

An inexpensive method for identifying predators of passerine nests using tethered artificial eggs

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Abstract: We identified nest predators of two European thrush and three European finch species in the central North Island, New Zealand, using artificial clay eggs in active natural nests. The acceptance of the artificial egg by females was 75%, with low rates of female egg ejection (7%) or desertion (7%). Due to high predation rates we could not confirm the acceptance of six (11%) artificial eggs before predation occurred. Of the 57 nests that received an artificial egg 30 were preyed upon. We were able to successfully identify predators from 18 (60%) nests by imprints left in the artificial eggs, with rats (*Rattus* sp.), Australasian Harriers (*Circus approximans*) and Australian magpie (*Gymnorhina tibicen*) accounting for nine, eight and one of the predatory events respectively. In the remaining twelve predatory events imprints were too faint or no marks were left on the clay egg for identification. This study successfully demonstrates the use of an inexpensive, seldom-used method for quantifying and identifying nest predators, with low rates of nest abandonment and high rates of predator identification. We believe this method could add valuable information for future studies of nest predation in New Zealand.

Keywords: artificial egg; clay egg; introduced birds; nest predation; New Zealand.

Introduction

Nest predation is often the primary cause of reproductive failure in bird species (Ricklefs, 1969). Although nest predation plays a crucial role in studies of reproductive output, the event is rarely witnessed. Subsequently, the numerous ornithological studies that examine reproductive success often lack any conclusive evidence or quantitative information regarding the identity of important nest predators within their research systems. This lack of predator identity is partly due to the rarity of directly observing such events, as well as the inaccuracy involved when studies try to infer predator identification from signs left at the nest site (Storaas, 1988; Major, 1991; Brown *et al.*, 1998; Larivière, 1999; Williams and Wood, 2002; Staller *et al.*, 2005).

The variability in individual predator behaviour at nest sites means the assessment of sign left at nests can be an unreliable method of predator identification. Moors (1983a) inferred that “clean” signs left at nests in New Zealand were the result of stoat or weasel (*Mustela* sp.) predation and “messy” signs were the result of rats (*Rattus* sp.) or mice (*Mus musculus*). Footage from cameras set up at New Zealand robin (*Petroica australis*) and tomtit (*P. macrocephala*) nests revealed that these classification schemes were misleading.

Not only was the overlap between rat scavenging and predation impossible to distinguish, but nest sign was also sometimes caused by parents removing egg and nestling remains after predation (Brown *et al.*, 1998). Even when researchers only attempt to classify nest predators into classes (e.g. birds, mammals, reptiles) incorrect classification can be extremely high. Williams and Wood (2002) attempted to identify the class of nest predator from sign left at nests before observing video footage of the predation event. They found that the class of nest predator was misidentified in 57% of cases.

Images from photography and video cameras offer an extremely powerful method for identifying predators of eggs and nestlings (Major, 1991; Brown *et al.*, 1998; Thompson *et al.*, 1999; Sanders and Maloney, 2002; Williams and Wood, 2002; Morgan *et al.*, 2006). However, in many studies it is unfeasible to use cameras because of their high cost and so only a small number of predation events can be recorded. Saunders and Maloney (2002) spent between NZ\$3200 and NZ\$4400, and Morgan *et al.* (2006) spent over NZ\$2000 (D. Morgan, Waikato University, personal communication), on each video camera setup, although cheaper options are available (see Major and Gowing, 1994; King *et al.*, 2001). Cameras are also very labour intensive to use, with long set-up times, as well as

requiring frequent battery and tape changes, further reducing available sample sizes. Considering the frequent criticism of sample sizes used in studies of behavioural and evolutionary ecology (e.g. Møller and Jennions, 2002), it is essential that researchers respond with alternative methods, decreasing the cost and labour of intensive field methods and increasing the possible number of replicates. We suggest that nest predation studies with small budgets or limited time would greatly benefit from a cheaper alternative to using cameras, and a more reliable method than attempting to identify signs left by predators at nests.

One such methodology, now widely published is the use of artificial bird nests containing clay eggs which can preserve impressions of predators' teeth and beaks for the identification of nest predators (see review in Major and Kendall, 1996). However, there is growing evidence, and criticism, that these artificial nests do not accurately reflect predation rates and patterns from real nests (e.g. Pärt and Wretenberg, 2002; Zanette, 2002; Berry and Lill, 2003; Boulton and Clarke, 2003; Thompson and Burhans, 2004). Artificial eggs are also frequently used in active passerine nests testing species acceptance (or ejection rates) of brood parasite eggs (Davies and Brooke, 1989; Higuchi, 1989; Moksnes *et al.*, 1991; Ortega *et al.*, 1994; Briskie, 2003). Considering the widespread use of artificial eggs, and the potentially high acceptance rate by many species, it is surprising they have not been utilized more in active nests for the purpose of nest predator identification. We were only able to find two such studies: one involved the Canada goose (*Branta canadensis*) where domestic goose eggs were blown and filled with paraffin and petrolatum and anchored in active nests (Anthony *et al.*, 2004), the other identified magpies (*Pica pica*) as nest predators using plasticine eggs placed in active blackbird (*Turdus merula*) nests (Groom, 1993).

Here we describe a study using tethered artificial clay eggs in active European blackbird (*Turdus merula*), song thrush (*Turdus philomelos*), greenfinch (*Carduelis chloris*), goldfinch (*C. carduelis*) and chaffinch (*Fringilla coelebs*) nests in farmland and orchard habitat in New Zealand. We assessed the acceptance of artificial eggs by the female, the effect of artificial eggs on nest survival and whether imprints in the artificial eggs could be used to identify nest predators.

Methods

Study sites and species

The response of European passerines to the addition of artificial eggs and subsequent predator identification was tested from September to January 2002–2005. The main study took place in the Benneydale region (175° 22' E, 38° 32' S) of the central North Island, New Zealand.

An additional site near Hamilton (175° 19' E, 37° 47' S) was used during 2004–2005 primarily for greenfinch, goldfinch and chaffinch nests. These nests were easily located in blueberry (*Vaccinium* sp.) orchards where these species are regarded as agricultural pests. The Benneydale study site is situated in an agricultural region, on the sheep and cattle farming Maori Trusts of Te Hape, Tiroa and Wharakeri. Blackbird and song thrush nests were found in native podocarp-broadleaf fragments and exotic trees and shrubs across the study area. We systematically searched for nests in this habitat, and often located nests by flushing the female.

Artificial clay egg construction

Artificial eggs were made to mimic real eggs by moulding them from white, blue, and brown Sculpey III® polymer clay to the appropriate size, shape and colour for each species. Clay was moulded around small Styrofoam balls for the larger blackbird and song thrush eggs to produce artificial eggs similar in mass to real eggs. Brown flecks and spots were painted onto the eggs to approximately simulate the egg markings for each species. All eggs were dipped three times into Cabot® satin wood varnish (enamel based). This resulted in a soft centre, allowing predators to leave imprints, while the harder outer-surface coats of varnish allowed the female to sit on the egg without distorting the egg surface. Each egg took less than ten minutes to make, and applying the three coats of varnish took between three to five days including drying time. These drying times could not be reduced as the clay cracked if it was dried too quickly.

Artificial clay egg attachment

In the first trial, we placed the artificial egg in a song thrush nest with no attachment mechanism, analogous to the method used by Groom (1993). After this nest was preyed on we could not relocate the clay egg, which had been removed along with all the natural eggs, eliminating our ability to identify the nest predator. To prevent predators removing the artificial egg we devised a tethering system. Each egg was made with a short piece of fine black elastic protruding from the bottom, this was tied to a short piece (~5 mm) of fine timber doweling (matchstick) that was embedded into the moulded egg during construction. The elastic was long enough that it could be threaded through the bottom of the nest, using a very thin piece of wire with a hook on one end to push through the nesting material. The elastic was then tied to the nearest branch below the nest and the artificial egg was placed in the nest (Figure 1a, b). This attachment method prevented the complete removal of the artificial egg by predators. Excess elastic was pulled through to prevent either the incubating female or nestlings from becoming entangled. Some

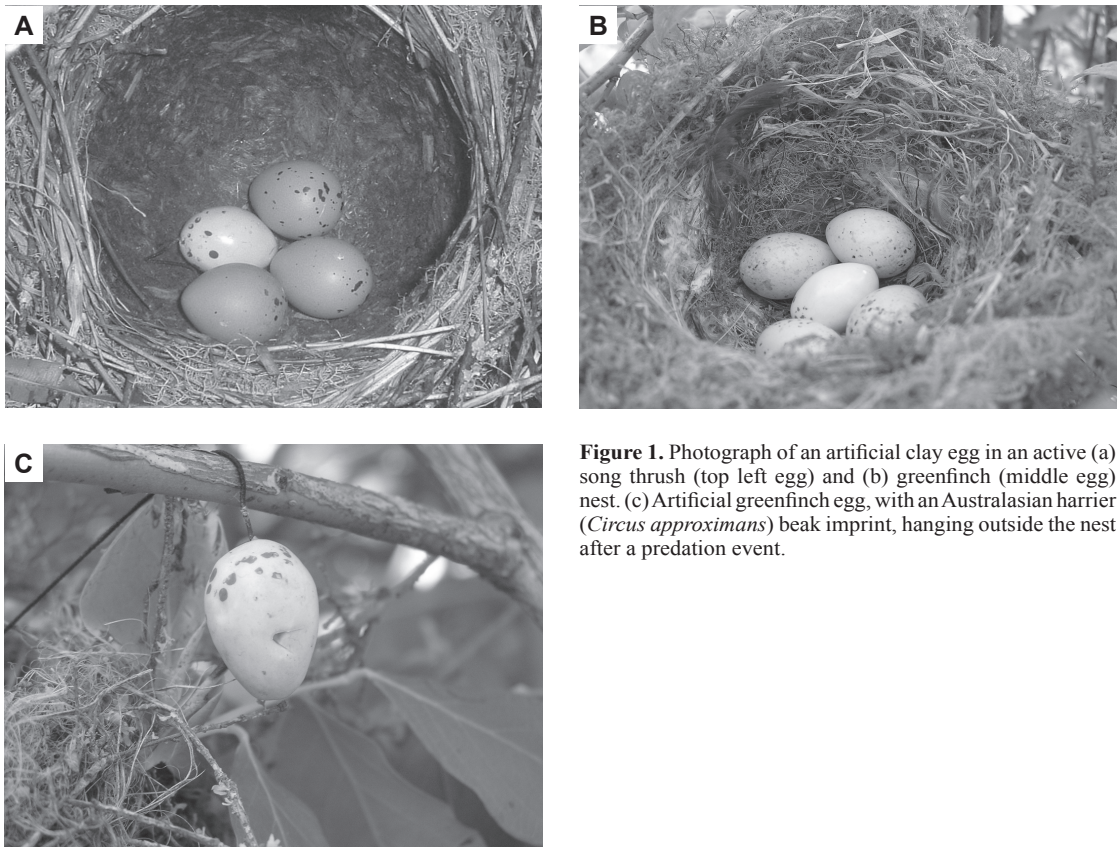


Figure 1. Photograph of an artificial clay egg in an active (a) song thrush (top left egg) and (b) greenfinch (middle egg) nest. (c) Artificial greenfinch egg, with an Australasian harrier (*Circus approximans*) beak imprint, hanging outside the nest after a predation event.

excess elastic was necessary as it allowed females (and predators; Figure 1c) who rejected the artificial egg to eject it over the side of the nest.

Nests were normally located only 1–2 m above the ground, making accessibility straightforward. One artificial egg was placed in each nest found during the laying and incubation period. Because nests were found (and subsequently candled with a small handheld flashlight) at different stages of development, 12 artificial eggs were added during the laying period, 27 during early incubation (days 1–6 of incubation), eight during late incubation (days 7–12 of incubation) and 10 were added during unknown stages of development. Ideally, the artificial egg was added early in the nesting period, allowing us to assess the female's behaviour towards the foreign egg for a longer period and increasing the chance of witnessing a predation event. In 39 of 57 cases one un-incubated egg was removed from the clutch at the same time the artificial egg was added. The removed egg was kept for chemical analysis in a future study. To minimize disturbance in future studies this egg removal is unnecessary, as the

experimental removal of one host egg has not been found to increase the acceptance rates of model eggs (Davies and Brooke, 1989).

Most rejections of artificial eggs occur during the first three days (Davies and Brooke, 1989), therefore once an artificial egg had been added to a clutch we re-visited the nest 3–5 days later to confirm whether the female had accepted or rejected the egg. The artificial egg was considered rejected if after this period the female had ejected the artificial egg over the nest rim and was still observed to be incubating or brooding the nest. However, each time this behaviour was observed we replaced the artificial egg if the incubating female had not damaged it. If the female accepted the egg on the second occasion this was termed “partial acceptance”. Nests were considered deserted if the eggs were cold and the female could not be located. After the artificial egg had been accepted we typically visited the nest every 3–6 days, until it either successfully fledged or was depredated.

For the two most common species (song thrush and blackbirds), we also monitored a larger number of nests

for a subsequent study. These nests included two control groups, allowing for a comparison between female desertion rates for nests containing an artificial clay egg and non-manipulated nests. One group contained no artificial egg and because they were located after incubation commenced no egg was removed from these clutches (control group). The second control group was found before incubation was initiated and had one egg removed from the clutch (egg removal group). We include this group in the analysis to test for the possible effect of removing a single egg from a number of the nests in which an artificial egg was placed. Control nests were monitored at the same frequency as the artificial egg nests, every 3–6 days. We present absolute nest success (proportion of successful nests/total number of nests) for artificial egg nests as we know the exact outcome (success or failure) of every nest into which an artificial egg was placed. For control nests we present both apparent nest success (proportion of successful nests/total number of nests) and an estimate of overall nest survival calculated in SAS Version 9.1 (SAS Institute, 1999) following the methods outlined in Shaffer (2004) to avoid underestimating nest failure. Overall nest survival was calculated for the combined control groups to increase the available sample size and provide a useful estimate of the 95% confidence interval.

Predator identification

Predators were identified by positioning the skull (tooth and beak) of potential nest predators obtained from museum specimens onto the imprints left on the artificial eggs. Mammalian predators were easily identified to genus, as there were only five potential predator genera in the region, *Rattus*, *Mus*, *Trichosurus*, *Mustela* and *Felis*, and these differ markedly in size and dentition. Three predatory bird species were observed regularly at the study sites, the Australian magpie (*Gymnorhina*

tibicen), Australasian harrier (*Circus approximans*) and Morepork (*Ninox novaeseelandiae*). All three species have characteristic beak shape and size, leaving distinctive imprints in the artificial clay eggs.

Results

Artificial clay egg acceptance

During the study 57 nests received an artificial egg, in 43 cases (75%) the female accepted the artificial egg and incubated it as one of her own (Table 1). In one case, the female continued to incubate the artificial egg for three days after her own eggs were preyed on, until the artificial egg was also depredated. In six cases (10.5% of the 57 nests), the nest had been preyed on when first checked following the addition of the artificial egg. Hence it was impossible to assess whether the artificial egg had been accepted or not (Table 1).

Of the eight remaining nests (14%), the female rejected the artificial egg either by ejection or desertion (Table 1). Three females (one blackbird, one chaffinch, one goldfinch) ejected the artificial egg by hanging it over the nest rim, and one greenfinch apparently pulled the artificial egg apart. In these four cases the female continued to incubate her clutch after removing the artificial egg. Four nests (one blackbird, three song thrush) were found deserted when first checked following the addition of the artificial egg (Table 1). In three other cases (5.3%), all involving song thrushes, the female initially rejected the artificial egg by removing it over the edge, but subsequently accepted the egg when we replaced it in the nest (Table 1).

Control groups

Nest survival of the artificial egg nests and the estimated survival for the control groups were relatively similar (Table 2), with no increase in absolute nest failure due

Table 1. Individual responses of five European passerine species following the addition of an artificial clay egg to their clutch. Mode of rejection includes removal of egg from nest (ejection) or abandonment of the nest immediately after receiving artificial egg (desertion). Numbers in parenthesis represent the total number of nests sampled for each species.

Species	Acceptance rate	Unknown	Rejected	Mode of rejection	
				Desertion	Ejection
Song thrush ^a	30 (36)	3	3	3	
Blackbird	5 (8)	1	2	1	1
Greenfinch	5 (6)		1		1 ^b
Goldfinch	3 (5)	1	1		1
Chaffinch	0 (2)	1	1		1
TOTAL	43 (57)	6	8	4	4

^a Acceptance includes three partial acceptance events, whereby the female initially ejected the artificial egg but subsequently accepted it after it was replaced.

^b Only the elastic attached to the small piece of doweling remained in the nest, no clay.

to the addition of the artificial clay egg. It is unclear how many of the nest desertions for artificial egg nests were directly caused by the addition of the artificial egg (Table 2). Four song thrush females deserted their nests after initially accepting the artificial egg for 5–10 days and both control groups had very similar or even higher desertion rates than the artificial egg nests (Table 2). It appears that neither the addition of an artificial egg nor the removal of a female's egg had a detectable effect on female desertion rates (or apparent nest survival rates).

Predator identification

Thirty predation events took place at nests containing artificial eggs. We observed clear imprints in 19 cases (Table 3), while no imprints were recorded in the other 11 cases resulting in no clear identification. Nine of the eggs were imprinted by *Rattus* sp., and probably by *R. rattus* based on the distribution of rat species in New Zealand (King *et al.*, 1996; Innes, 2001). Where rats were identified as the predators, they generally left

shell fragments in or on the nest rim, indicating eggs were eaten in the nest (Table 3). Most of these artificial eggs were also left in the nest. Large bird imprints were found on nine artificial eggs, eight were identified as Australasian harriers and one as an Australian magpie (Table 3). The remaining egg was imprinted by an unknown smaller bird species, the imprint was too faint to accurately identify and may have been the incubating female. The large birds appeared to eat eggs away from the nest site, as only one left shell fragments in the nest, and most tried to remove the artificial egg from the nest (Table 3; Fig. 1c).

Of the 30 predatory events, 25 occurred during the incubation period. Females continued to incubate the artificial egg after their clutch hatched, making no attempt to remove the artificial egg with the hatched eggshell fragments. Five nests subsequently failed during the nestling period, two after predation by *Rattus* sp. and the other three after predation by an unknown predator.

Table 2. The number of song thrush and blackbird nests monitored in the three different study groups, the percentage of nests deserted, their percentage nest success (absolute nest success for experimental nests and apparent nest success for control nests, see text), and estimated nest survival (\pm 95% CI) for 54 song thrush and 18 blackbird nests without artificial eggs. Note that overall nest survival was calculated for the combined control groups (see text). No estimate of nest survival is available for nests in the 'artificial egg' group because the exact outcome (success or failure) of every nest into which an artificial egg was placed is known.

Species	Group	<i>n</i>	% Deserted Nests	% Nest Success	% Nest Survival (95% CI)
Song thrush	Artificial egg	36	19	22	
	Egg removal	29	24	21	
	Control	25	24	16	18 (12, 24)
Blackbird	Artificial egg	8	13	62	
	Egg removal	9	22	55	
	Control	9	22	33	47 (21, 73)

Table 3. Predator identification at the 30 active bird nests preyed on while containing artificial clay eggs. Numbers are given for nests where predator sign was left at the nest site and where partial predation occurred (one or more eggs from a clutch disappearing before complete predation).

Predator	<i>n</i>	Shell fragments	Clay egg out of nest	Partial predation
<i>Rattus</i> sp.	9	8	2	1
Harrier	8	1	7	2
Magpie	1	0	1	0
Unknown bird	1	0	1	0
No imprints	11	4	2	4

Discussion

The drive to incubate has meant that birds will accept and sit upon a variety of objects irrespective of whether or not they resemble eggs (Skutch, 1976). Fortunately, the willingness to accept egg-shaped objects has allowed researchers to use both artificial and telemetric eggs to study behavioural patterns during incubation such as parasitic egg acceptance, egg turning behaviour, and to monitor nest conditions (Deeming, 2002). Researchers may gain further benefit from this willingness by using artificial eggs to assist in predator identification. Modifying the methodology described for a large ground nesting species and a medium open-cup nesting species (Groom, 1993; Anthony *et al.*, 2004), we successfully demonstrated the use of an inexpensive method of predator identification, using tethered artificial clay eggs in active European thrush and finch nests. The acceptance of the artificial egg by female blackbird and song thrush was high, with similar nest survival and desertion rates for experimental and control nests, suggesting that predators were neither attracted nor repelled by the artificial eggs. For this method to be of practical use for researchers, study species clearly need to exhibit low desertion rates towards the artificial egg. Species acceptance of model eggs will likely depend on their historical levels of parasitism and the incidence of intraspecific parasitism (Briskie, 2003).

Blackbird and song thrush desertion may not have been directly caused by the addition of an artificial egg as control nests had similar desertion rates. Other studies have also found desertion rates similar to those recorded in this study with 6–22% for blackbirds (Osborne and Osborne, 1980; Moors, 1983b; Kentish *et al.*, 1995; Hatchwell *et al.*, 1996) and 18% for song thrush (Moors, 1983b). To reduce the possible negative effect of nest desertion and egg ejection in future studies we believe that every attempt should be made to closely mimic species eggs when constructing artificial eggs. For example blackbirds and song thrush show high rejection rates toward model cuckoo (*Cuculus canorus*) eggs, 62–100% for blackbirds and 58–80% for song thrush, with egg ejection the preferred method of rejection (Davies and Brooke, 1989; Moksnes *et al.*, 1991; Grim and Honza, 2001). When model eggs are painted to resemble blackbird and song thrush eggs acceptance significantly increases, with only 23% of blackbird and 14% of song thrushes ejecting model eggs (1989).

A large number of previous studies have used clay eggs in artificial nests to identify nest predators, but they have also received much criticism as they frequently report different predation rates from those on natural nests. Without reliable predator identification from natural nests the processes behind these discrepancies remain largely speculative, although they are generally

believed to be caused by the avoidance/attraction of different nest predators to artificial nests. Although our estimated nest survival for control nests was lower than absolute survival of the experimental nests, it is expected that without controlling for nests that failed before a clay egg could be added apparent nest success will over-estimate the true estimate of nest survival (Mayfield, 1961; Mayfield, 1975; Shaffer, 2004). Even when no difference between artificial and natural nest survival is recorded interpretation without reliable predator identification for natural nests may be incorrect. Thompson and Burhans (2004) found similar predation rates for artificial and natural nests, but showed via video cameras that racoons (*Procyon lotor*) were the major nest predator at artificial nests while snakes were responsible for the predation at natural nests. The use of artificial eggs in active nests is clearly advantageous to any nest studies which lack a cost-effective method for identifying predators at natural nests.

Nest predators that pose only a small threat to real nests can also prey on contents of artificial nests at unnaturally high rates. Nest visitation by small mice, for example, can complicate artificial nest study results as it is unclear whether they are true nest predators (Buler and Hamilton, 2000), incidental scavengers facilitated by the lack of a parental bird defending the nest (Pärt and Wretenberg, 2002), or simply attracted by the plasticine (Rangen *et al.*, 2000). Similar biases exist for small birds scavenging undefended nests in artificial nest experiments (Zanette, 2002; Boulton and Clarke, 2003). Using artificial eggs in active nests eliminates these biases and one of the major criticisms for the use of artificial nests, i.e. the lack of a parental bird and therefore, the lack of nest/egg concealment, bird odour and nesting activity.

Like camera failures, the addition of an artificial egg to a nest does not guarantee that every predator will be identified, as 37% of our predatory events recorded no predator imprints. The absence of any mustelid or felid imprints within this study may indicate that the artificial eggs do not deceive these predators, and it is possible that they represent the proportion of unidentified predators or they are not major nest predators within this system. Video camera recordings from nests elsewhere in New Zealand have also failed to find mustelids or feral cats as major predators (Innes *et al.*, 1996; Brown *et al.*, 1998), although Morgan *et al.* (2006) recently found high predation by feral cats (23% of lethal events) in a study similarly carried out within the rural Hamilton region. A pilot study, either with cameras or in captivity, could reveal if these predators are likely to take artificial eggs.

Outside New Zealand, there are two potential difficulties with using this methodology; predation by snakes, and a much larger array of potential nest predators. Thompson and Burhans' (2004) study failed

to detect snake predation at any artificial nests, although snakes accounted for 65% of predation at natural nests. It seems unlikely that snakes would attempt to eat an artificial egg, so species outside New Zealand that suffer high predation due to snakes may not be suitable candidates for this method. In areas with a larger number of potential nest predators, imprints may be difficult to identify (Major *et al.*, 1994; Maier and DeGraaf, 2001) or several different predators may visit a nest between visits by researchers (Larivière, 1999). Because New Zealand has only a limited number of potential predators, it makes predator identification from imprints relatively straightforward. Therefore we believe this method should be of explicit interest for New Zealand scientists and conservation managers.

While it was not surprising to find *Rattus* sp. as a major nest predator (Brown, 1997; Brown *et al.*, 1998), it was interesting that our study, like Morgan *et al.* (2006) in the same central North Island region identified Australasian harriers as major nest predators. Although harriers may also be important nest predators of kokako (*Callaeas cinerea wilsoni*) (Innes *et al.*, 1996), they appear to be minor nest predators on ground-nesting birds of braided riverbeds in the Upper Waitaki Basin even though they are abundant in the area (Keedwell and Sanders, 2002; Sanders and Maloney, 2002). Currently, information about the importance of this species as a nest predator of native New Zealand species, especially open-cup nesting species, is limited. Species situated close to agricultural landscapes (i.e. native podocarp-broadleaf fragments) may be more susceptible to predation from harriers than currently estimated.

In summary, we present data from a method for quantifying and identifying natural nest predators that had relatively low rates of nest desertion and high rates of predator identification. Arguably, this is not a benign technique as it involves direct manipulation at active nests. However, there seems no reason why this method should not be investigated further. Similar techniques are routinely being used in cuckoo host-parasitism experiments, while studies do not hesitate to use nest cameras although they also have the potential to cause high nest desertion rates (34% in Williams and Wood, 2002). With each artificial egg costing less than NZ\$0.20, construction time of ten minutes (plus drying time), and field set-up of one minute we believe this method could add valuable information for future studies of nest predation. Before using artificial eggs we recommend pilot studies with different host species to assess rates of acceptance, probability of identifying imprints and to test hatching success and predation rates between control and experimental nests. Some of this necessary information is already available for a number of New Zealand species, with high acceptance rates observed for clay eggs mimicking long-tailed

cuckoo (*Eudynamys taitensis*) eggs (Briskie, 2003). We are surprised considering the large number of cuckoo host-parasite studies currently being conducted (with artificial and mimetic eggs in natural nests) that imprint data are not being routinely used to identify natural nest predators. Ultimately, if this method is to be successfully used by researchers to quantify proportions of different nest predators it will benefit from a study similar to that of Williams and Wood (2002) using both artificial eggs and video cameras to confirm its efficiency.

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