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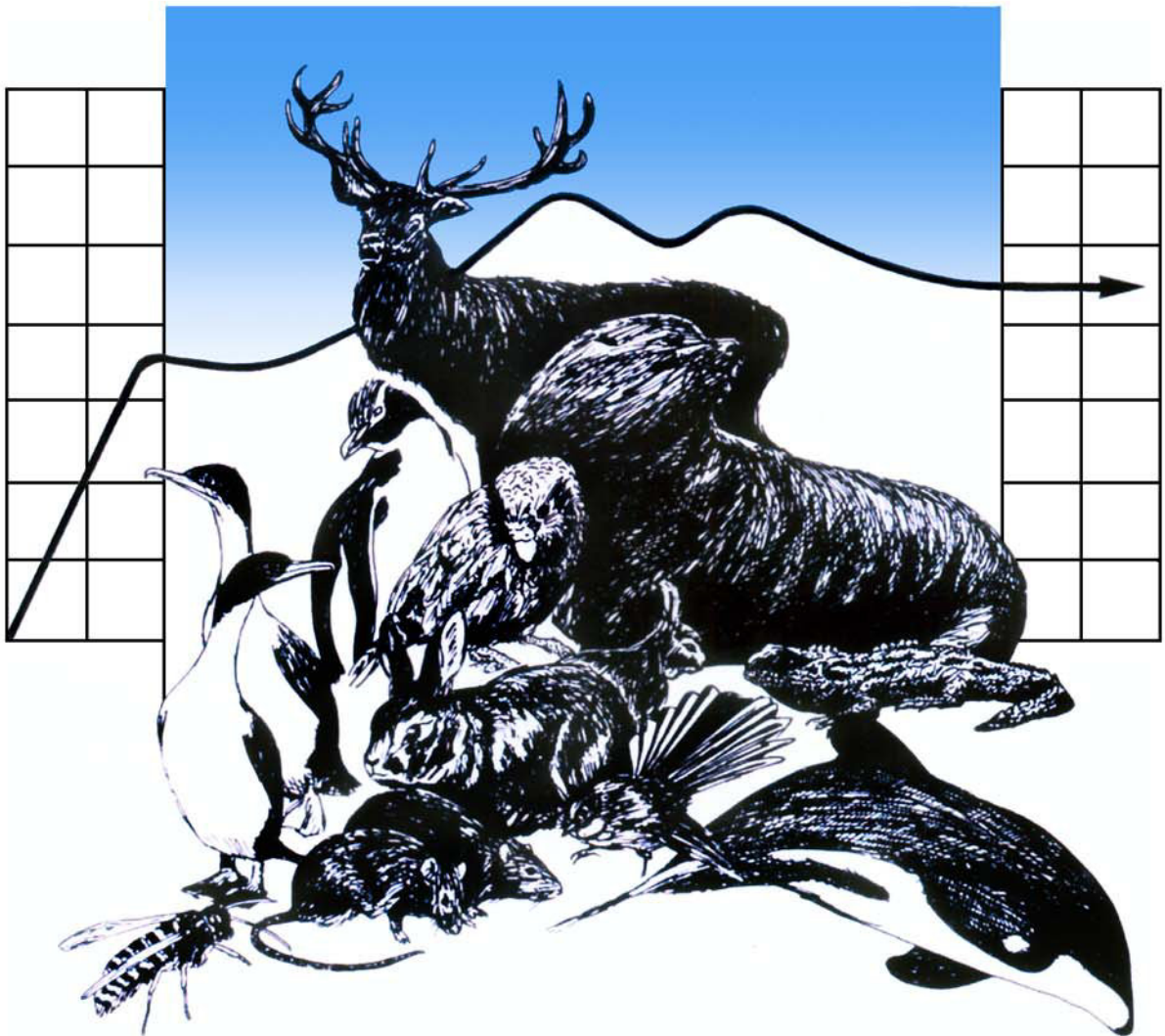

WILDLIFE MANAGEMENT

Invasive mice and their effects on birds: do mice (Mus musculus) within fenced sanctuaries prey on bird eggs?

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Invasive mice and their effects on birds: do mice (Mus musculus) within fenced sanctuaries prey on bird eggs?

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Executive Summary

Biodiversity impacts of house mice (Mus musculus) when they are the sole mammalian predator present have rarely been studied. In the absence of larger predators like ship rats, stoats, and cats, mice populations can reach much higher densities and can have a significant impact on the surrounding environment. Such environments are common at fenced and island sanctuaries, especially after multiple species eradications have taken place. This is a basic study of mouse behaviour addressing the questions of whether mice in fenced sanctuaries recognise eggs as food and have the ability to harvest eggs of two sizes, and (if so) what characteristic signs they leave behind. This study took place in a 17 ha pest-fenced area (QEII block) adjacent to the main Maungatautari sanctuary (3400 ha) in the Waikato region of New Zealand. Both areas are near pest-free, with mice being the only mammalian predator present. Program MARK (v.6.0) was used to estimate the daily survival rate (DSR) of artificial nests containing quail, canary, and finch eggs at Maungatautari. Nests also contained an artificial egg to aid with predator identification. Some nests were filmed for direct evidence of mice preying on bird eggs. During a period of five days 32.5% of nests within the QEII block at Maungatautari were preyed on. The probability of a nest surviving one day (DSR) was 0.910. Damage left on real and artificial eggs showed typical rodent damage as documented in other nest predation studies, e.g. gnawed edges with small shell fragments broken off, incisor imprints left in artificial eggs. Mice were observed preying on quail and artificial eggs at two nests during two nights of filming. The video footage obtained showing mouse behaviour at filmed nests will prove highly useful for advocacy and seminar purposes. The proportion of quail eggs preyed on was significantly less than the proportion of smaller eggs that were preyed on suggesting that eggs of quail size (30 x 24 mm) are likely to be at the upper limit of a mouse's harvest capability. While these results are preliminary and have limitations, they

support the few studies of wild mice eating bird eggs when they are the only mammalian predator present. If these results reflect reality, and if they are paralleled in other sanctuaries with similar mouse densities, managers can expect that mice are likely to prey on eggs up to approximately 30 x 24 mm of birds in forest environments, especially at or near ground level, and especially if parent birds do not defend nests or are absent. The impact of this on populations will require further research.

Table of Contents

1. Introduction

House mice (Mus musculus) are one of the most widely spread invasive predators in the world, partly due to their varied and flexible diet, including both small invertebrates and a wide range of seed species (King 2005). Despite their widespread distribution, in non-island environments their biodiversity impacts are often overlooked and sometimes thought to be negligible (Russell 2012). One reason for this may be the fact that mouse densities tend to become supressed in the presence of other mammalian predators such as ship rats, stoats, and possums (Goldwater et al. 2010).

Mouse densities are sometimes controlled by interactions with both food and predation. For example, in beech forests across the South Island of New Zealand house mice experience major population eruptions following masting events (Fitzgerald et al. 1996, Ruscoe et al. 2004). These eruptions cause a direct increase in stoat populations, which in turn pose a greater threat to the native avifauna (Choquenot & Ruscoe 2000, King 1983). King (1983) found that increased stoat numbers also resulted in significantly more mice being eaten. However, mice were still able to reproduce at a faster rate than these predators could remove them (King 1983).

In the absence of larger predators including ship rats, stoats, and cats, mice populations are able to reach much higher densities (Angel et al. 2009, Goldwater et al. 2010). Such environments are common at fenced and island sanctuaries, where native flora and fauna are especially vulnerable to invasive species.

Mice have been implicated in the decline of many macroinvertebrate populations and changes in ecosystem functions on many islands where they are the only mammalian predator (Smith et al. 2002, Angel et al. 2009, St Clair 2011).

The predation impacts of mice on birds in environments where they are the sole mammalian predator have rarely been studied. When larger predators are absent mice

populations are able to reach much higher densities, which in turn may trigger predatory behaviour (Jones & Ryan 2010, Goldwater et al. 2012). Such a response has been documented on Gough Island, where house mice are known to be significant predators of Tristan albatross (Diomedea dabbenena) chicks and of several burrowing petrels (Cuthbert & Hilton 2004, Angel & Cooper 2006). They have also been documented preying on real and artificial Gough bunting (Rowettia goughensis) eggs (28 mm; Ryan & Cuthbert 2008). Mice on Gough Island average a considerably larger body size (34g, with a head to body length of 105mm) than mice elsewhere (Rowe-Rowe & Crafford 1992). In New Zealand, mice vary in size and mass, with some of the largest being from Mabel Island (25.7g, with an average head to body length of 99.5 mm; King 2005). At Maungatautari in this study, mice averaged 19.1g with an average head to body length of 77.4 mm (D. Wilson, Landcare Dunedin, pers. comm. 2013).

There are very few accounts of house mice eating bird eggs. In addition to the Gough bunting example (Cuthbert & Hilton 2004), mouse nests have been found in the walls of rock wren (Xenicus gilviventris) nests, along with rock wren eggs (22mm) with bite-marked edges (S. Heath, University of Otago, pers. comm. 2013). Furthermore, captive mice in laboratory experiments ate small starling eggs (30 mm) and nestlings (Moors 1978).

Knowing whether or not wild house mice will prey on bird eggs is important for increasing our understanding of their overall impact, and could have a significant influence on future mouse control, particularly at fenced and island sanctuaries where mice are often the sole mammalian predator. This is a basic study of mouse behaviour with the advantage of observing wild mice in a wild environment. I aim to address the questions of whether mice in fenced sanctuaries recognise eggs as food and have the ability to harvest eggs of two sizes, and (if so) what characteristic signs they leave behind.

2. Methods

2.1. Study site

The main Maungatautari sanctuary consists of 3400 ha of mixed podocarp/broadleaf forest encompassed by a 42km long pest-proof fence, in the Waikato region of New Zealand's North Island. The sanctuary is near pest-free, with mice being the only mammalian predator present (Innes 2012). Adjacent to the main sanctuary is a privately owned fenced block protected by a QEII covenant. The density of mice in this block is similar to that in the main sanctuary meaning the two fenced areas are suitably analogous (preliminary estimates of mouse densities in the QEII block in February 2013 was 18.9 +/- 3.3 mice per hectare (95% CI 13.4-26.5) compared to an estimated 12.4 +/- 3.1 per ha (95% CI 7.7-20.1) at the northwest corner of the main mountain; D. Wilson, Landcare Research, Dunedin, pers. comm. 3013).

This study took place in the fenced QEII block (Figure 1). This 17 ha block was pest-fenced in 2006 and is now free of all mammalian pests except mice, which are currently uncontrolled (Innes 2012). Mice were eradicated in 2008 and the block remained pest-free until May-Aug 2009. Since then, 65-100% of tracking cards placed there using DOC SOP techniques have shown mouse tracks (J. Innes, N. Fitzgerald, Landcare Research, pers. comm. 2013) The latest tracking efforts in February 2013 recorded 65% of tracking cards placed having shown mouse tracks, the lowest tracking percentage since 2009. This is comparable to the main sanctuary where the most recent tracking percentage in January 2013 was 70% (P. Quin, K. Richardson, Maungatautari Ecological Island Trust, pers. comm. 2013). There are four existing transect lines 100 m apart throughout the study site (Figure 1), which are periodically used for accessing tracking tunnels. These tunnels are baited with a pea sized ball of peanut butter and set for one night once every three months. These transects were used in this study.

Access to the QEII block was via dirt and metal tracks across Bill Garland's private farm. Permission to access his land was granted by Bill Garland, with whom Landcare Research has a well-established amicable relationship.
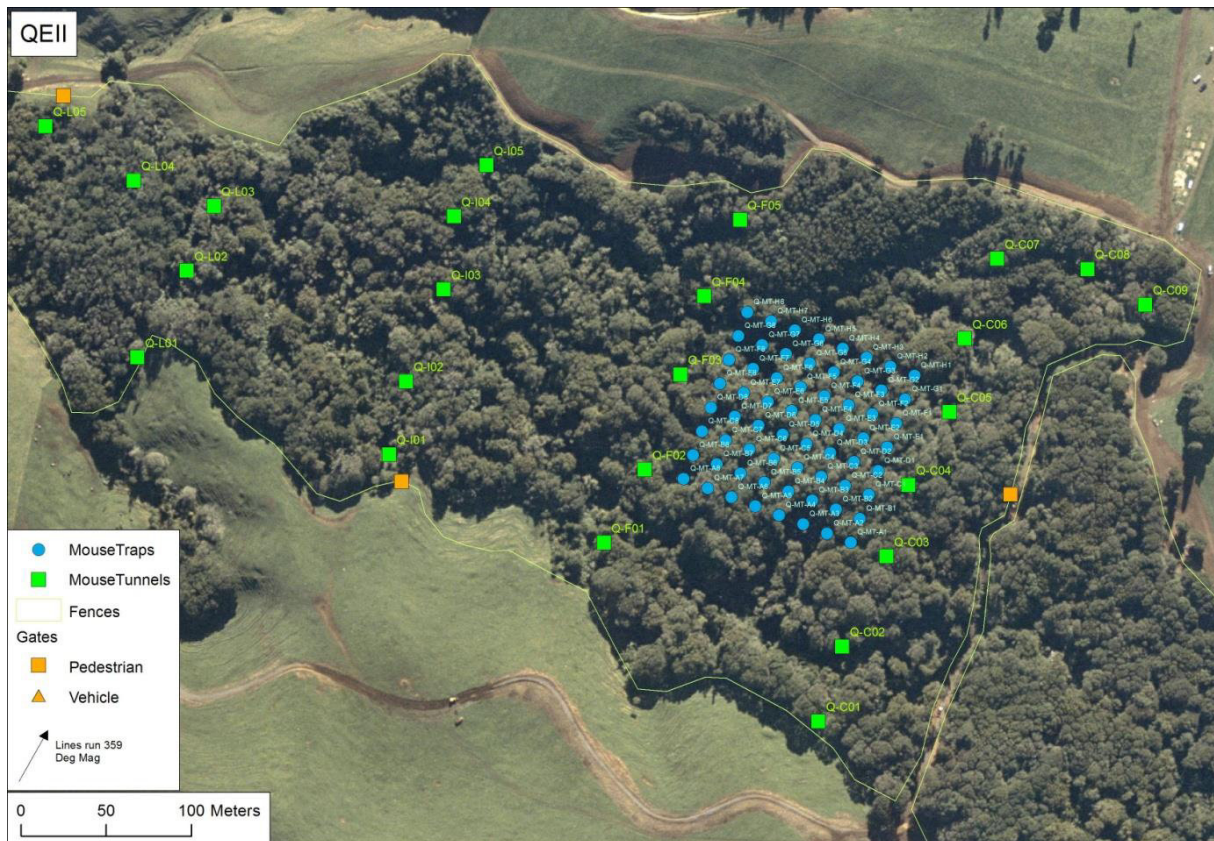
Figure 1: Aerial view of the QEII block at Maungatautari. Mouse tunnels (green squares) are placed at 50m intervals on lines 100 m apart. I followed these transect lines and placed nests at ground level at 25m intervals. Image by Neil Fitzgerald.

2.2. Study design

A total of 40 used blackbird (Turdus merula) and song thrush (Turdus philomelos) nests were collected from around the University of Waikato and Ruakura campuses. These nests were placed at ground level at 25 m intervals along four transect lines 100 m apart across the QEII block. The location of each nest was marked by tying flagging tape at least 1 m above the nest. No nest was placed closer than 2 m to a tracking tunnel. Thirty three nests contained

two real eggs: one quail egg (30 x 24 mm) and either a canary (16 x 11 mm) or zebra finch (14 x 9 mm) egg. The remaining seven nests contained just one real egg: a quail egg. All 40 nests also contained one artificial clay egg (16 x 11 mm; see below), which was tethered to the base of the nest (Boulton & Cassey 2006). Artificial eggs helped to determine whether a mouse has visited the nest. The nests were left out for a period of five days and were checked daily between 9 am and 12 pm for any signs of predation. If a nest was preyed on and eggs were damaged, the damage was described and the egg remains were collected. If any eggs remained undamaged they were left in the nest, but only the first event of predation was recorded. If a nest showed no sign of predation it was left as it was for another night. After the final check on the fifth day, all nests, eggs, and flagging tape were removed from the site.

2.3. Artificial clay egg creation

Artificial eggs were made to mimic real canary eggs following the methods of Boulton & Cassey (2006). White modelling clay was moulded around a ball of polystyrene to create artificial canary eggs similar in mass to real ones. The clay was also moulded around a small (~5 mm) piece of matchstick, which was tied to the end of a 20 cm length of black elastic string. The matchstick functioned to hold the elastic string inside of the clay egg. After moulding the clay to the correct shape and size, the artificial eggs were left to dry overnight before being painted to look like real canary eggs. Two coats of matte finish varnish were then applied to the artificial eggs allowing at least six hours of drying time between coats.

One artificial egg was threaded through the base of each nest using a darning needle. The end of the elastic string was tied to a whole matchstick (the red end was removed), which prevented the fake egg from being fully removed from the nest. Each artificial egg was placed in the nest with all of the elastic string on the outside of the nest. This meant that if a mouse attempted to take the egg away, it was evident by the elastic string that had been pulled through and into the nest.

2.4. Nest predation

A nest was considered preyed on when any one egg within it was damaged or removed from the nest. Artificial eggs helped determine whether a mouse had visited a nest. If an artificial egg displayed any mouse imprints, or if it had been pulled out from the nest, those nests were recorded as preyed on, even if none of the real eggs were damaged or removed. Nests were also inspected for mouse droppings.

2.5. Filming nests

On the third day of the trial, three nests were filmed for the remainder of the study period. Filmed nests were chosen on the basis of whether or not they had been preyed on during the first two nights, and on their proximity to each other (due to cable constraints). Accordingly, one nest that was preyed on during the first night (N1), one nest that was preyed on during the second night (N2), and one nest that had not been preyed on (N3) were filmed. A fresh quail egg and an artificial canary egg were placed in both N1 and N2. N3 was left as it had been set at the start of the study period (with one quail, one canary, and one artificial egg). Cameras with 6mm and 8mm lens were used, with one camera securely attached to a nearby tree at each nest.

2.6. Data analysis

Nest survival was estimated using the nest survival mode in program MARK v.6.1 (White & Burnham 1999). Daily survival rates were assumed to be constant across all nests and all days. There were no covariates in this model. It was not useful to model the effects of different egg combinations in nests because they were unlikely have influenced the outcome. To support this, the null hypothesis that the proportions of nests with different egg combinations preyed on were equal was tested. Significant differences in the proportions of individual egg types preyed on were evaluated by testing the null hypothesis that the

proportions of different eggs preyed on were equal. These tests were performed in R (v.2.12.2) using the package "ctest", function "prop.test", without correction for continuity. Finally, characteristic signs of predation left by mice were described by looking at egg shell remains and video footage of filmed nests.

3. Results

3.1. Nest and egg predation

During a period of five days (128.5 exposure days) 13 of the 40 nests (32.5%) were preyed on (Table 1). Within these 13 nests, 2 quail eggs, 7 canary eggs, 3 finch eggs, and 10 artificial eggs were either damaged or removed from the nest. These eggs represent 5% of the total quail eggs, 31.8% of the total canary eggs, 27.3% of the total finch eggs, and 25% of the total artificial eggs contained in all of the nests (Table 2). Of the two quail eggs that were preyed on, only one had actually been consumed. The other had been removed from the nest, but remained undamaged.

Table 1: Number of nests containing different egg combinations that were preyed on over a period of five days. Nests either contained a quail and artificial egg (Q+A), a quail, canary, and artificial egg (Q+C+A), or a quail, finch, and artificial egg (Q+F+A).

Egg combination	Total number of nests with each egg combination	Nests depredated	Percentage depredated
Q+A	7	2	28.6
Q+C+A	22	8	36.4
Q+F+A	11	3	27.3
Total	40	13	32.5

Table 2: Number of each type of egg that was preyed on over a period of five days. Small eggs include all canary, finch, and artificial eggs.

Egg type	Total number of eggs available to predators	Number depredated	Percentage depredated
Quail	40	2	5.0
Canary	22	7	31.8
Finch	11	3	27.3
Artificial	40	10	25.0
Small	73	20	27.4
Total	113	22	19.5

There was clear statistical significance at the in the difference between the proportion of quail eggs and the proportion of small eggs preyed on (-0.224, p = 0.004, 95% CI: -0.347,-0.101; Table 3). Pooling all of the small eggs and comparing them to quail eggs is the most useful way of looking at the potential influence of egg size on mouse predation.

Table 3: Summary of statistics (tests of equal proportions) comparing mouse predation rates of different egg types at Maungatautari (program R v.2.12.2).   Prop 1 and Prop 2 are proportions of the two respective egg types eaten, and 95% confidence intervals are of the difference between proportions.

Egg types preyed on	Prop 1	Prop 2	Difference	df	p-value	95% Confidence Intervals	
						Lower	Upper
Quail*Canary	0.050	0.318	-0.268	1	0.004**	-0.474	-0.062
Quail*Finch	0.050	0.273	-0.025	1	0.028*	-0.494	0.049
Quail*Artificial	0.050	0.250	-0.200	1	0.012*	-0.350	-0.050
Quail*Small[1]	0.050	0.274	-0.224	1	0.004**	-0.347	-0.101
Canary*Finch	0.318	0.273	0.045	1	0.789	-0.281	0.373
Canary*Artificial	0.318	0.250	0.068	1	0.565	-0.168	0.305
Finch*Artificial	0.273	0.250	0.023	1	0.594	-0.213	0.358

[1] "Small" refers to a pooled total of all small eggs (canary, finch, and artificial) that were preyed on.
* significant when p < 0.05.
** significant when p < 0.01.

From 7 nests containing only quail and artificial eggs (Q+A) 2 were depredated (28.6%; Table 1). In one case the quail egg was taken out of the nest and was left slightly burrowed under tree roots and leaves approximately 10 cm from the nest. The artificial egg in this nest displayed no sign of predation. In the other case the quail egg remained undamaged in the nest, but the artificial egg had been pulled out of the nest as far as the elastic tether had allowed. There were no obvious marks on this artificial egg. From 22 nests containing quail, canary, and artificial eggs (Q+C+A) 8 were depredated (36.4%; Table 1). In one of these

cases the canary egg had been broken open, but the contents were uneaten and appeared to be rotting. No other eggs in this nest were damaged. From 11 nests containing quail, finch, and artificial eggs (Q+F+A) 3 were depredated (27.3%; Table 1). Having different egg combinations in each nest did not significantly influence the results (Table 4).

Table 4: Summary of statistics (tests of equal proportions) comparing mouse predation rates of nests with different egg combinations at Maungatautari (program R v.2.12.2). Nests either contained a quail and artificial egg (Q+A), a quail, canary, and artificial egg (Q+C+A), or a quail, finch, and artificial egg (Q+F+A). Prop 1 and Prop 2 are proportions of the two respective nest types preyed on, and 95% confidence intervals are of the difference between proportions.

Nest type	Prop 1	Prop 2	Difference	df	p-value	95% Confidence Intervals	
						Lower	Upper
Q+A*Q+C+A	0.286	0.364	-0.078	1	0.7056	-0.468	0.312
Q+A*Q+F+A	0.286	0.272	0.014	1	0.9522	-0.413	0.439
Q+C+A*Q+F+A	0.364	0.272	0.092	1	0.6015	-0.240	0.422

There were two cases where the artificial egg was the only egg in a nest to be preyed on. One case was in a nest with only a quail egg in (Q+A). The other case was in a nest which also contained a canary egg (Q+C+A).

In one nest a canary egg appeared to be degrading as the egg shell gradually broke inwards over the course of the week. The contents of this egg did not appear very fresh and the nest showed no signs of being preyed on during the week.

3.2. Nest survival

The probability of a nest surviving one day (i.e. the daily survival rate (DSR)) was 0.910 (CI: 0.848-0.948, SE 0.025; Table 5). With this rate of survival, the probability of a nest surviving the duration of the study (5 days) was 0.685 (CI: 0.524-0.811, SE 0.075; Table 5).

Table 5: Survival estimates based on Mayfield estimations of survival of artificial nests in the QEII block of Maungatautari in February 2013. "DSR" is the probability of a nest surviving one day when the daily survival rate is constant across all dates and all nests in the sample. "Survival" is the probability of a nest surviving the duration of the study (5 days) with a constant daily survival rate.

	Estimate	SE	95% Confidence Intervals	
			Lower	Upper
DSR	0.910	0.025	0.848	0.948
Survival	0.685	0.075	0.524	0.811

3.3. Characteristics of predation by mice

Of all the real eggs that were preyed on, the shell remains exhibited similar patterns of gnawed and broken edges (Figure 2A-D). In most cases of predation on real quail and canary eggs, the entire eggs' contents were consumed. Only in one case, in which the contents did not appear to be very fresh, were they not consumed. No shell remains of finch eggs were left in any nest to be examined. Mice incisor impressions were evident on some of the artificial eggs (Figure 2E-F). In some cases mice had removed a portion of the outer layer of an artificial egg (Figure 2G). In other cases mice had broken right in to the centre of an artificial egg (Figure 2H). Sometimes the majority of the damage on the artificial eggs was at the base of the egg (Figure 2G), and sometimes it was at the top (Figure 2H).

No mouse droppings were found at any nest at any time during the study period.
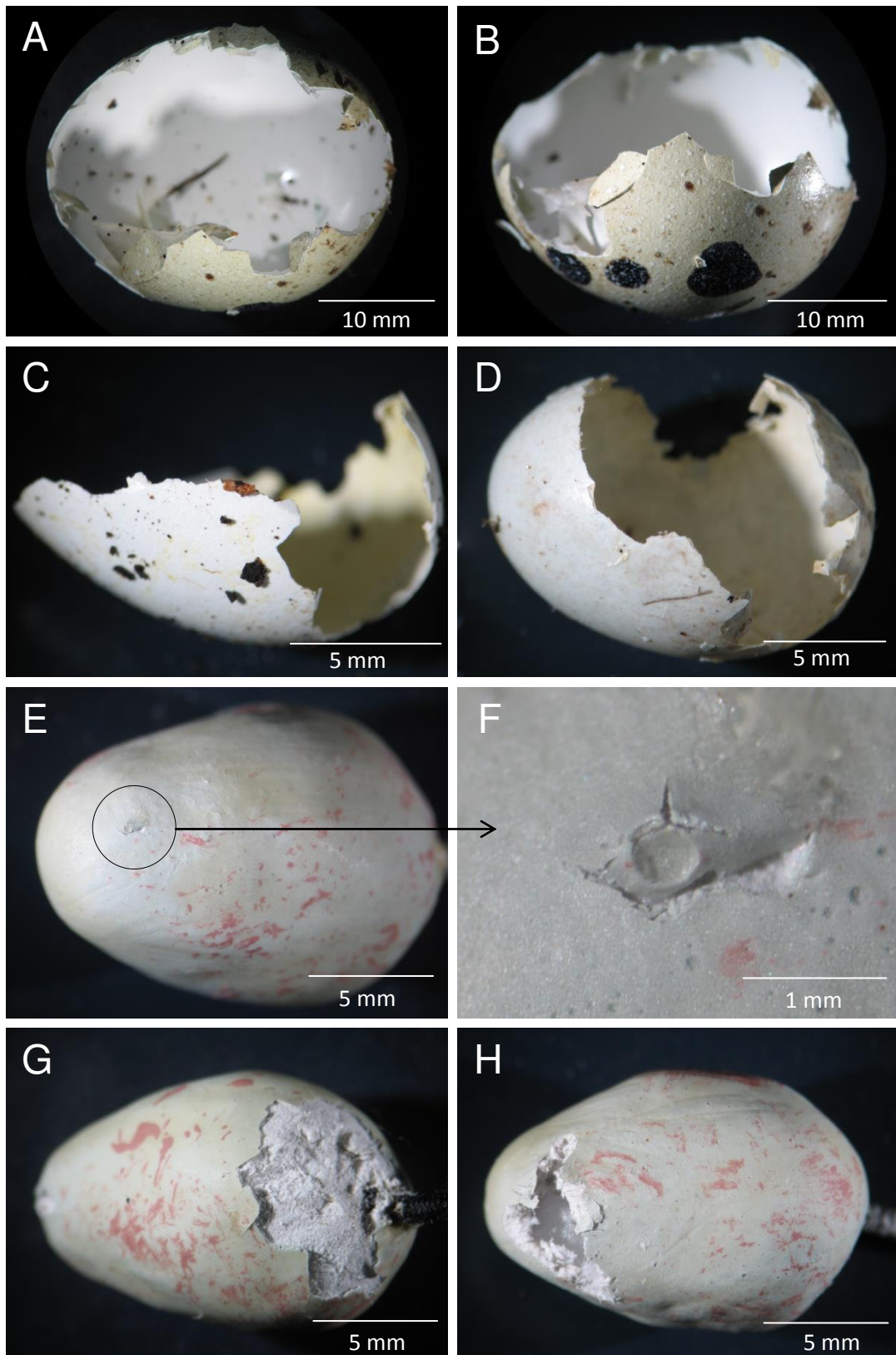
Figure 2: Photographs of various egg remains showing damage by mice. (A) Emptied shell of a quail egg; (B) Broken/gnawed edges of the same quail egg; (C) Gnawed edge of a damaged canary egg; (D) Emptied shell of a canary egg; (E) An artificial egg with mouse incisor impressions on the tip; (F) Close up of the mouse incisor imprints. The circular indentation was formed when the paint/varnish dried; (G) Damage to the base of an artificial egg; (H) Damage to the tip of an artificial egg. Photos by Kelly Frogley.

3.4. Filmed evidence of predation by mice

Three nests within the QEII block were filmed over two days and two nights beginning on the third day of the nest survival experiment. The first nest (N1) had been preyed on during the first night (during which a quail egg was eaten) and was filmed with a fresh quail and artificial egg in. At 21:00h a mouse with an ear tag (the tag number was indiscernible) approached the nest where it immediately began attempting to break into the quail egg (Figure 3A). After nearly one minute the mouse focused its efforts on the artificial egg (Figure 3B). For the next five minutes the mouse attempted to break the artificial egg from its tether. The mouse then temporarily left the nest, returning 10 seconds later to have another go at the quail egg. The mouse spent approximately six minutes trying to break into both the quail and artificial eggs, and succeeded in hollowing out the centre of the artificial egg. The remains of the artificial egg can be seen in Figure 4. The mouse left the nest at 21:12h. One hour later, a mouse (also with an ear tag and likely to be the same individual) returned to the nest for two minutes during which it attempted to break into the quail egg. There was no more action at the nest for the rest of the film. Unfortunately the camera ran out of battery around 20:00h on the second night. It therefore remains unknown whether or not the mouse returned to the nest a second time.

The second nest that was filmed (N2) had been preyed on during the second night of the nest survival experiment. As with N1, a fresh quail and artificial egg was placed in the nest. At 19:28h, a mouse was filmed around the nest, but it did not immediately interact with the nest itself. After a few minutes, the mouse sniffed the eggs (quail egg first), but didn't bite or scratch them until a few more minutes had passed. This mouse appeared to be very cautious and skittish, jumping out of the nest at any sign of movement, e.g. when a moth flew by, or when an egg rolled in the nest. Over the following three hours, what I assume to be the same mouse intermittently returned to the nest, occasionally inspecting the eggs very briefly.

There was considerably less action during the second night of filming. On two occasions between 21:00h and 23:00h a mouse, which behaved in a similar way to that on the previous night, visited N2. On the first occasion, the mouse did not interact with the nest at all. On the second occasion, it sniffed the quail egg briefly, touched it with one paw, and then left the nest.

The third nest that was filmed (N3) was left as it had been set at the start of the study period (with one quail, one canary, and one artificial egg). No mice were filmed at this nest during either of the two filmed nights.

Figure 3: Still images from video footage filmed at N1 of a mouse preying (A) unsuccessfully on a quail egg, and (B) on an artificial canary egg. Images by Neil Fitzgerald.

Figure 4: Remains of the artificial canary egg from one of the filmed nests (N1) after being preyed on by a mouse. Image by Kelly Frogley.

4. Discussion

This study verifies that introduced house mice in a fenced sanctuary will eat bird eggs of a certain size if they are available.

Nest survival

During a period of five days 32.5% of nests within the QEII block at Maungatautari were preyed on. The probability of a nest surviving one day (DSR) was 0.910. With this rate of survival, the probability of a nest surviving the duration of the study (5 days) was 0.685. When the DSR of nests at Maungatautari is projected over the length of an actual incubation period, the probability of survival becomes much lower. For example, the stitchbird/hihi, an endangered New Zealand endemic forest passerine present in Maungatautari with eggs similar in size to those of a canary (stitchbird/hihi eggs average 19 x 15 mm compared to canary eggs which average 16 x 11 mm), incubates eggs for c.15 days (Heather & Robertson 1996). When the DSR of nests in the QEII block (0.910) is applied, the probability of a stitchbird/hihi nest surviving to hatching is just 0.243. This assumes that nests up trees and with a sitting female are preyed on at the same rate as our nests, which is unlikely to be true. However, mice in the QEII block at Maungatautari have been tracked not only at ground level, but also up in trees. In November 2011, 67% of tunnels placed at head height for six nights showed mouse tracks, and in May 2012, 15% of tunnels placed at 8-20 m above ground for seven nights showed mouse tracks (Innes 2012).

Characteristic sign

I can be confident that mice were responsible for all predation events as they were the only mammalian predators present in the fenced block and video footage verified that mice were indeed the predation culprits at filmed nests. Furthermore, the damage left on real and artificial eggs was similar to typical rodent damage, e.g. gnawed edges with small shell

fragments broken off, documented in other nest predation studies (Innes et al. 1996, Brown et al. 1996). Weta have been known to damage artificial eggs made of Blu-tac (van Heezik et al. 2008) leaving small pinch marks on the eggs (S. Whitwell, pers. comm. 2013). The clay eggs in this study were a lot harder than the Blu-tac ones, which meant that weta did not leave any obvious marks. Unlike plasticine, the clay used to make the artificial eggs in this study was not soft enough to leave fan-fluted marks characteristic of small rodents (Smith et al. 2008). Occasionally though, clear mouse incisor marks were left in the outer layers. More often, large areas of the outer shell (the painted and varnished layers) had been scratched or bitten off leaving a patch of exposed white modelling clay. Sometimes the majority of the damage on the artificial eggs was at the base of the egg and sometimes it was at the top. This may have something to do with the curvature of the clay eggs. Not all of the artificial eggs were perfectly formed, and some had a narrower tip than others. It may be that the mice were better able to get their jaw around the tip of these malformed clay eggs. Nevertheless, this isn't likely to have affected the mouse's ability to prey on wider tipped clay eggs, because they were capable of damaging the base of many other clay eggs as well as real canary eggs, on which the clay eggs were modelled.

Mouse behaviour at nests

Directly witnessing nest predation by mice is a rare event (Boulton & Cassey 2006), usually because nests are filmed in environments where other mammalian predators are present and mice are scarce (Brown et al. 1993, Thompson & Burhans 2004). There are no published accounts of mice being filmed preying on NZ forest bird nests. The video footage obtained in this study showing mouse behaviour at filmed nests will prove highly useful for advocacy and seminar purposes.

Of the 22 eggs that were either damaged or removed from nests, only two were quail eggs. Moreover, the proportion of quail eggs (0.050) preyed on was significantly less than the

proportion of smaller eggs (0.274) that were preyed on (difference = -0.224, p = 0.004, 95% CI: -0.347,-0.101). Video footage showed that mice attempted to break into quail eggs, but the mice caught on film could not get their jaw well enough around the shell to bite into it. This suggests that eggs of this size (30 x 24 mm) are likely to be at the upper limit of a mouse's harvest capability. In comparison, mice were much more capable of preying on smaller finch (14 x 9 mm) and canary (16 x 11 mm) eggs.

In each case when a mouse visited a filmed nest it attempted to prey on the quail egg first, indicating perhaps that mice are aware that the larger egg will provide more food. Munoz & Bonal (2008) found that granivorous mice preferred larger seeds because they offer a higher nutrient content, but such preferences were often counterbalanced by higher costs of handling and transporting. With consideration to the size of eggs that mice at Maungatautari are likely to be able to prey on (i.e. anything up to the size of a quail egg), and to mouse climbing ability, New Zealand native birds at risk of predation in sanctuaries where mice are the sole mammalian predator include, but are not limited to, fantail (Rhipidura fuliginosa), rifleman (Acanthisitta chloris), grey warbler (Gerygone igata), silvereye (Zosterops lateralis), brown creeper (Mohoua novaeseelandiae), Stitchbird/hihi (Notiomystis cincta), fernberd (Bowdleria punctata), rock wren (Xenicus gilviventris), tomtit (Petroica macrocephala), whitehead (Mohoua albicilla), bellbird/korimako (Anthornis melanura), yellowhead/mohua (Mohoua ochrocephala), kakariki/yellow-crowned parakeet (Cyanoramphus auriceps), kakariki/red-crowned parakeet (Cyanoramphus auriceps), NZ robin (Petroica australis), saddleback/tieke (Philesturnus carunculatus), and tui (Prosthemadera novaeseelandiae) (Table 6).

Table 6: Dimensions of the eggs used in this study (in bold) relative to those of New Zealand native species often found in fenced sanctuaries throughout New Zealand, ordered by increasing egg length. The dimensions of New Zealand native birds' eggs are from Heather & Robertson (1996).

Common name	Scientific name	Egg length (mm)	Egg width (mm)
Zebra finch	**Taeniopygia guttata**	**14**	**9**
Canary	**Serinus canaria domestica**	**16**	**11**
Fantail	Rhipidura fuliginosa	16	12
Rifleman	Acanthisitta chloris	16	12.5
Grey warbler	Gerygone igata	17	12
Silvereye	Zosterops lateralis	17.5	13
Brown creeper	Mohoua novaeseelandiae	18.5	14
Stitchbird/Hihi	Notiomystis cincta	19	15
Fernbird	Bowdleria punctata	19.5	14.5
Rock wren	Xenicus gilviventris	20	15.5
Tomtit	Petroica macrocephala	20	15.5
Whitehead	Mohoua albicilla	20	15
Bellbird/Korimako	Anthornis melanura	23	16
Yellowhead/Mohua	Mohoua ochrocephala	23.5	18
Kakariki/Yellow-crowned parakeet	Cyanoramphus auriceps	24	19
Kakariki/ Red-crowned parakeet	Cyanoramphus novaezelandiae	25	22
New Zealand Robin	Petroica australis	25	18.5
Saddleback/Tieke	Philesturnus carunculatus	29	22
Tui	Prosthemadera novaeseelandiae	29	21
Quail	**Coturnix japonica**	**30**	**24**
Kokako	Callaeas cinereus	37	26.5
Kaka	Nestor meridionalis	42	31
Kereru/New Zealand woodpigeon	Hemiphaga novaeseelandiae	60	40
Takahe	Porphyrio hochstetteri	74	49
Kiwi	Apteryx australis	125	78

The obtained video footage offered a rare look at the variability in predatory behaviour of mice at bird nests. The behaviour of mice filmed at N1 and N2 appeared very different. I cannot be sure that that the mouse filmed throughout the two nights at N2 was the

same mouse, although it did behave in a consistent manner. The mouse filmed at N2 was considerably more timid than the mouse at N1, showed little determination to break into either egg, and ultimately failed at preying on the nest. This variability may be due to a number of reasons including individual ability, maturity, and/or personality.

5. Limitations of study

The use of artificial nests and eggs to study predation is common practice in New Zealand and elsewhere (Cuthbert & Hilton 2004, van Heezik et al. 2008, Smith et al. 2008). It can be extremely difficult and time consuming to search for and find natural native bird nests, especially if they are scarce, and doing so often results in small sample sizes (Smith et al. 2008). Artificial nests provide an opportunity to collect nest predation data in a simple, controlled way and with large sample sizes (Smith et al. 2008). However, artificial nests have their limitations and are often criticised because they do not realistically represent predation rates of natural nests (Major & Kendal 1996). Artificial nests in this study had no sitting female to defend the eggs, and were placed on the ground, whereas most forest birds nest in trees or shrubs and remain on the nest during incubation. The timing of this experiment, which occurred just after the nesting season had finished, may have also influenced nest survival rates. Wilson et al. (2007) found that natural Willow Ptarmigan (Lagopus lagopus) nests were more likely to be preyed on during peak breeding periods, suggesting predators may adjust their search effort based on the likelihood of locating nest. Also because of the timing of this study, it was difficult to source small passerine bird eggs from breeders. Consequently, some of the real canary eggs used were not very fresh and may have negatively influenced predation by mice.

Artificial eggs offer a simple and inexpensive way to identify nest predators, but they do not necessarily tell us about their ability to prey on eggs (Purger et al. 2012). For example, although video evidence proved that a mouse did visit one of the filmed nests (N2), there were no signs left on the artificial egg to suggest that a predation attempt had occurred (and failed). Coupling the use of artificial eggs with video cameras will, therefore, provide a better idea of what happens at nests.

It has been suggested that artificial eggs of different materials can influence and modify the behaviour of predators that rely on olfactory cues (Major & Kendal 1996). Smith et al. (2008) found that artificial nests with plastilina eggs had a higher risk of predation than artificial nests with wax eggs. There has been no investigation into any possible influence of artificial eggs made of painted and varnished modelling clay on nest survival. I found no evidence to suggest that the clay eggs had any deterring or attracting influence on mice. Video footage at two different nests demonstrated that mice will certainly attempt to prey on the clay eggs, although the mice on film consistently preyed on the real egg first every time they visited the nests. More evidence is needed to determine any real pattern.

Finally, this study involved a satisfactory sample size (n=40), but there was no replication at a site level. Thus, the reliability of the predation and nest survival rates, and therefore the applicability of the results to other similar environments may be limited.

6. Conservation implications

Despite the fact that 32.5% of the nests were preyed on during the five days of this study, it is clear that the damage inflicted by mice will be less than what ship rats, stoats, and possums are capable of. Future eradications and sanctuary monitoring should therefore continue to focus on the latter species, particularly on islands or in fenced sanctuaries.

While these results are preliminary and have limitations, they are consistent with studies that showed that wild mice ate eggs of Gough buntings and rock wrens (Cuthbert & Hilton 2004, S. Heath, University of Otago, pers. comm. 2013). Mice are also likely to eat nestlings up to a certain size as has been observed in captivity experiments with starling nestlings (Moors 1978), and with Atlantic Petrel (Pterodroma incerta) nestlings on Gough Island (Cuthbert & Hilton 2004). It is also important to note that mice alone can have significant impacts on altricial chicks. Such is the case with albatross chicks at some sub-Antarctic islands (e.g. Gough and Marion Islands) where mice have inflicted fatal wounds to many individuals and are thought to be constraining population growth rates and distributions of some species, e.g. Diomedea dabbenena, Diomedea exulans, and Phoebetria fusca (Angel & Cooper 2006, Wanless et al. 2007, Jones & Ryan 2010). With prospects of introducing kakapo (Strigops habroptilus) to Maungatautari in the future (MEIT 2010a), it is worth considering the effects that mice may have on their altricial chicks when females are out foraging.

To date, the biodiversity impacts of mice alone have rarely been studied. However, it is important they are considered by managers of sanctuaries. Sanctuaries like Maungatautari provide an important refuge for many threatened species and can act as a source for translocations to other sites (MEIT 2010b). They offer unique insights into what some forest ecosystems looked like in the past and provide valuable opportunities for research and progress in biodiversity management (MEIT 2010b, Innes et al. 2012). If my results from the

QEII block are paralleled in the main mountain sanctuary, managers can expect that mice are likely to prey on eggs up to approximately 30 x 24 mm and nestlings (up to a certain size) of birds in forest environments, especially at or near ground level, and especially if parent birds do not defend nests or are absent. The impact of this on populations will require further research.

Future research should focus on monitoring survival of natural nests (up to c.20 m high) of birds with eggs less than 30 mm in length in sanctuaries with mice alone that are not managed.

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