu, Y., Dou, L., Zhang, K. & Ran, J. (2016). Effects of supplementary feeding on the breeding ecology of the Buff-throated Partridge in a Tibetan sacred site, China. *Plos one*, *11*(1), e0146568.

Appendix

Appendix A: Tables on demographics of hihi population and overview of the observation sessions.

Table A-1: Breeding pairs at the different nestboxes

Nest box ID	Female	Social male
NB10	UBF10	DG-W/M
NB33/34	Y/M	LG-DB/M
NB30	Y-BK/M	Y-DG/M
NB45	UBF45 (Died)	W-M/W
NB11/12	LB/M-O	W-DG/M
NB24	UBF24	W-DB/M
NB17	DB/M-DB	Y-W/M
NB 31	OM-OW	R-DB/M

Table A-2: Overview of the observation sessions. In the analysis, the observation hours of feeder 11 and 12 and 33 and 34 were counted together, as these nests were built by the same breeding pair.

Feeder	Type	Dates observations	Observation sessions	Hours
1	General	21/10/24 – 15/01/25	27	18
2	General	21/10/24 – 15/01/25	27	18
3	General	21/10/24 – 15/01/25	27	18
4	General	21/10/24 – 15/01/25	27	18
5	General	21/10/24 – 15/01/25	27	18
10	Nestbox	12/11/24 – 25/11/24	6	4
11	Nestbox	25/11/24 – 18/12/24	8	5.3
12	Nestbox	07/11/24 – 15/01/25	3	2
31	Nestbox	14/01/25 – 15/01/25	2	1.3
33	Nestbox	12/11/24 – 25/11/24	6	4
34	Nestbox	14/01/25 – 15/01/25	2	1.3
45	Nestbox	25/11/24 – 13/12/24	8	5.3

Appendix B: Ethograms

Table B-1: Ethogram of female behaviour (adapted from Higgins et al., 2001).

Category	Behaviour	Description
Feeder behaviour	Drinking	Has accessed feeder hut, and drinks from the sugar water feeder.
	Enter feeder	Female enters the feeder
	Leave feeder	Female leaves the feeder, flies away
Social interactions	Chased by individual	Bird goes after female, forcing it to leave
	Fighting	Birds hold each other's claws while pecking one another
	Avoiding male	Female does not interact with male and moves away from male without the male chasing or threatening the female
	Chasing	Female goes after another individual, forcing it to leave,
	Threat displays	Vocalisations and female leans forward with tail cocked at 90-degree angle to body, wings are lifted at shoulders.
	Pecked by individual	Female is pecked by a conspecific
	Pecking	Female pecks a conspecific
Reproductive behaviour	Conventional copulation	Members of pair display to each other with feathers of head raised, and wings crossed then vibrated; Also warble. Once on ground, birds give a neck rubbing display, which includes touching bills. Male climbs onto female's back
	Face-to-face copulation	Single male chases female to ground and then mounts her, holding her upside-down on her back, so birds are face to face; female's wings are spread, and she tries to fly, or kicks male, as though trying to escape
Resting behaviour	Perching near feeder	Female is perching near the feeder, not necessarily moving towards the feeder
Vigilance	Scanning surroundings	Female looks around her and seems alert

Table B-2: Ethogram for aggressive interactions male and female hihi, and korimako (adapted from Higgins et al., 2001)

Category	Behaviour	Description
Social interactions	Chased by individual	Is being forced to leave by another bird through a chase
	Fighting	Birds hold each other's claws while pecking one another
	Avoiding male	Male does not interact with male and moves away from male without the male chasing or threatening the female
	Chasing	Male goes after male, forcing it to leave
	Threat displays	Vocalisations and female leans forward with tail cocked at 90-degree angle to body, wings are lifted at shoulders and ear tufts are displayed
	Pecked by individual	Male is pecked by a conspecific
	Pecking	Male pecks a conspecific

Appendix C: Extra explanatory graphs

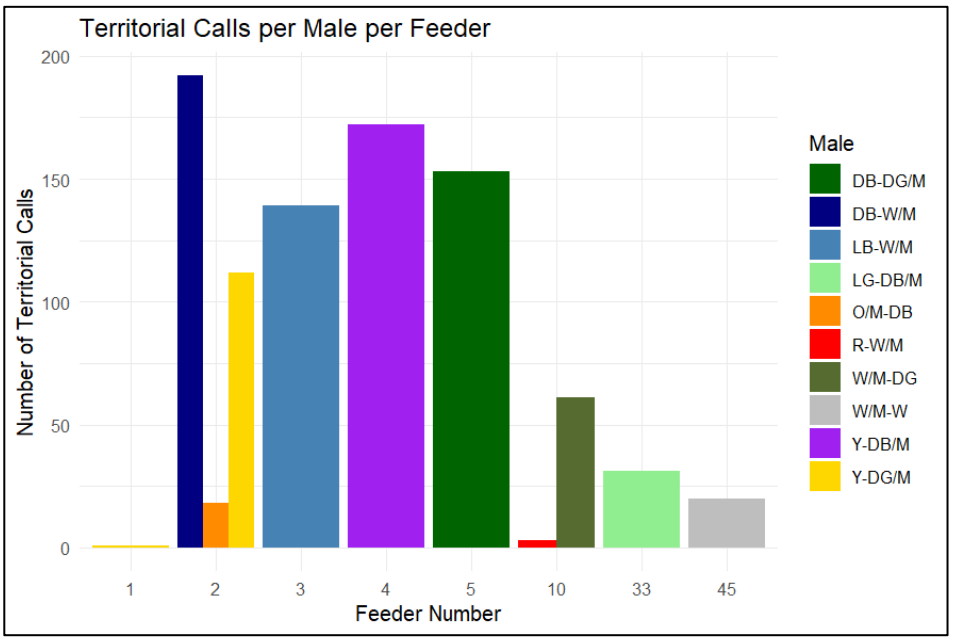

Figure C-1: The number of territorial calls recorded at each feeder. At feeder 3, 4, 5, and nestbox feeders 33 and 45 we can see that only one male is consistently singing, whereas at feeder 2 and nestbox feeder 10, there were multiple males singing. At feeder 1, there are barely any calls at all.

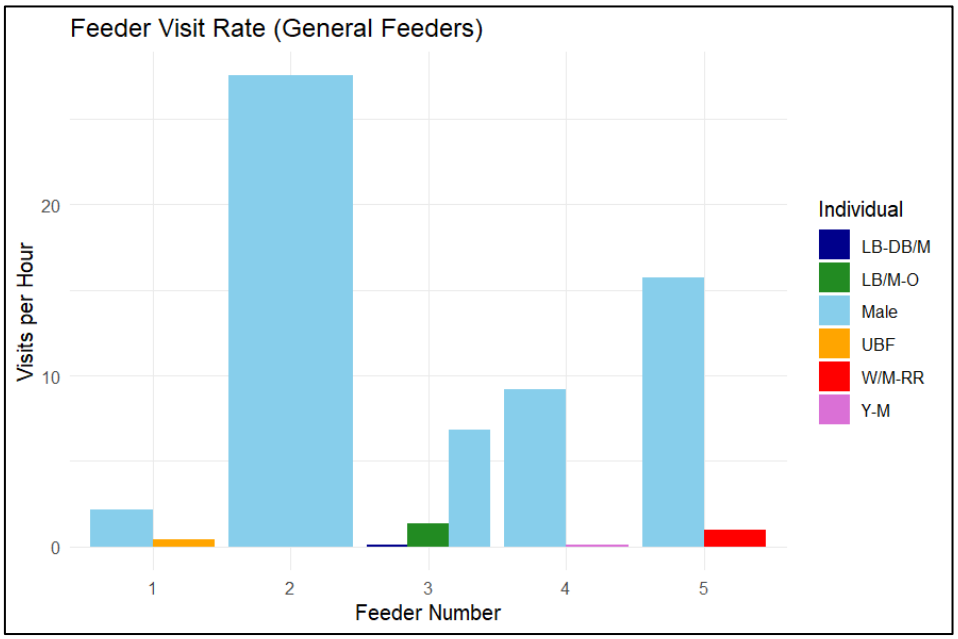

Figure C-2: The distribution of individual females and males visiting the general feeders, when no nestbox feeders were present in the forest. A total of 5 females have been observed to visit the feeder. In total, there should have been about 14 females in Tarapuruhi Bushy Park at this moment in time.

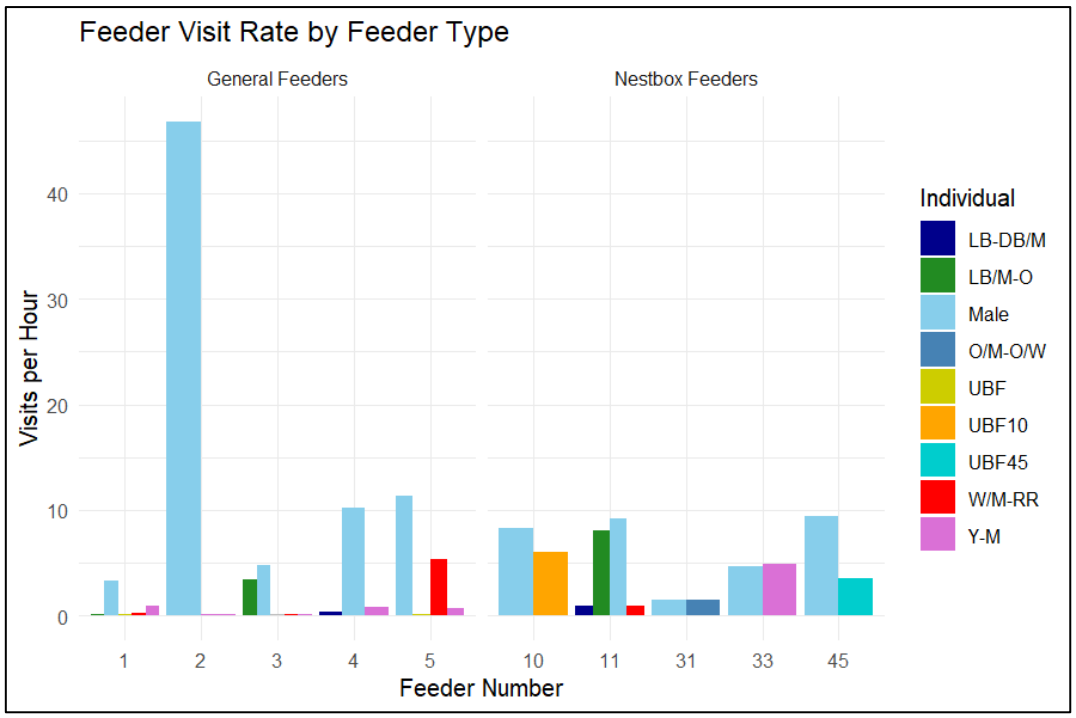

Figure C-3: Distribution of feeder visit rate during the period when nestbox feeders were present in the feeder.

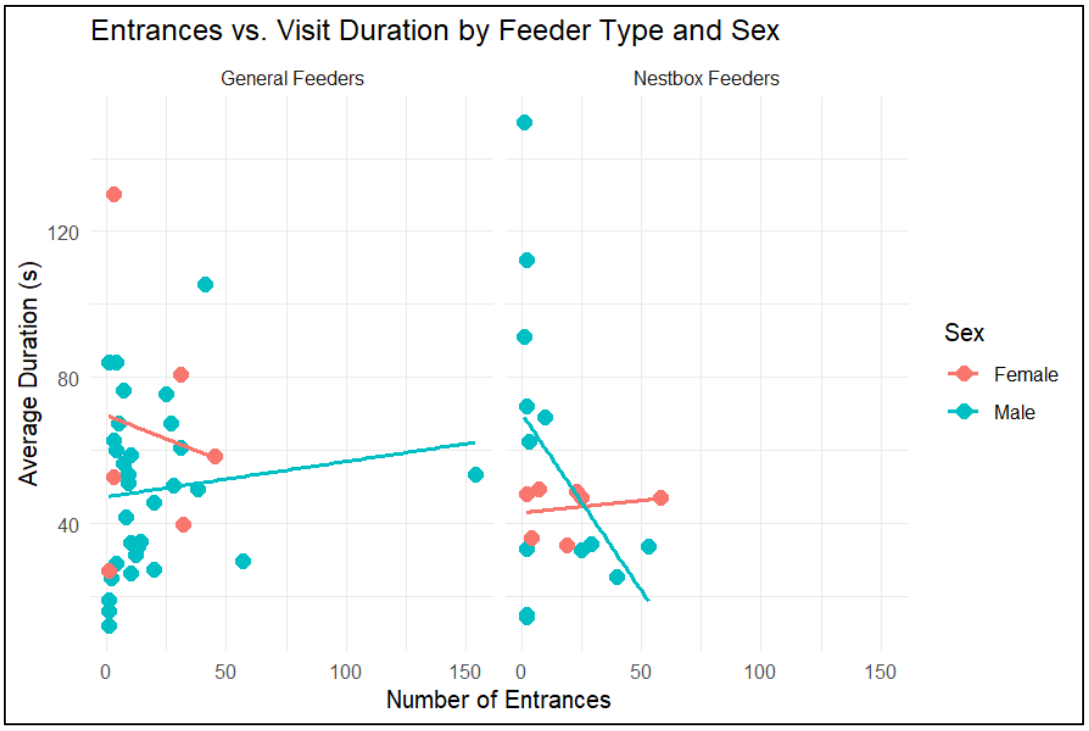

Figure C-4: Correlation between feeder visits and feeder visit durations for male and female hihi across two feeder groups. General feeder: females ($r = 0.232$, $p = 0.66$), males ($r = 0.176$, $p = 0.345$); Nestbox feeder: females ($r = –0.071$, $p = 0.906$), males ($r = –0.425$, $p = 0.148$). No correlations were statistically significant.

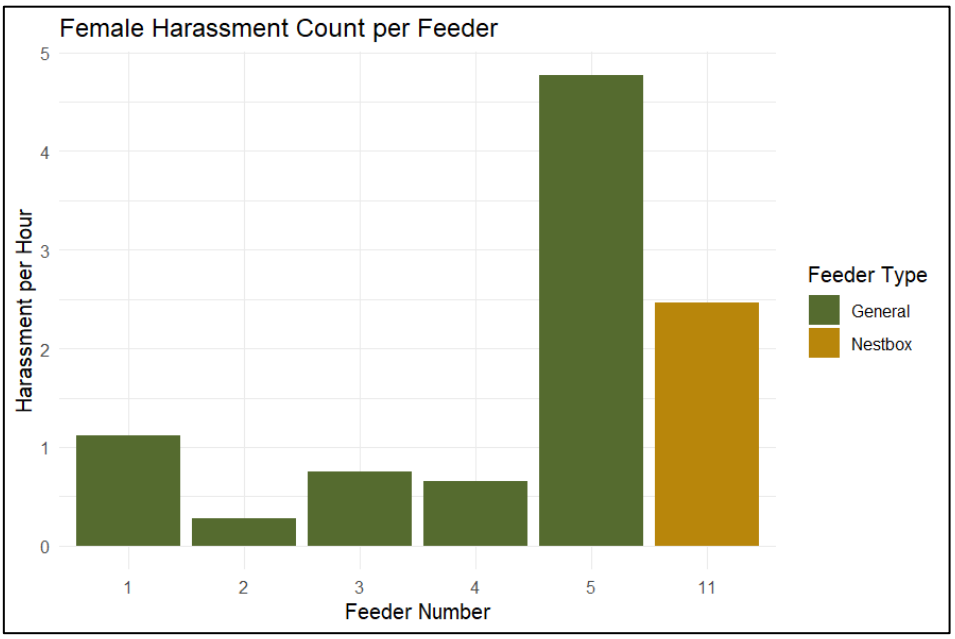

Figure C-5: Harassment rate of female hihi per feeder number and feeder type.