A preliminary study on the diet and breeding success of ruru (*Ninox novaeseelandiae*) on Tiritiri Matangi Island

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This research project was carried out on Tiritiri Matangi Island under a general permit from the Department of Conservation (SKMBT_C280 14121208320) which allows for non-invasive research and monitoring of flora and fauna on the Island.

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Abstract

An observational study on the diet and breeding success of ruru (*Ninox novaeseelandiae)* was undertaken during the 2016-2017 breeding season on Tiritiri Matangi Island. Ten nest sites were monitored. Motion-detecting infrared cameras were used to investigate diet composition, the frequency of prey deliveries, timing and frequency of chick provisioning and the behaviour of ruru and their young. Nest sites that did not have cameras were observed, pellets were collected opportunistically and, after fledging had taken place, nests were excavated to identify prey remains. The objective of the study was to learn more about the breeding success and diet of ruru on the Island, and to investigate the possibility that ruru predation was having a negative impact on species of conservation importance. Ruru have a generalist diet consisting predominantly of abundant invertebrate prey types. However, they are also known to be opportunistic predators of vertebrate prey. On Tiritiri Matangi Island, tree weta (*Hemideina spp.*) were found to be the most common prey type consumed by both adult ruru at the nest site and chicks. Evidence of predation on endangered bird species including hihi (*Notiomystis cincta*) was also found. Breeding pairs were found to have a typical clutch size of two, and a mean fledging rate of 1.1 chicks per nest. In a 'natural' system it is unlikely ruru will have a significant destabilizing effect on uncommon prey populations. However, if such populations are extremely small, genetically depauperate, confined to a small area, or have been recently translocated, the potential impacts of opportunistic predation by ruru may be significant.

Introduction

The ruru or morepork (*Ninox novaeseelandiae)* is a species of forest-dwelling owl, native to New Zealand. The genus is represented throughout much of Australasia, the southwest Pacific Islands, and the Indonesian archipelago with the Australian boobook (*N. novaeseelandiae boobook*) considered to be conspecific with ruru (Stephenson, 1998; Stephenson & Minot, 2006). Ruru are relatively common in New Zealand and are found distributed throughout areas of native forest, as well as within modified habitats such as farmland, pine plantations, and peri-urban green space (Stephenson, 1998; Stephenson & Minot, 2006). They are small at approximately 29 cm and 175 g and have a longevity of approximately 6 years (Morgan & Styche, 2012; Seaton & Hyde, 2013). During the day, they roost amongst foliage of trees and epiphytes, and occasionally in crevices, on ledges, or in burrows (Denny, 2009). After dusk, they leave their roosts to hunt (~~Dylan~~ van Winkel, 2008). They are territorial and have been found to defend a territory of 3.5 to 7.8 ha (Seaton & Hyde, 2013).

Ruru exhibit a monogamous mating system, with their breeding season running from September to February (Seaton & Hyde, 2013). The season begins with pairs roosting together, before moving to a nest with egg laying beginning in October (Stephenson, 1998). Nests are usually found within cavities of dead or live trees, but have also been found in burrows or scrapes on the ground, in thick clusters of epiphytes, in caves, tree forks, and in nest boxes (Denny, 2009; Seaton & Hyde, 2013; Stephenson & Minot, 2006). Nest sites are often reused and so, once found, can be checked annually (Stephenson, 1998). Their clutch size consists of 1 – 3 eggs, with a typical clutch size of two

(Stephenson & Minot, 2006). Hatching is asynchronous, and eggs are incubated by the female for a period of 20-30 days (Seaton & Hyde, 2013). During this time the female is fed by the male on the nest (Stephenson & Minot, 2006). Nestlings are altricial and don't reach independence until approximately 91 days, fledging at approximately 35 days from December to January (Seaton & Hyde, 2013; Stephenson, 1998). Prior to fledging both adults provide food for the young (Seaton & Hyde, 2013).

We studied a total of 10 ruru pairs over the 2016/17 breeding season on Tiritiri Matangi Island. The objective of this study was to obtain more knowledge regarding the dietary composition and breeding success of the resident ruru population on the Island. Diet can be studied through direct field observations, nest sampling, the use of motion detecting infrared cameras, faecal analysis, gut analysis and pellet analysis (van Winkel, 2008). As with other owl species, any indigestible material consumed by ruru is ejected through the mouth as a pellet which may then be collected from beneath a daytime roost (Heather & Robertson, 1997; Seaton & Hyde, 2013).These pellets consist mostly of bones, fur and exoskeleton and can be examined to identify prey (Moon, 2010). For the purpose of this study we used direct field observations, motion detecting cameras, nest sampling, and collected pellets opportunistically. A combination of these techniques has been proposed as the best method for determining owl diet during the breeding season (Southern, 1969). As adults often consume small prey themselves at the point of capture while delivering large prey to chicks, this can result in a sampling bias if only one technique is used (Southern, 1969). In conjunction with investigating diet, nest sites were visited approximately once a week and breeding observations recorded on nest record cards. At the end of the season, breeding success was measured as the number of chicks fledged from a nest per breeding pair.

Previous studies have found ruru to be opportunistic predators, making it likely their diet will vary according to differences in habitat, vegetation, and seasonal abundance of prey species (Denny, 2009; Seaton & Hyde, 2013). Macro-invertebrates are the core component of ruru diet with them consuming species such as weta, beetles, cicadas, moths, stick insects, and spiders (Denny, 2009; Seaton & Hyde, 2013). They are also known to hunt for larger prey items such as birds, lizards, and small mammals if present (van Winkel, 2008). We were particularly interested in investigating the quantity of vertebrate prey that was being taken by ruru on Tiritiri. In the longer term it is hoped to determine whether or not ruru are acting as a limiting factor for endemic bird populations, in particular hihi (*Notiomystis cincta*). The majority of hihi chicks fledged on the Island are lost and therefore not recruited to the breeding population (pers. comm. John Stewart). The cause of this juvenile mortality is unknown. It has been noted that ruru have the potential to increase the risk of mortality in local bird populations and a previous examination of nest contents on the island found individually marked leg-bands originating from at least five hihi, four of which were juveniles (Low, 2010). This indicates ruru predation may be a factor involved in low recruitment of juvenile hihi. This project was intended to be a preliminary study that would inform a more comprehensive study over the following breeding seasons. There are relatively few comprehensive scientific studies on ruru, and the effect they may have on small populations of endemic wildlife on offshore islands has not been thoroughly investigated. Such research is important so that we can elucidate the potential for negative impacts on small valuable populations of conservation species within reserves such as Tiritiri Matangi as well as following any translocations.

Methods

Data collection

Nests and roosts were located opportunistically. Researchers and volunteers on the island were asked to keep an eye out for any ruru sightings, unintentional disturbances of adult birds from nest sites and roosts, and instances of mobbing from other species. Seven nests had been located by the time this study began and, following three more discoveries, the final total was 10 nest sites. Roost sites were located in a similar manner. As noted by Stephenson (1998), the position of a roost is sometimes given away by the presence of 'white-wash' or build-up of the uric acid-rich white part of the bird faeces below the roost. This visual cue assisted us in locating roosts in the area surrounding nest sites. Once nest sites had been located, four Bushnell HD NatureView cameras (model: 119440) were used to observe the ruru nests. Once chicks at a nest site had fledged, we then moved the camera to another nest site. Ruru activity was detected by a Passive Infra-Red (PIR) motion sensor, at which time the camera was set to record a 15 second video. No-glow "black" IR LEDs provided sufficient illumination for the camera to deliver black and white video in the dark. The following camera settings were used to capture videos: video size = 1920 x 1080, sensor level = high, LED control = low, capture set to "night", sound capture = on. For each nest site, nest characteristics were recorded, and at least once a week nests were checked and further observational data collected. This included number of eggs or chicks present, appearance of chicks, whether the female was present on the nest or sighted nearby, and whether they were any prey items present in the nest. Approximate dates of hatching and chick fledging were estimated where possible if exact dates were not known. Pellets were collected opportunistically from below roost sites and stored in bags labelled with the corresponding site. To prevent decay, the samples were frozen. Once chicks had fledged, nests were scraped of all material which was then searched through for prey remains. Material found was then bagged and labelled with the nest site and, along with the pellet samples, frozen to prevent decay.

Data entry

All relevant information taken from the video footage was entered into an Excel spread sheet. This included the video reference number, site, date and time of video, sex of the bird if able to be determined, whether the bird was arriving or departing, whether a definite or probable food pass had occurred, the prey type (invertebrate, bird or lizard), prey identification to the lowest taxonomical level, prey order, whether or not chicks had been fed, the prey they had eaten, any vocalisations heard, and any other miscellaneous observations.

As both sexes of ruru are similar in appearance and size, it is difficult to sex birds from external morphology alone (Haw & Clout, 1999; Stephenson & Minot, 2006). We determined the sex of birds where possible based on behavioural observations. In the camera footage, if there were two birds present with one in the nest and one arriving, we assumed the bird in the nest was female and the bird arriving was male. If a single bird arrived and dropped down to fully enter the nest we assumed it was female. Likewise, if a bird jumped out of the nest and departed we also assumed it was female. This assumption was based on the observation that male ruru don't seem to fully enter the nest. Furthermore, if there were two birds present and the arriving bird dipped into the nest and the other bird reached up we also assumed this to be a food pass even if the item was not visible to the camera. Also, as various incidences of short-term food caching were observed, we created separate columns for food pass prey and prey fed to chicks in an attempt to avoid counting prey items twice.

Results

Ruru population on Tiritiri Matangi

Table 1. Ruru sightings and locations on Tiritiri Matangi for 2015-2016.

Location	Sighting	No. of ruru
Wattle Valley	Single	1
Wharf Road/firebreak	Single	1
Shortcut	Family	≥3
Bush 6	Family	≥3
Bush 5	Family	≥3
Bush 4	Single	1
Bush 3	Family, and a single	≥4
Bush 2	Two singles	2
Bush 1/Kawerau Track	One pair and two singles	4
Sonya's Valley	Single	1
Bush 23 - single	Single	1
Bush 22	Family, pair and single	≥6
Bush 21	Pair and single	3
Apple Bush	Family	≥3
Fisherman's Bay Track	Single	1
Bush 12	Single	1
Lighthouse Valley	Two singles	2
Visitor Centre	Family	≥3
Bunkhouse	Family	≥3
	Total number of ruru recorded:	~46

Table 2. Additional recorded ruru locations from 2015-2016 kiwi call survey.

Location:
NE Bay
Silvester Wetlands
Pohutukawa Cove
Junction of Ridge Road and TTM Pa Track
Junction of Cable Road and Ridge Road
Ngati Paoa Track
Stagnant Dam Bush

Table 3. Ruru sightings and locations on Tiritiri Matangi for 2016-2017.

Location	Sighting	No. of ruru
Northeast bay	Single	1
B22	Two singles, two families	9
B21	Pair	2
Cable track	Single	1
Junction of Tiritiri Matangi Pa Rd and Ridge Rd	Pair	2
Sonyas' valley	Single	1
Junction of Grahams Rd and Wharf Rd	Single	1
Wattle valley	Pair	2
Little wattle valley	Pair	2
Bunkhouse	Pair	2
Apple Bush	Family	4
B3	Family	3
Inner Coastal Walk	Family	3
Lighthouse valley	Family	3
B5	Pair	2
B6	Family	4
Shortcut	Family	3
	Total number of ruru recorded:	45

Table 4. Additional recorded ruru locations from 2017 kiwi call survey.

Location:
Bush 2
Pohutukawa Cove
Bush 12
TTM Pa Track
Ngati Paoa Track
Stagnant Dam Bush

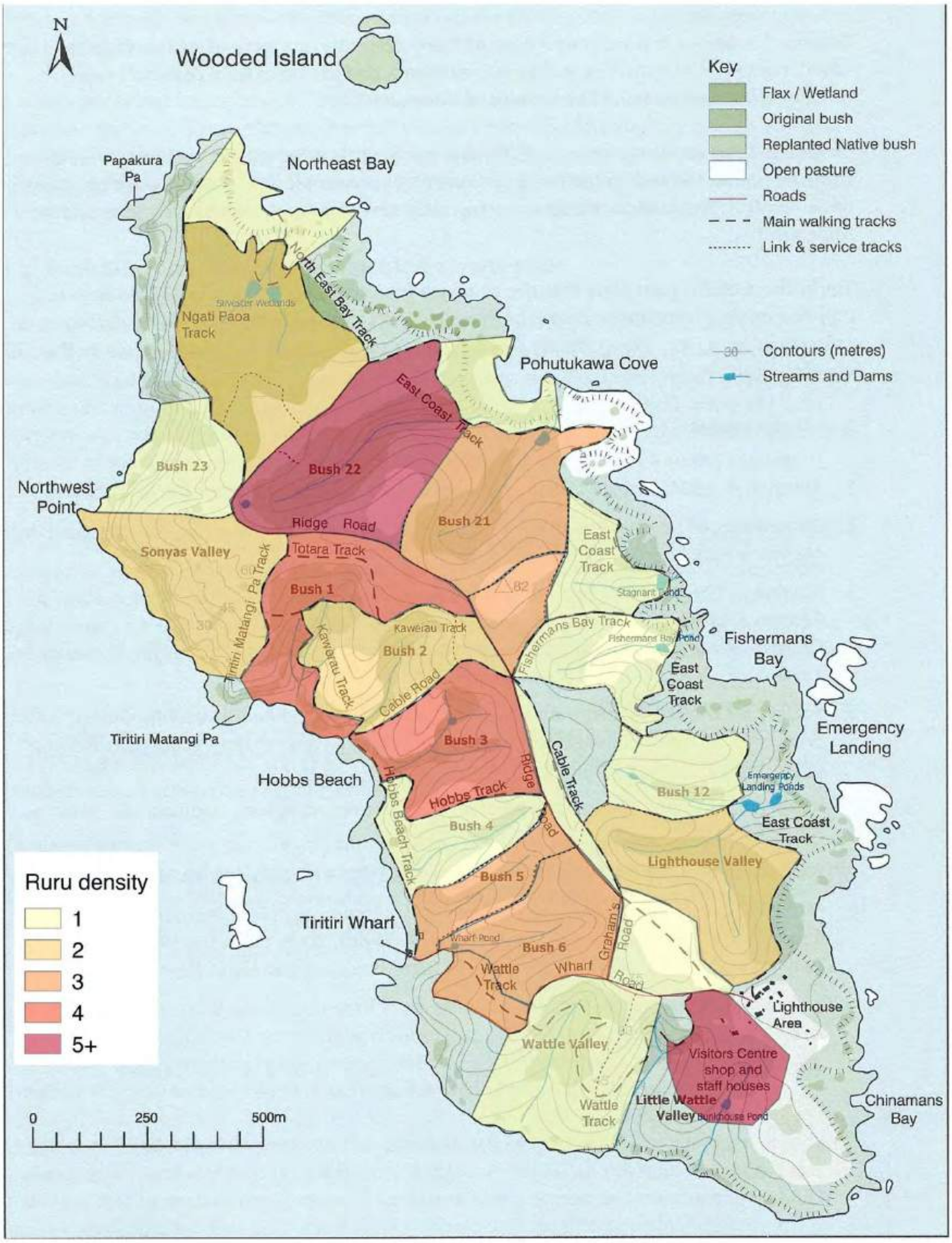

Figure 1. Estimated density of ruru on Tiritiri Matangi based on sightings and calls recorded during the 2015-16 season. From these records we can roughly estimate density at 0.23 ha^{-1} (one bird per 4.4 ha) across the island, or 0.28 ha^{-1} (one bird per 3.6 ha) in forested areas at this time.

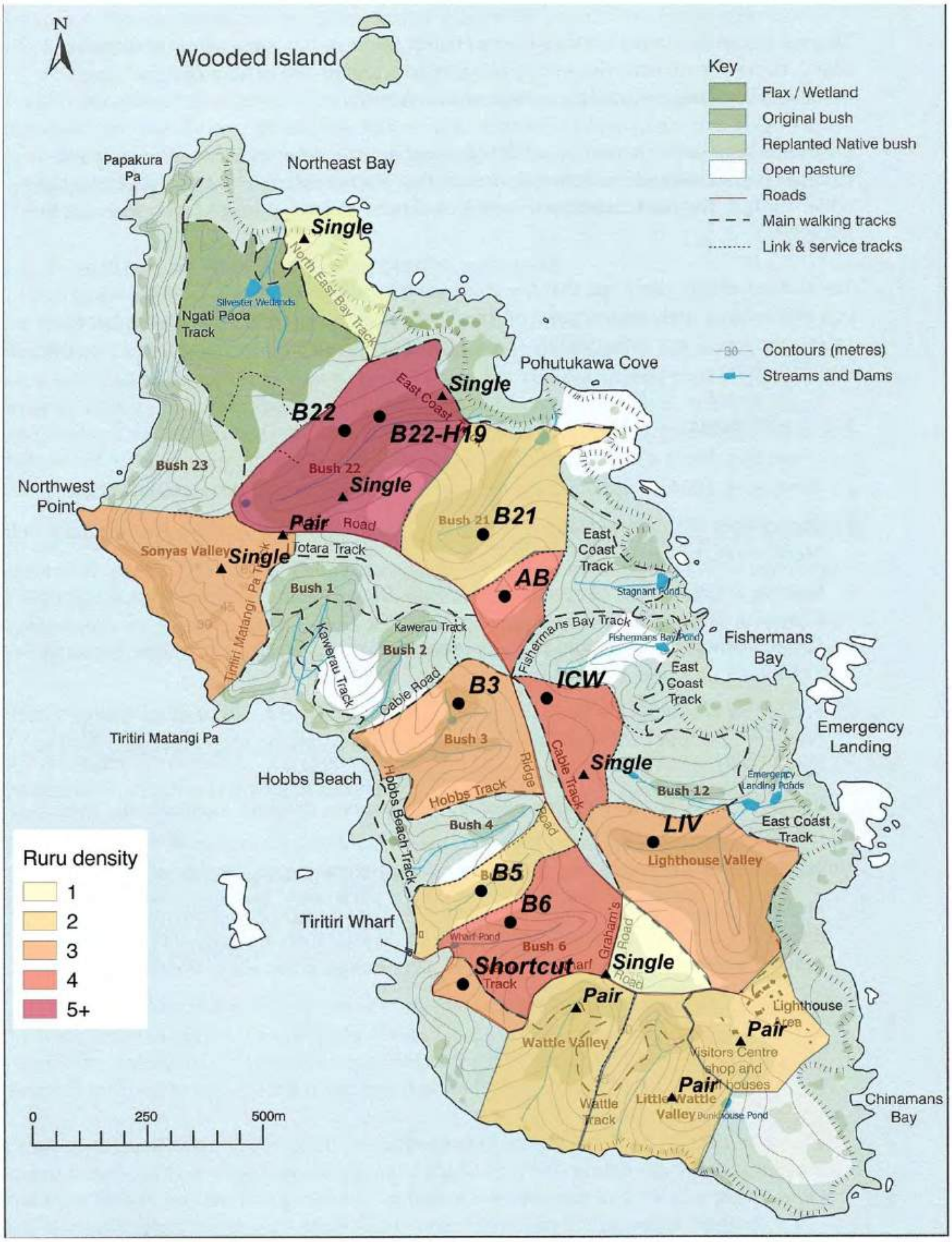

Figure 2. Estimated density of ruru (including fledglings) on Tiritiri Matangi island based on observed ruru nest sites, single roosts, and pair sightings during the 2016-2017 season. Density can be roughly estimated at 0.21 ha^{-1} (one bird per 4.89 ha) across the island, or 0.25 ha^{-1} (one bird per 4 ha) in forested areas at this time.

Breeding success

Table 5. Ruru nest site descriptions and 2016-2017 breeding season records on Tiritiri Matangi Island.

Nest site	Nest description	Height	No. eggs	No. Young	No. fledged	Incubation period	Nestling period
AB	Small indent at the base of a pohutukawa tree	0 m	2	2	2	16-25 days	27-35 days
LIV	On ground inside the shell of a dead cabbage tree	0 m	2	1	1	NA	31-38 days
ICW	In small hollow at base of pohutukawa tree	0 m	2	2	1	26-31 days	33-38 days
B5	Cavity in dead cabbage tree	1 m	2	0	0	NA	NA
B21	Cavity in dead cabbage tree	1.5 m	2	0	0	NA	NA
Shortcut	In old kakariki nest box with no roof	1 m	2	1	1	NA	25-33 days
B6	Cavity in dead cabbage tree	0.5 m	NA	2	2	NA	<34 days
B22	Burrow at foot of pohutukawa tree	0 m	2	1	1	NA	28-37 days
B3	Inside shell of dead cabbage tree	0.5 m	2	1	1	27 days	29 days
B22-H19	In cabbage tree	1 m	NA	2	2	NA	34-39 days

The clutch size was determined for eight nest sites, all of which had two eggs. Two of these nests (B5 and B21) failed and were subsequently abandoned. No second breeding attempt was detected. Two sites (AB and ICW) had two chicks hatch; however at the ICW site one chick died from unknown causes around 8 days after hatching. Four nest sites (LIV, Shortcut, B22 and B3) had only one egg hatch. Two sites (B6 and B22-H19) were discovered later in the study with two chicks already hatched, indicating they had a minimum clutch size of two. The exact incubation period was not determined but from our data it can be broadly estimated as between 16 and 31 days. Chicks had a nestling period ranging from a possible minimum of 25 days to a possible maximum of 39 days. A mean incubation and nestling period could not be calculated as we had only estimated dates for all but one site. Two chicks were fledged by three breeding pairs. Five pairs fledged one chick, and the two pairs with failed eggs fledged no chicks. The mean fledging rate was 1.1 chicks pair^{-1}.

Nest provisioning

Figure 3. Prey remains uncovered from B3 nest.

Figure 4. Prey remains uncovered from Shortcut nest.

Table 6. Invertebrate and vertebrate prey remains identified at each nest site (n=10) during nest sampling after chicks had fledged.

	B5	**B21**	**Shortcut**	**LIV**	**B3**
Invertebrate remains	Weta mandibles		Weta mandibles x 6 Weta leg parts x 7 Weta heads x 2 Whole weta x 1	Small pieces of invertebrate remains	Weta mandibles x 49 Weta leg parts x 12 Weta antennae x 4 Small pieces of invertebrate remains
Vertebrate remains	1 set of hihi colour bands Whitehead feathers	2 hihi colour bands	1 set of bellbird colour bands 2 B size colour bands Kakariki feathers Saddleback feather Blackbird feathers Various avian bones Leg (tarsus measurement=33mm) Leg (tarsus measurement=33.8mm) Leg (tarsus measurement=32.8mm) Leg (tarsus measurement=39mm) Leg (tarsus measurement=23mm) Wing x 2 Partial bird carcass x 2	Whitehead feathers Kakariki feathers Saddleback feathers Spotless crake feathers Blackbird feathers Leg x 3	Assorted unidentified feathers Wing x 1 Leg (possible saddleback) Leg (possible bellbird)
	AB	**B6**	**B22**	**ICW**	**B22-Hihi19**
Invertebrate remains	Tree weta mandibles x 10 Tree weta legs x 38	Weta mandibles x 16 Weta leg parts	Weta mandibles x 16 Weta leg parts Large weta ovipositor (wetapunga?) Moth wings	Weta mandibles x 5 Weta leg parts x 22	Tree weta mandibles x 27 Weta leg parts x 10
Vertebrate remains	Upper and lower bird bill (unidentified) Kingfisher feathers Whitehead feathers Black flight feathers (unidentified)	2 colour bands (robin size) 4 x avian bones	Song thrush feathers Juvenile robin feathers	1 complete bird (unidentified) Whitehead feathers Unidentified feathers	Bird carcass without head (possible spotless crake) One leg with colour bands (possible hihi) 3 colour bands (hihi or bellbird size) 1 colour band (robin size) Tui feathers Saddleback feathers Fantail feathers Whitehead feathers Robin feathers? Bellbird feathers?

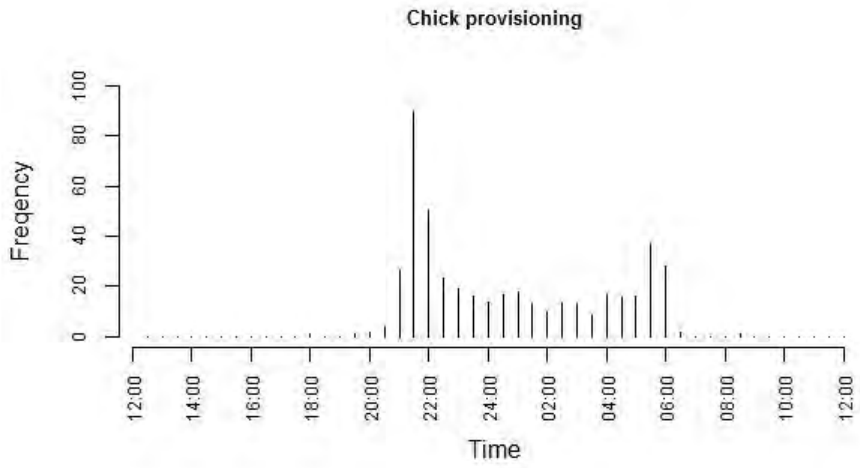

Figure 5. Frequency of chick provisioning (n=457) at all ruru nest sites according to time from 27/10/16 to 06/01/17.

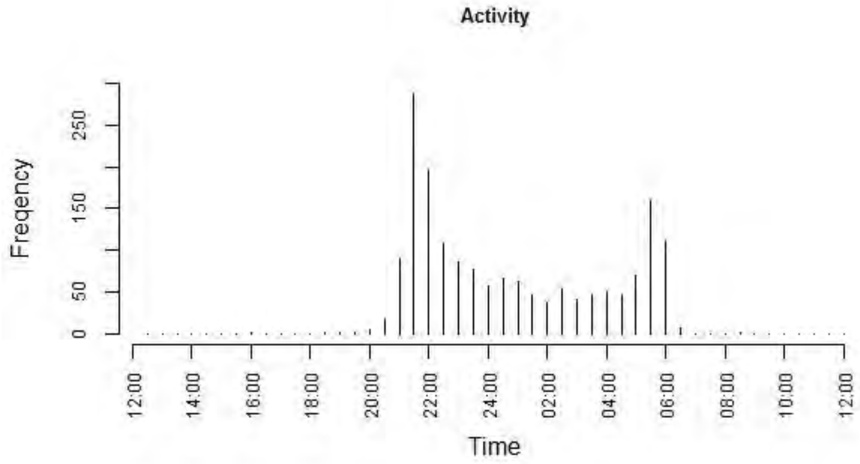

Figure 6. Frequency of ruru visits (recorded as an arrival, departure, or both, n=1729) to all nest sites by male or female adult ruru according to time from 27/10/16 to 06/01/17.

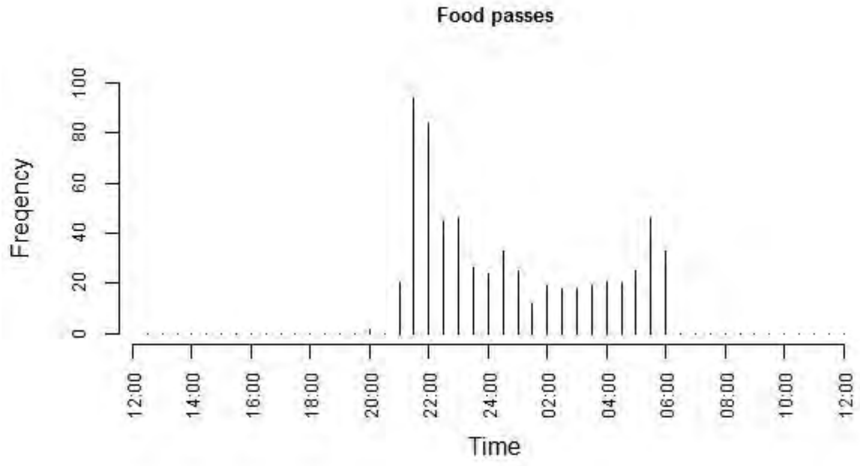

Figure 7. Frequency of food pass events (n=630) at all ruru nest sites according to time from 27/10/16 to 06/01/17.

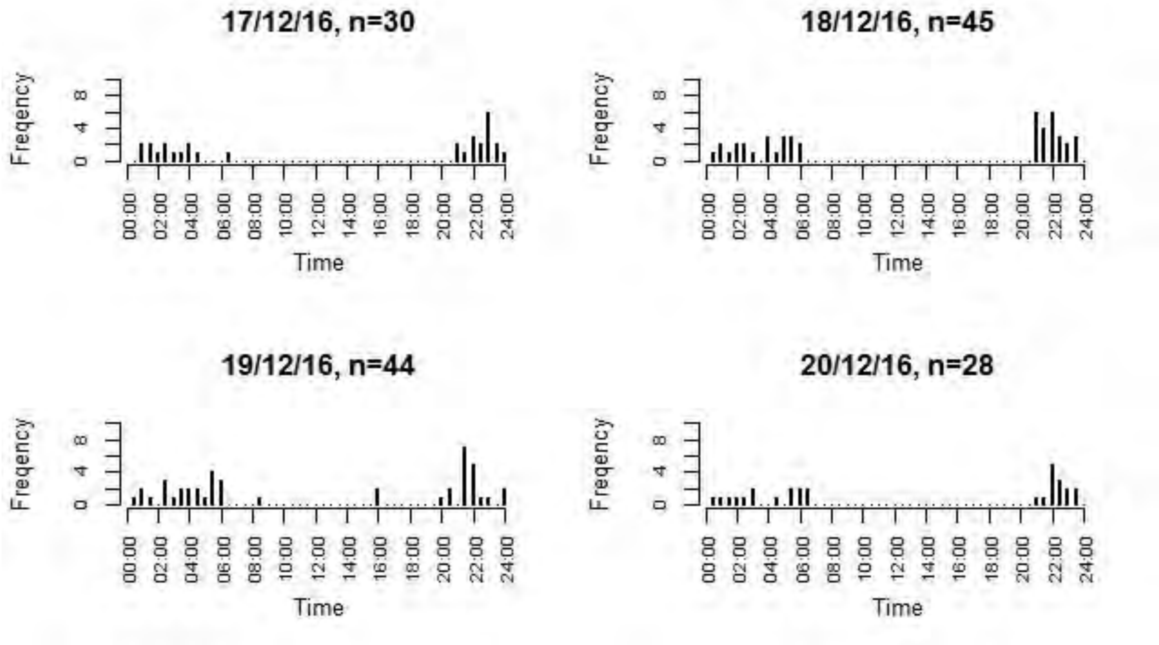

Figure 8. All activity (including arrivals, departures, food passes, and chick provisioning) recorded by trail cameras across four consecutive nights at the AB site.

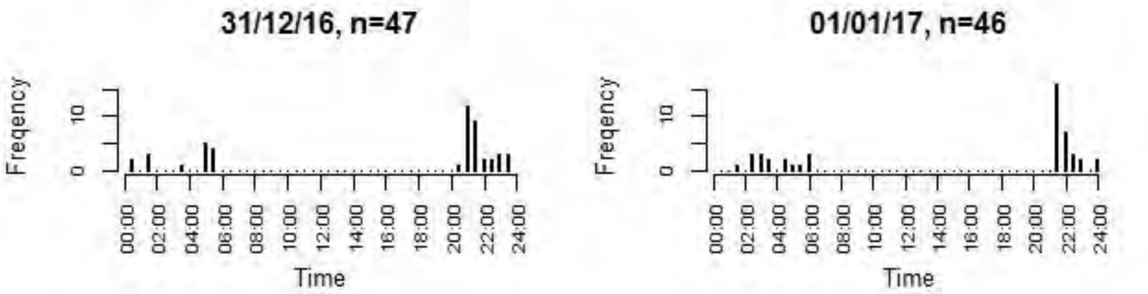

Figure 9. All activity (including arrivals, departures, food passes, and chick provisioning) recorded by trail cameras across two consecutive nights at the B22 site.

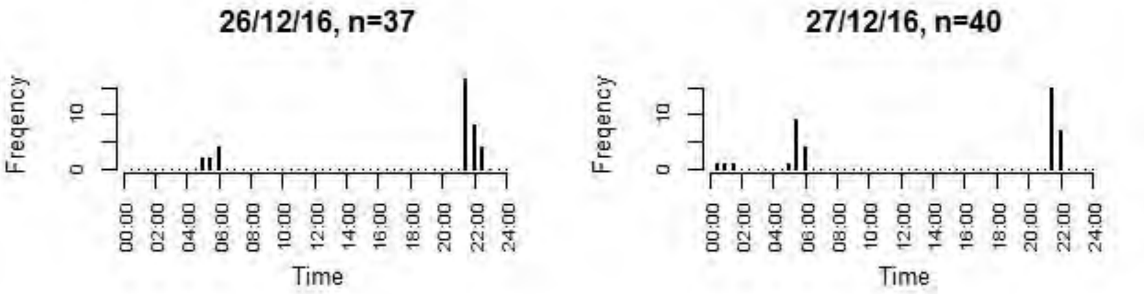

Figure 10. All activity (including arrivals, departures, food passes, and chick provisioning) recorded by trail cameras across two consecutive nights at the ICW site.

Visitation rate to nests peaked following sunset with the largest number of visits occurring between 21:00 and 22:00 (Fig. 6). There was another small increase occurring just before sunrise between 5:00 and 6:00 (Fig. 6). Frequency of food passes and chick provisioning followed a similar bimodal distribution with a large peak between 21:00 and 23:00 and a smaller peak between 5:00 and 6:00 (Fig. 5, Fig. 7). The maximum frequency of recordings of arrivals, departures, food passes and chick provisioning for one night was 47 (Fig. 9), while the maximum frequency of the same activity recorded within an hour was 25. This was recorded between 21:00 and 22:00 on the 26/12/16 at ICW (Fig. 10). The majority of prey able to be identified were invertebrates which made up 96% of identified food pass prey (Fig. 11). The most common invertebrate was tree weta (*Orthoptera*) which had a percentage occurrence of 30.6% followed by moths (*Lepidoptera*) which had a percentage occurrence of 5.6% (Fig. 12). In 30.2% of all food passes recorded the prey was not able to be identified.

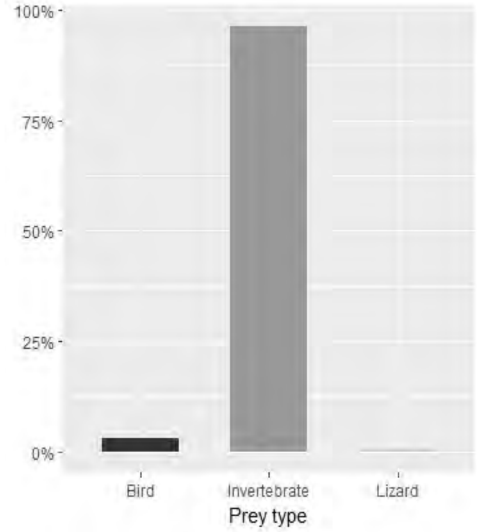

Figure 11. Percentage occurrence of identified prey types delivered to ruru nest sites during food pass events (n=441).

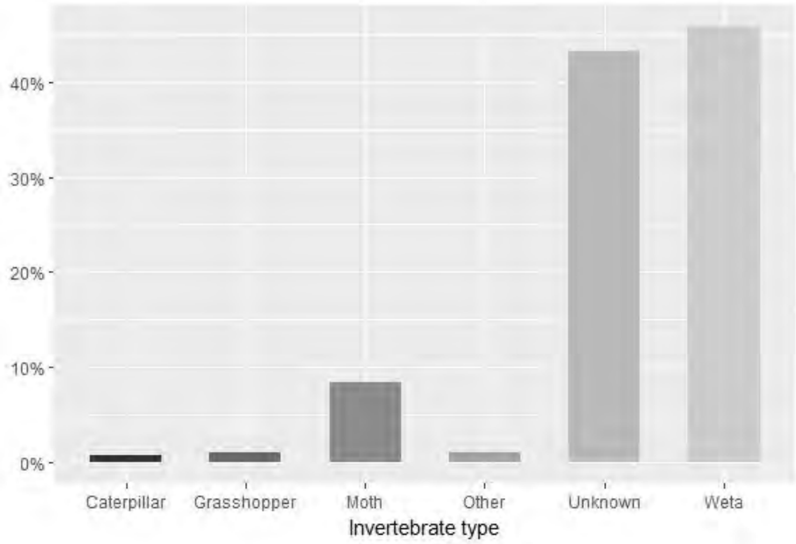

Figure 12. Percentage occurrence of invertebrate types delivered to ruru nest sites during food pass events (n=424).

Table 7. Comparison of frequency and percentage occurrence of prey items observed during food passes at ruru nest sites (n=630). No correction for biomass applied.

Prey Type	Frequency occurrence	Percentage occurrence
Bird	14	2.2%
Lizard	3	0.5%
Weta	193	30.6%
Moth	35	5.6%
Grasshopper	4	0.6%
Caterpillar	3	0.5%
Other	7	1.1%
Unidentified invertebrate	181	28.7%
Unidentified prey	190	30.2%

Discussion

Breeding biology

Figure 13. B3 nest site inside a dead cabbage tree.

Figure 14. ICW nest site at the base of a pohutukawa tree.

Of the ten nest sites studied, three were located at the base of pohutukawa trees (Fig. 14), five were located in dead cabbage trees (Fig. 13), one in a live cabbage tree, and one in an old kakariki nest box that was missing its lid. Other studies have found ruru to use a broad variety of nest sites suggesting that they do not have overly specific nest requirements (Stephenson & Minot, 2006). However, the popularity of dead cabbage trees suggests these may be favoured by ruru on Tiritiri Matangi. It's possible these sites are being selected based on their cryptic characteristics which may be advantageous as an avoidance strategy against mobbing by other birds (Denny, 2009). The nest sites consisted of leaf litter, twigs, and wood dust material, with no additional material added. Nest height ranged from ground level to 1.5m with a mean height of 0.55m. Four of our ten nest sites were at ground level. Ground nesting is rarely observed on the mainland, possibly due to risk of predation from introduced mammals.

Our study began with ruru already nesting. Stephenson and Mimot (2006) found prior to nesting, the breeding season begins with ruru pairs roosting together in late September. Laying on Tiritiri Matangi occurred during the October to November period, with eggs hatching from early November to early December, and fledging in December and January. This is consistent with current knowledge of ruru breeding season dates. Chicks hatched with whitish down and their eyes closed. This white down was gradually replaced by grey down and around day 20 chicks started to colour. We were not always able to determine the exact date of laying, hatching or fledging for nest sites but incubation and nestling periods were estimated where possible. The one nest site we were able to obtain accurate dates for was B3 (Fig. 15) which had an incubation period of 27 days and a nestling period of 29 days. However, three days after fledging the chick at this site was observed back in the nest suggesting that fledging may at times be a gradual process. The nest was checked again the following day and the chick was once again gone. Fledging is said to usually occur around 35 days so 29 days is relatively early for a chick to fledge, although it's possible that nestling period may vary depending on food supply (Moon, 2010).

Figure 15. Chick (aged 29 days) at B3 on day of fledging.

The mean clutch size for the nest sites studied on Tiritiri Matangi was 1.9 (n=8), with all but one nest having a clutch size of two. These findings are consistent with published data that ruru have a typical clutch size of two (Seaton & Hyde, 2013). Not all eggs were viable with an average of 1.2 chicks hatching per nest (n=8). Two nests that were discovered later in the study had already hatched so we could not determine initial clutch size, but given each nest site had two chicks, it was also at least two. One chick died from unknown causes at the ICW site and subsequently disappeared from the nest (Fig. 16). This was the only hatched chick that did not make it to fledging. There was a mean fledging rate of 1.1 chicks per breeding pair (n=10). This is slightly higher than the mean fledging rate of 0.9 chicks per breeding pair (n=10) that

Figure 16. Dying chick (on right) at ICW.

Stephenson and Minot (2006) recorded during the 1995/1996 breeding season on Mokoia Island. We attempted to locate chicks once they were no longer in the nest to confirm they had fledged, however, we did not investigate juvenile mortality post-fledging or follow the activity of chicks once they had left the nest. A study by Stephenson and Minot (2006) found that the female usually roosted within 1m of the chicks after fledging. Chicks stayed within their natal territories for the first 2-3 months and gradually roosted further from the adults (Stephenson & Minot, 2006). The same study also found quite a high incidence of juvenile mortality after fledging (Stephenson & Minot, 2006). It has been suggested that high post-fledging mortality rates for many owl species are the result of the difficulty of learning to locate and catch prey, combined with the highly territorial behaviour of many owls (Stephenson & Minot, 2006). Further studies may investigate ruru fledgling mortality on Tiritiri Matangi to determine breeding success and recruitment to the breeding population more accurately.

Looking at the frequency and pattern of activity and chick provisioning at the nest, there was a peak in visits by adult ruru after sunset, followed by a steady rate of less frequent visits and another small peak before sunrise (Fig. 4, Fig. 5). This bimodal pattern of nocturnal visits has been found in other owl species (Stephenson & Minot, 2006). Gaps in our data caused by difficulties with the cameras made it impossible to calculate the mean visits per night for each site. However, our maximum of 47 is relatively low in comparison to the means of 81 and 91 night^{-1} recorded for flammulated owls (another small owl with a primarily invertebrate diet) (McCallum, Gehlbach, & Webb, 1995; Powers et al., 1996). We attempted to compare visitation rates and timing between the period when males were feeding incubating females on the nest, and when both adults were feeding chicks but were unable to detect any differences, possibly due to insufficient data. During the extent of the study, we experienced occasional technical difficulties with cameras running out of battery, video files corrupting, and at times not having cameras correctly positioned to capture activity at the nest. It is therefore important to note that there were many gaps in the data in this study. Not all nest sites were monitored with cameras, and the fact that we recorded more departures than arrivals indicates we are missing footage. Furthermore, not all nests were easy to see into and so we had to settle for capturing arrivals and departures rather than observing activity happening inside the nest. The Apple Bush (AB) site gave us the most consistent camera footage once we had the camera positioned correctly due to the fact the nest was quite open, allowing for behavioural observations.

Following hatching, adults were observed feeding chicks from the bill. This continued at AB for approximately the first six days. Following this, chicks began to consume invertebrate prey delivered to them by adults independently. Small invertebrates were consumed whole while larger prey items such as weta were held in the chick's foot while it tore off segments with its beak. Throughout the nestling period, we recorded 14 instances of avian prey being delivered to nest sites and 15 observations of chicks being fed these prey items. Juveniles struggled to consume avian prey themselves. While some of the older chicks at AB were observed plucking feathers successfully from a bird left at the nest site, this was a slow process followed by the adult ruru subsequently tearing the item up and feeding it to the chicks. Similar feeding behaviour was observed at other sites. It is possible that avian prey has developmental significance for the chicks and by learning to handle such prey they are better equipped for independence. At AB we also observed that one of the two chicks was dominant consuming the majority of the food during the first two weeks following hatching. As the chicks got older however this did not seem as obvious with both chicks consuming similar amounts of prey. It is possible that this observation was a result of incomplete camera footage as both chicks seemed healthy and reached fledging. As the study was purely observational, we did not weigh chicks or measure their growth although if further research was undertaken this would provide valuable information.

Nest caching was observed throughout the course of the study. Both chicks and the female ruru at AB were often observed feeding on prey items found in the nest that had either not been consumed at the time of delivery, or left only partially consumed. Whole and partially consumed weta and avian prey items were also noted at various nest sites during field monitoring (Fig. 17, Fig. 18). Likewise, this food caching behaviour was observed during incubation and chick rearing during a study by Stephenson (1998). As stated by Krebs & Davies (1993), “reproductive success in birds can be limited by the rate at which food is delivered to the nest” (p. 209). Therefore, short-term caching of prey may act as insurance against chick starvation during the period of the night when prey drop-offs are not as frequent or allow chicks to feed during daylight hours.

Figure 17. Chicks at AB nest site. Two unconsumed weta are visible to the right.

Once chicks were around 20 days old they became more active and we could observe them waiting at the nest entrance for adults to return with prey, or moving around just outside the nest at ground-level sites. As chicks matured, we also observed numerous videos of chicks exercising their wings and allopreening between chicks and adults. An increase in activity was most notable in the nests at ground level where chick behaviour was clearly visible. At these sites chicks were observed venturing incrementally further from the nest, exercising their wings, and occasionally climbing up nearby branches or onto fallen logs. Time spent active continued to increase the closer chicks got to fledging. At the B22 nest site, the chick was observed making short flights off a low branch a few days prior to fledging. Chicks in nests above ground level may not be able to move around as much without risking not being able to get back into the nest. This may give chicks at ground level sites an advantage in preparation for fledging.

One weakness of this study was our inability to sex the birds. Male and female ruru are indistinguishable in the field with no obvious size difference or difference in plumage (Stephenson, 1998). This made it difficult to determine the parental care provided by each sex, or if one sex delivered the most food. We could assume that following hatching it was the female that stayed on the nest for the majority of the time, departing infrequently for short periods probably to feed.

However, these periods of parental absence grew longer as chicks matured and it became impossible to determine the sex of the bird delivering prey. It seems from the incidence of videos with two adults present, that the male delivers prey to the chick at least until fledging. Further studies would greatly benefit from the banding of at least one of the adult ruru, so the sex of birds can be differentiated.

Diet

We found that the majority (96%, n=440) of the prey items delivered to the nest that were captured by the camera and able to be identified were invertebrates. Weta made up 45.5% (n=424) of observed invertebrate prey and 30.6% of prey recorded in total (n=630). This was followed by Lepidoptera which made up 8.3% of invertebrate prey (n=424), and 5.6% of prey recorded in total (n=630). It is important to note 30.2% of prey could not be identified from footage and 28.7% could only be confidently identified as invertebrate. Furthermore, it is likely that large invertebrates were over-represented in our results due to the foraging behaviour of ruru during the breeding season. If adult ruru are only able to deliver one prey item at a time to their nest, they may optimize foraging by consuming small invertebrate prey at the point of capture, while bringing larger prey items back to chicks (Denny, 2009). Birds made up only 3.2% of all identified prey items delivered to the nest (n=440), although this did not account for corrections for biomass. 14 incidences of avian predation were observed in total. This may be as high as 19 but as some videos were not clearly identifiable as birds or did not show footage of an arrival or food pass and were possible duplicates, we did not include them.

From the video footage, species were not able to be determined but during nest sampling we identified remains of hihi, whitehead (*Mohoua albicilla*), red-crowned parakeet (*Cyanoramphus novaezelandiae*), North Island robin (*Petroica longipes*), saddleback (*Philesturnus carunculatus*), bellbird (*Anthornis melanura*), blackbird (*Turdus merula*), songthrush (*Turdus philomelos*), kingfisher (*Todiramphus sanctus vagans*) and spotless crake (*Porzana tabuensis*). During nest sampling, and during nest monitoring we also recorded two songthrushes in the Shortcut nest, and one juvenile robin in the B3 nest (Fig. 18). We observed three incidences of predation on lizards, however like bird items, the species were not able to be confidently identified from the video footage. Based on the size of the lizards, it is likely that one was a gecko, and the other two were skinks. No identifiable lizard remains were found at nest sites or roost sites. While lizards do not seem to be a common prey item for ruru, it is evident opportunistic predation does occur, and may be more common when lizard abundances are high (van Winkel & Ji, 2012). Other reports of ruru preying on nocturnal geckos (*Hoplodactylus* spp.) on Three Kings islands, and the Hen and Chickens

Figure 18. Chick at B3 nest site with partially consumed juvenile robin on the left.

islands are also available (Chambers, Chambers, & Sibson, 1955; Ramsay & Watt, 1971).

The predominantly insectivorous diet of ruru, is probably facilitated by the low searching and handling times associated with such prey (Denny, 2009). An invertebrate prey item, although it might not be the most energetically profitable, is still likely to be consumed when encountered (Denny, 2009). While avian prey offers a higher energetic return, it may only be taken opportunistically due to the searching and handling costs associated with its capture and consumption. It was clear from the videos that handling time for birds was much greater than that of invertebrates which were very quickly and easily ingested in comparison. Furthermore, ruru are thought to rely heavily on sound and motion when hunting (Denny, 2009). As most potential avian prey is diurnal, this reduces predation opportunities to dawn and dusk when birds are still active (Denny, 2009). Our results support this with 11 of the total possible 19 observations of avian predation being recorded at dawn during 5 am and 6 am, and six at dusk between 8 pm and 9:15 pm. The remaining observations were recorded at 4:37 am and 3:17 pm.

It has been previously been noted that avian prey is of particular significance as a food source for chicks (Imboden, 1985), with adult ruru appearing to provide their young with more vertebrate prey than they consume themselves (Denny, 2009; Stephenson, 1998). While most avian prey delivered to our nest sites was observed being fed to chicks, adult ruru were also occasionally seen feeding on them. It is also possible avian prey was consumed by adults out of the sight of the camera. Adult ruru were observed leaving the nest with birds that had been previously delivered suggesting these prey items may be taken to be consumed at roosts, or simply removed from the nest. If avian prey consumption is indeed increased during the breeding season of ruru, it is expected that any impact on local bird populations would be most evident during this time. The fact that some birds on Tiritiri Matangi use nest boxes which ruru are unable to access may provide them with protection and limit nest predation opportunities, although juveniles are likely to be especially vulnerable once they have fledged. Moving nest boxes that are located in close proximity to known ruru nest sites may offer further protection. Further research on diet outside of the nesting season would be of value in determining whether there is significant seasonal variation in vertebrate prey consumption and whether endemic bird populations on the island are at the highest risk of predation during the breeding season.

During the extent of this study we did not discover as many pellets as expected. We collected a total of 2.5 pellets. One pellet was collected from under a roost site discovered in Sonya's valley, part of pellet from under a roost beside the B22 nest, and one was found during nest excavation. We did not observe any pellets being regurgitated during video footage which suggests they are primarily ejected at roost sites or during the day. Perhaps, to improve pellet collection in future studies, sheets or netting could be strung up underneath known roosts. This has been noted as assisting in the collection of whole pellets as those consisting entirely of invertebrate remains may otherwise shatter when they hit the ground (Stephenson, 1998). It would also reduce time spent searching for pellets amongst the leaf litter.

In another study carried out on Tiritiri, Dylan van Winkel (2008) found ruru pellets to consist almost entirely of invertebrates, with weta (*Orthopera: Anostostomaidae*) present in 85.1% of pellets. Other remains included earwigs (*Dermaptera*), huhu beetles (*Coleoptera: Cermabicidae*), click beetles (*Coleoptera: Elateridae*), and the occasional incidence of bird remains (Dylan van Winkel, 2008). In contrast, during nest sampling in the same study, it was found that 91% of nest sites contained bird remains, while 36% contained weta (Dylan van Winkel, 2008). Similarly, Stephenson (1998), found bird remains in a relatively high proportion of samples on Mokoia Island. This is likely due to the abundant availability of avian prey on these islands in the absence of mammalian predators, increasing predation opportunities for ruru. Like van Winkel, we also found a discrepancy between the number of avian prey items recorded on the cameras and the number found during nest sampling. This may be because nest sampling is biased towards the representation of vertebrate prey whose remains will persist for much longer than invertebrate remains (Denny, 2009). Furthermore, as this is the first time nest sites have been excavated it is possible that some remains uncovered were from previous breeding seasons making it unwise to attempt to quantify predation rates from these results. It is also possible that our results were influenced by systematic error. As the cameras were set to record at night, evidence of avian predation that occurred in late morning or early evening may have been missed.

Implications for conservation management

Predation plays a significant role in population dynamics, trophic networks, and community ecology (van Winkel, 2008), yet there is a lack of intensive studies on the role and conservation impact of predation by native avian predators such as ruru. As a pest free island, Tiritiri Matangi is home to many small populations of threated and endangered species, as well as establishing translocated populations. Exact numbers of ruru on Tiritiri are unknown, however based on the 2015-16 sightings we can roughly estimate that there are around 20 breeding pairs. Based on our results, ruru diet on the island consists predominantly of tree weta, and other common invertebrates. However, we have also found evidence of predation upon indigenous bird species including hihi, whitehead, red-crowned parakeet, North Island robin, saddleback, bellbird, and spotless crake. Established prey populations are usually robust enough to withstand predation pressures from natural predators (van Winkel, 2008). However, in such a small area with many small populations of indigenous species, effects of opportunistic predation may be significant. Even a small loss due to predation could significantly impact on the establishment of a vulnerable population and affect genetic diversity, sex ratios, overall viability and resilience (van Winkel, 2008).

It has been proposed that translocated populations, especially captive bred individuals, may be particularly at risk of predation due to unfamiliar habitat, or naivety to natural predators such as ruru (van Winkel, 2008). Low (2010) suggested that survival differences between translocated hihi populations on Tiritiri Matangi and Mokoia island, were partially influenced by differing predation pressures from ruru. At this time ruru densities on Mokoia Island (average density of 0.393 ha^{-1} across the island) were much higher than on Tiritiri Matangi (average density of 0.013 ha^{-1} across the island (Low, 2010). It was also found that soil spore counts of *Aspergillus fumigatus* were much higher on Mokoia than Tiritiri Matangi (Low, 2010; Perrott & Armstrong, 2011). *A. fumigatus,* is a common fungus in the environment giving rise to aspergilliosis in hihi and subsequent respiratory problems (Thorogood, Armstrong, Low, Brekke, & Ewen, 2013). While post-mortems have shown apergilliosis is a major cause of mortality for hihi (Perrott & Armstrong, 2011), it's also possible aspergilliosis and ruru predation may interact in certain ways. Hihi suffering from respiratory problems (or affected by other diseases) may be rendered more vulnerable to predation, and a loss of genetic diversity due to predation could reduce adaptive potential and make it less likely hihi will cope with stochastic events such as disease outbreaks or environmental changes (Frankham, JD, &

Briscoe, 2002; Low, 2010). Ruru densities are now much higher (~0.228 ha^{-1}) than when hihi first arrived on Tiritiri Matangi. A subsequent re-evaluation of the predation pressures from ruru on the island would therefore be valuable. Wetapunga have also been recently been translocated to Tiritiri Matangi and may be at risk from ruru predation. Due to the high predation rates on tree weta, if wetapunga were encountered it is likely they would make an excellent prey choice with a large energy return. The fact they are active at night would reduce searching time, further increasing profitability. While we have found evidence of predation on hihi and other at-risk species, further research which attempts to quantify predation rates and provide a more accurate estimate of ruru population numbers may be useful in establishing whether ruru predation is in fact limiting juvenile recruitment of hihi, or impacting on any other species populations such as wetapunga.

Conclusion

This study provides preliminary data for a better understanding of the diet and breeding success of ruru on an offshore island free of mammalian predators. Breeding pairs were found to have a mean fledging rate of 1.1 chicks per nest with the majority of chicks hatched surviving to fledging. Ruru diet on Tiritiri Matangi was found to consist predominantly of weta over the nesting season. Published data suggests ruru are opportunistic predators, with optimal prey choice influenced by the relative abundances of species within their habitat. Their varied and mostly insectivorous diet makes it unlikely they will pose a major threat to uncommon prey populations. However, if populations are already perilously small, confined to a small area, or potentially rendered further vulnerable by disease, competition, reduced genetic diversity, or nutritional deficiencies, the impact of opportunistic predation by ruru may be greater than in a ‘natural’ system. This should be taken into consideration in areas where small populations of prey species of high conservation value are present, or are to be translocated, or if populations are already known to be suffering from nutritional deficiencies or disease. Further research is needed to provide a more accurate estimate of ruru population density, investigate survival of fledglings, quantify the impact of predation on conservation species and assess whether ruru are indeed a limiting factor for hihi on the island.

Data

Electronic copies of the video footage collected over the course of the study and associated Excel files have been lodged with the Supporters of Tiritiri Matangi.

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