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A video camera assessment of morepork (*Ninox novaeseelandiae*) diet and breeding success on Tiritiri Matangi Island

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Abstract: An observational study on the diet and breeding success of morepork (ruru; *Ninox novaeseelandiae*) was undertaken using video capture methods during the 2016-2017 breeding season on Tiritiri Matangi Island. The study investigated diet composition, frequency of prey deliveries, timing and frequency of chick provisioning, the behaviour of morepork and their young at 10 nest sites, and considered the possibility that morepork predation was having a negative impact on species of conservation importance. Tree wētā (*Hemideina* spp.) were found to be the most common prey type consumed at nest sites. Evidence of predation of bird species of conservation importance including stitchbird (hihi; *Notiomystis cincta*) was also found. Prey species continue to exhibit positive population growth rates, indicating predation rates are too low to have a significant destabilizing effect. However, as the population of moreporks has also grown, it is recommended that their impact on prey species be monitored.

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Key words: ruru, morepork, *Ninox novaeseelandiae*, dietary composition, breeding biology, island conservation, Tiritiri Matangi Island

INTRODUCTION

The morepork (ruru; *Ninox novaeseelandiae)* is a forest-dwelling owl native to New Zealand. Morepork 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 a small owl, approximately 29 cm long, weighing 175 g and have an average life span of approximately 6 years (Morgan & Styche 2012; Seaton & Hyde 2013). During the day they roost amongst the foliage of trees and epiphytes, and occasionally in crevices, on ledges, or in burrows (Denny 2009). After dusk, they leave their roosts to hunt (van Winkel 2008). They are territorial and have been found to defend a territory of 3.5 to 7.8 ha (Seaton & Hyde 2013).

Morepork exhibit a monogamous mating system with their breeding season running from September to January (Stephenson 1998; 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 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 (Stephenson & Minot 2006; Denny 2009; Seaton & Hyde 2013).

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Nest sites are often reused and once found can be checked annually (Stephenson 1998). Clutch size consists of 1–3 eggs, with a typical clutch size of 2 (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 on the nest by the male (Stephenson & Minot 2006). Nestlings are altricial and reach independence at approximately 91 days, fledging at approximately 35 days in December to January (Stephenson 1998; Seaton & Hyde 2013). Prior to fledging, both adults provide food for the young (Seaton & Hyde 2013).

Previous studies have found morepork to be opportunistic predators, making it likely their diet will vary according to differences in habitat, vegetation, and seasonal abundance of prey species (Lindsay & Ordish 1964; Denny 2009; Seaton & Hyde 2013). Macro-invertebrate species including wētā (Orthoptera), beetles (Coleoptera), cicadas (Hemiptera), moths (Lepidoptera), stick insects (Phasmatodea), and spiders (Araneae) are the core component of morepork diet (Cunningham 1948; Stephenson 1998; Haw & Clout 1999; Denny 2009; Seaton & Hyde 2013). They are also known to hunt for larger vertebrate prey including birds, lizards, and small mammals such as mice (*Mus musculus*), kiore (*Rattus exulans*), and ship rats (*Rattus rattus*) if present (Saint Girons *et al.* 1986; Stephenson 1998; Haw & Clout 1999; Haw *et al.* 2001; van Winkel 2008).

We studied a total of 10 morepork pairs over the 2016-2017 breeding season on Tiritiri Matangi Island, a 220 ha Scientific Reserve located in the Hauraki Gulf, 28 km north of Auckland and 3.5 km east of the Whangaparaoa Peninsula (Baber & Craig 2003; Galbraith & Cooper 2013). The objective of this study was to obtain more knowledge of the dietary composition and breeding success of the resident morepork population on the Island. We were particularly interested in the quantity of vertebrate prey that was being taken by morepork on Tiritiri Matangi Island with the hope of determining whether morepork are acting as a limiting factor for endemic bird populations, in particular stitchbird (hihi; *Notiomystis cincta*). The majority of stitchbird chicks fledged on the island are not recruited to the breeding population (McCready & Ewen 2017). The cause of this juvenile mortality is not well understood. It has been noted that morepork 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 stitchbirds, four of which were juveniles (Low 2010). There have been relatively few comprehensive scientific studies of morepork diet on offshore islands (Stephenson 1998; Denny 2009), and the effect they may have on small populations of endemic bird species has not been thoroughly investigated (but see Low 2010). Such research will lead to better understanding of the relative importance of native predators among all the factors that impact on these species.

METHODS

Data collection

The study took place between late October 2016 and late January 2017. Nests and roosts were located opportunistically. Researchers and volunteers on the island were asked to report any morepork sightings, unintentional disturbances of adult birds from nest sites and roosts, and instances of mobbing from other bird species. Seven nests were located by the time this study began in October, and 3 more were discovered during the course of the study, resulting in a total of 10 nests being studied on the Island. 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' from bird faeces below the roost. This visual cue provided additional assistance 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 morepork nests. Morepork 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 was 1920 x 1080 pixels, sensor level was high, LED control was low, night-time only capture, sound capture was on.

For each nest site, nest characteristics were recorded, and at least once a week nests were checked and further observational data collected and recorded on nest record cards. Approximate dates of hatching and chick fledging were estimated where possible if exact dates were not known. At the end of the season in January, breeding success was measured as the number of chicks fledged per breeding pair.

Diet was studied using direct field observations, footage from the motion detecting cameras, nest sampling, and analysis of regurgitated pellets consisting of indigestible material consumed by moreporks. 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). Pellets were collected opportunistically from below roost site and stored in bags labelled by site. Roost sites located near active nests were checked weekly, while other roost sites were checked only once. Once chicks had fledged, nests were scraped out and the material collected was searched through for prey remains. The remains were then bagged and labelled with the nest site and, along with the pellet samples, frozen to delay decay.

Data collection and storage

The following information was taken from the video footage and entered into an Excel spread sheet: 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 possible, prey order, whether or not chicks had been fed, the prey they had eaten, any vocalisations, and any other notable behavioural observations.

As both sexes of morepork 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. It has previously been noted that only females seem to brood nestlings (Stephenson & Minot 2006). Therefore, in the camera footage, if there were 2 birds present with 1 in the nest and 1 arriving, we assumed the bird in the nest was female and the bird arriving was male. We also observed that male morepork did not seem to fully enter the nest, so if a single bird arrived and dropped down and fully entered the nest we assumed it was female. Likewise, if a bird jumped out of the nest and departed we also assumed it was female. In addition, if there were 2 birds present and the arriving bird dipped into the nest while the other bird reached up we assumed this to be a food pass, even if the item was not visible to the camera.

Data were exported into R 3.4.3 version 1.1.4193 (R Core Team 2017) and a Chi-square goodness-of-fit test was used to compare the observed frequency occurrence of activity, food passes and chick provisioning between early (1800 h – 2159 h), mid (2200 h – 0159 h), and late night (0200 h – 0600 h) with hypothesised equal frequency occurrences across these three time periods.

RESULTS

Breeding success

Nest floors comprised mainly soil, leaf litter, twigs, and wood dust material, with no additional material added. Nest height ranged from ground level (n = 4) to 1.5 m, with a mean height of 0.55 m (Table 1). Laying occurred from early October to early November, with eggs hatching from early November to early December, and chicks fledging in December and early January. Chicks hatched with whitish down and closed eyes. This white down was gradually replaced by grey down and around day 20 chicks started to acquire adult colouring.

Clutch size was determined for 8 nest sites, all of which had 2 eggs (Table 1). Two nests failed and were subsequently abandoned with no second breeding attempt detected. At the ICW site, 1 chick died from unknown causes approximately 8 days after hatching and subsequently disappeared from the nest. This was the only hatched chick that did not fledge. There was an average of 1.2 chicks hatched per nest (n = 8). The exact incubation period could not be determined but 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 1 site (B3) which had an incubation period of 27 days and a nestling period of 29 days. At this site the chick was observed back in the nest three days after fledging, suggesting that fledging may at times be

Table 1. Morepork nest site descriptions and 2016-2017 breeding season records on Tiritiri Matangi Island.

Nest site	Nest description	Height (m above ground level)	No. eggs	No. Young	No. fledged	Incubation period (days)	Nestling period (days)
AB	Small indent at the base of a pohutukawa tree (*Metrosideros excelsa)*	0.0	2	2	2	16-25	27-35
LIV	On ground inside the shell of a dead cabbage tree (*Cordyline australis*	0.0	2	1	1	NA	31-38
ICW	In small hollow at base of pohutukawa tree	0.0	2	2	1	26-31	33-38
B5	Cavity in dead cabbage tree	1.0	2	0	0	NA	NA
B21	Cavity in dead cabbage tree	1.5	2	0	0	NA	NA
Shortcut	In old red-crowned parakeet nest box with no roof	1.0	2	1	1	NA	25-33
B6	Cavity in dead cabbage tree	0.5	NA	2	2	NA	<34
B22	Burrow at foot of pohutukawa tree	0.0	2	1	1	NA	28-37
B3	Inside shell of dead cabbage tree	0.5	2	1	1	27	29
B22-H19	In cabbage tree	1.0	NA	2	2	NA	34-39

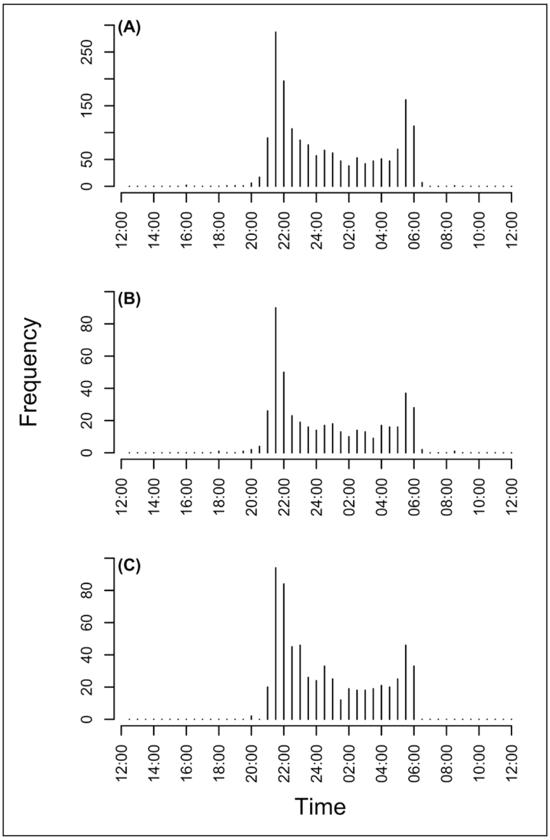

Figure 1. Nest visit and provisioning frequencies (per 30 minutes) recorded from 27 October 2016 to 06 January 2017: (A) All visits (recorded as arrival, departure or both, n = 1,732), (B) Provisioning chicks (n = 457), (C) Food pass events (includes to female on nest, n = 630).

a gradual process. The nest was checked again the following day and the chick was once again gone. Fledging is said to usually occur at around 35 days so 29 days is relatively early for a chick to fledge, although it is possible that nestling period may vary depending on food supply (Moon 2010). The mean fledging rate was 1.1 chicks per pair (n = 10).

Nest provisioning

Visitation rate to nests peaked following sunset with the largest number of visits occurring between 2100 h and 2200 h (Fig. 1A). There was another small increase just before sunrise between 0500 h and 0600 h (Fig. 1A). Frequency of food passes and chick provisioning followed a similar bimodal distribution with a prominent peak between 2100 h and 2300 h and a smaller peak between 0500 h and 0600 h (Fig. 1B, Fig. 1C). Despite the two peaks in activity around dusk and dawn, a Chi-squared analysis showed no significant difference in the frequency of visitation ($X^2 = 2.45$, $df = 2$, $P>0.05$), food passes ($X^2 = 3.15$, $df = 2$, $P>0.05$), or chick provisioning ($X^2 = 4.81$, $df = 2$, $P>0.05$) among early (1800 h – 2159 h), mid (2200 h – 0159 h) and late night (0200 h – 0600 h) time periods. The maximum number of arrivals, departures, food passes, and instances of chick provisioning for one night at a single nest was 47, while the maximum frequency of the same activity recorded within an hour was 25. This was recorded between 2100 h and 2200 h.

Diet

In 30.2% of all food passes recorded, the prey was not able to be identified while in 28.7% it could only be identified as invertebrate (n = 630). We found that the majority (96%) of the prey items delivered to the nest that were captured by the camera and able to be identified were invertebrates (n = 440). Wētā made up 45.5% of observed invertebrate prey (n = 424) 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). Birds made up 3.2% of all identified prey items delivered to the nest (n = 440), and 2.2% of prey recorded in total (n = 630). We have not attempted to assess the impact of differing biomass among prey items. Fourteen incidences of avian predation were observed. There may have been a further five, but the prey items were not clearly identifiable as birds or videos did not show footage of an arrival. Without observing the initial delivery of the item to the nest, we cannot be confident the footage is not of a previously cached prey item being consumed or fed to chicks, so these observations were excluded. During the study, we also 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. Furthermore, not all nest sites were monitored with cameras.

Pellet collection was largely unsuccessful with only 2.5 pellets collected beneath roost sites during the extent of the study. No pellets were observed being regurgitated during video footage. Examination of the pellets revealed only fragments of invertebrate exoskeletons.

All of the nest sites excavated contained bird remains, although some sites had a much higher proportion of bird remains than others (Fig. 2). Feathers were assumed to be evidence of predation as morepork are not known to add material to their nests (Stephenson 1998). The Shortcut nest site contained the remains of up to 13 birds although wings and legs could not be identified to species level. Tarsus measurements ranged from 23 mm to 33.8 mm. Stitchbird leg bands were found in two nest sites; whitehead (*Mohoua albicilla*) feathers were found at five nest sites; North Island saddleback (*Philesturnus rufusater*) feathers in three nest sites; red-crowned parakeet (*Cyanoramphus novaezelandiae*) feathers in two nest sites; North Island robin (*Petroica longipes*) feathers and a juvenile robin carcass in two separate nest sites; European blackbird (*Turdus merula)* feathers in two nest sites, and bellbird (*Anthornis melanura*), song thrush (*Turdus philomelos*), New Zealand kingfisher (*Todiramphus sanctus vagans*) and spotless crake (*Porzana tabuensis*) remains were each found in one nest site. Wētā remains were also common, excavated from 8 of the 10 nest sites. A total of 49 wētā mandibles were found at the B3 site alone. Some of the nests had relatively few easily identifiable remains and, since larger vertebrate prey items were easier to identify than small pieces of invertebrate exoskeletons, the percentage splits shown in Fig. 2 may not always represent accurate ratios of prey items.

DISCUSSION

Breeding biology

Our findings are consistent with those of Stephenson & Minot (2006) who observed morepork using a broad variety of nest sites on Mokoia Island, suggesting that they do not have overly specific nest requirements. The popularity of dead cabbage trees (*Cordyline australis*) suggests these may be favoured by morepork on Tiritiri Matangi Island, although, as most of the bush is less than 35 years old, it may be that dead cabbage trees are the most abundant acceptable sites. It is also 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). Ground nesting was observed at four of the nest sites (Table 1). This is rarely observed on the mainland, probably due to risk of predation from introduced mammals.

The mean clutch size of 2 (n = 8), is consistent with published data (Imboden 1985; Stephenson & Minot 2006; Seaton & Hyde 2013). The mean fledging rate was slightly higher than that of 0.9 chicks per breeding pair (n = 10) recorded by Stephenson & Minot (2006) during the 1995-1996 breeding season on Mokoia Island. This may be due to differences in habitat quality as Mokoia Island was covered in low regenerating vegetation with very few natural cavities at the time of their study.

Looking at the frequency and pattern of activity and chick provisioning at nest sites, there was a peak in visits by adult morepork after sunset, followed by a steady rate of less frequent visits and another small peak before sunrise (Fig. 1A & 1B). This bimodal pattern of nocturnal visits has been found in other owl species (Stephenson & Minot 2006; Scriba *et al.* 2017). Gaps in our data caused by the difficulties with 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 per night recorded for flammulated owls (*Psiloscops flammeolus*) (another small owl with a primarily invertebrate diet) recorded in North America and Mexico (McCallum *et al.* 1995; Powers *et al.* 1996), although higher than the mean of 16.2 per night recorded for morepork by Stephenson (1998).

Following hatching, adults were observed feeding chicks from the bill. At nest AB, chicks began to independently consume invertebrate prey delivered to them by adults after the first six days. Small invertebrates were consumed whole while larger prey items such as wētā were held in the chick's foot while it tore off segments with its beak. Throughout the nestling period, we recorded at least 14 instances of avian prey being delivered to nest sites. Juveniles struggled to consume avian prey themselves. While the two chicks at AB were observed successfully plucking feathers from a bird left at the nest site, this was a slow process followed by the adult 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 delivered during the first two weeks following hatching. As the chicks got older, however, this difference became less marked; both chicks consumed similar amounts of food and both fledged. As the study was purely observational, we did not weigh chicks or measure their growth, though if further research was undertaken this would provide valuable information.

Prey caching was observed throughout the course of the study. Both chicks and the female morepork at the AB site were often observed on video 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 wētā and avian prey items were also noted at various nest sites during field monitoring. This food caching behaviour was also observed during incubation and chick rearing during a study by Stephenson (1998). The rate at which food is delivered to the nest can limit reproductive success of birds (Krebs & Davies 1993), so short-term caching of prey may ensure more continuity of food supply to morepork chicks.

Once chicks were around 20 days old they became more active and could be observed 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 (up to ~3 m) 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 (0.3 m above ground) a few days prior to fledging. Chicks in nests above ground level may not be able to move around as much or they may risk being unable to get back into the nest. This may give chicks at ground level sites an advantage in preparation for fledging, and consequently benefit morepork populations on predator-free islands where ground nesting is feasible.

One weakness of this study was our inability to sex the birds. Male and female morepork 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 whether 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. Based on the incidence of videos with two adult birds present, it seems that both the male and the female deliver prey to the chick at least until fledging. Further studies would greatly benefit from the banding of at least one of the parents at each nest, so the sex of birds could be differentiated.

Diet

Our results provide evidence consistent with other studies that have found morepork to be primarily insectivorous (Imboden 1975; Stephenson 1998; Haw & Clout 1999; Haw *et al.* 2001; Denny 2009). Wētā were found to be the most common prey group, suggesting they were abundant on Tiritiri Matangi Island during the study period. However, it is also possible that large invertebrates were over-represented in our results due to the foraging behaviour of morepork during the breeding season. As noted by Denny (2009), if adult morepork 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 carrying more substantial prey items back to chicks.

The species of avian prey were not able to be determined from the video recordings, but during nest sampling we identified remains and/or feathers of stitchbird, whitehead, red-crowned parakeet, North Island robin, North Island saddleback, bellbird, European blackbird, song thrush, New Zealand kingfisher, and spotless crake. During nest monitoring we also recorded two song thrushes in the Shortcut nest, and one juvenile robin in the B3 nest. The remains of avian prey items are occasionally encountered away from morepork nest sites on Tiritiri Matangi. It is possible that remains with only the heads removed are morepork prey (Glue 1972; Brown & Mudge 1999). Examples encountered include common diving petrel (*Pelecanoides urinatrix*) and kōkako (*Callaeas wilsoni*) nestlings. There are no New Zealand falcons (*Falco novaeseelandiae*) on the Island.

We observed three incidences of predation on lizards; however, again 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 morepork, it is evident opportunistic predation does occur and may be more common when lizard abundances are high (van Winkel & Ji 2012). In earlier work on the Island, Raukawa gecko (*Woodworthia maculatus*) remains were found in the AB nest site (JRS *pers. obs.*). Other observers have reported morepork preying on nocturnal geckos (recorded as *Hoplodactylus* spp. possibly *Dactylocnemis pacificus* or a small *Hoplodactylus duvaucelii*) on Manawatawhi (Three Kings Islands) and Taranga Island (Hen Island) (Turbott & Buddle 1948; Chambers *et al.* 1955).

The predominantly insectivorous diet of morepork is probably facilitated by the low searching and handling times associated with such prey (Denny 2009). It was clear from the videos that handling time for birds was much greater than that for invertebrates, which were very quickly and easily ingested in comparison. Furthermore, morepork are thought to rely heavily on sound and motion when hunting (Denny 2009). As most potential avian prey is diurnal, this may reduce predation opportunities to dawn and dusk when some diurnal birds are active (Imboden 1975; Denny 2009). Our results support this with 11 of the total possible 19 observations of avian predation being recorded at dawn between 0500 h and 0600 h, and 6 at dusk between 2000 h and 2100 h. The remaining observations were recorded at 0437 h and 1517 h.

It has previously been noted that avian prey may be of particular significance as a food source for chicks (Imboden 1985), with adult morepork appearing to provide their young with more vertebrate prey than they consume themselves based on prey remains observed in nests (Stephenson 1998). While most avian prey delivered to nest sites was observed being fed to chicks, adult morepork were also occasionally seen feeding on them. Furthermore, adult morepork were observed leaving the nest with birds that had previously been delivered suggesting prey items were being taken to be consumed at roosts (Brown & Mudge 1999) or removed from the nest. If avian prey consumption is indeed increased during the morepork breeding season, it is expected that any impact on local bird populations would be most evident during this time. Some birds on Tiritiri Matangi use nest boxes which morepork are unable to access and this may provide protection before fledging and limit nest predation opportunities. Moving nest boxes that are in close proximity to known morepork nest sites is one strategy that might offer further protection. More research on diet outside of the nesting season would be of value in determining whether there is significant seasonal variation in vertebrate prey consumption.

We did not observe any pellets being regurgitated during video footage, which suggests they are primarily ejected at roost sites and/or during the day. Perhaps, to improve pellet collection in future studies, sheets or netting could be erected beneath 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 (Imboden 1975; Saint Girons *et al.* 1986; Stephenson 1998). It would also reduce time spent searching for pellets amongst the leaf litter.

Other studies have found morepork pellets to consist almost entirely of invertebrate remains, while vertebrate remains are more common in nest sites (Imboden 1975; Stephenson 1998; van Winkel 2008). Similarly, we 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). As this is the first time that nest sites have been excavated, it is also 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. Regardless, our results provide evidence of predation on endemic bird species and lizards. Offshore Islands such as Tiritiri Matangi may have higher avian and reptile predation rates than mainland New Zealand due to the increased availability of these prey types in the absence of mammalian predators.

Implications for conservation management

As a pest free island, Tiritiri Matangi is home to many small populations of endemic species of conservation importance, as well as establishing translocated populations. Exact numbers of

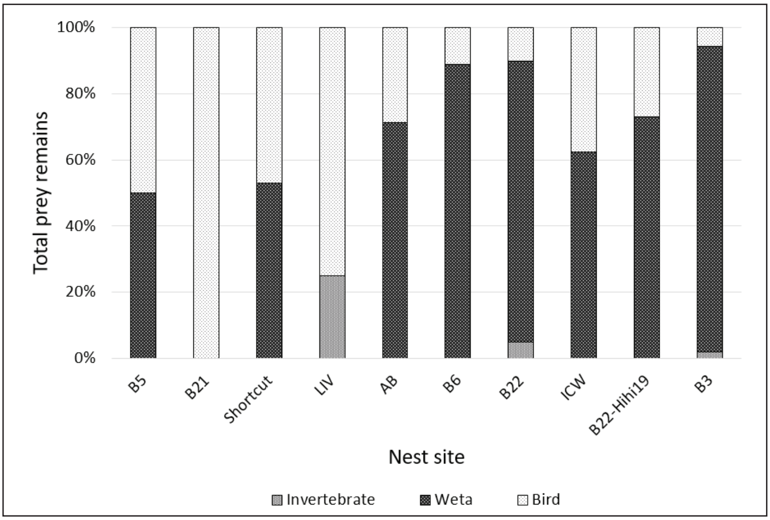

Figure 2. Percentage occurrence of invertebrate, wētā, and bird prey remains identified at each nest site when excavated after fledging (n = 10).

morepork on Tiritiri Matangi are unknown; however, using observational data from 2016-2017, we can estimate that there are around 20 breeding pairs. Our results indicate morepork diet on the Island consists predominantly of tree wētā and other common invertebrates. However, we have also found evidence of predation upon indigenous bird species including stitchbird, whitehead, red-crowned parakeet, North Island robin, saddleback, bellbird, and spotless crake. Natural predators such as morepork are an integral part of native ecosystems and are unlikely to have a significant destabilizing effect on established prey populations (van Winkel 2008). Nevertheless, morepork densities and their potential impacts on other species should continue to be monitored.

It has been proposed that translocated populations, especially captive-bred individuals, may be particularly at risk of predation due to unfamiliar habitat and/or loss of anti-predator responses (van Winkel 2008). Low (2010) suggested that survival differences between translocated stitchbird populations on Tiritiri Matangi and Mokoia Island were partially influenced by differing predation pressures from morepork. At the time of his study, morepork 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). The common fungus, *A. fumigatus*, causes aspergilliosis in stitchbird and subsequent respiratory problems (Thorogood *et al.* 2013). While post-mortems have shown apergilliosis is a major cause of mortality for stitchbird (Perrott & Armstrong 2011), it is also possible aspergilliosis and morepork predation interact, resulting in increased losses. Stitchbird 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 the likelihood stitchbird will cope with stochastic events such as disease outbreaks or environmental changes (Frankham *et al.* 2002; Low 2010). Based on morepork location records from the 2017 kiwi call survey, single roosts and pair sightings from the 2016-2017 period, and nest site observations, morepork densities are now estimated as being much higher (~0.23 ha^{-1}) than when stitchbird first arrived on Tiritiri Matangi. However, the highly managed stitchbird population on Tiritiri Matangi continues to be maintained at an artificially high level (McCready & Ewen 2018) indicating that morepork predation is not excessively limiting. Further research that attempts to quantify predation rates and provide a more accurate estimate of morepork population numbers on the Island would be necessary to confirm this.

In conclusion, this study provides preliminary data for a better understanding of the diet and breeding success of morepork 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. Morepork diet observed at nest sites on Tiritiri Matangi was found to consist predominantly of wētā and other invertebrates over the breeding season. As noted, other studies have found that morepork are opportunistic predators, with optimal prey choice influenced by the relative abundances of species within their habitat. Further work on abundance of prey taxa would be needed to confirm opportunistic prey selection on Tiritiri Matangi. Our results suggest that, with their varied and mostly insectivorous diet, morepork are unlikely to pose a major threat to uncommon avian prey populations. However, if populations have been recently translocated, are already perilously small, or potentially rendered further vulnerable by disease, competition, reduced genetic diversity or nutritional deficiencies; morepork densities and the risk of predation should be taken into account. Further research is needed to provide a more accurate estimate of morepork population density, investigate survival of fledglings, quantify the impact of predation on conservation species and further investigate whether morepork are limiting juvenile recruitment of stitchbird on Tiritiri Matangi Island.

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