Can small-scale predator control influence mallard duck (*Anas platyrhynchos*) nest survival? An experiment with artificial nests in Southland, New Zealand

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Abstract: Artificial mallard (*Anas platyrhynchos*) nests were used to identify potential nest predators and assess whether small, farm-scale predator control could reduce mallard nest predation in Southland, New Zealand. Artificial nests were deployed over the mallard nesting period (late winter – spring) in both 2019 and 2020 and monitored with motion detection cameras. Prior to 2020 artificial nest deployment, farm-scale trapping of mammalian predators was conducted on one farm whilst the other was left as a control. Feral cats (*Felis catus*), brushtail possums (*Trichosurus vulpecula*), and European hedgehogs (*Erinaceus europaeus*) frequently visited the artificial nests but seldom preyed on them (i.e. consumed the eggs). Swamp harrier (*Circus approximans*) were the most common predator and were responsible for the destruction or predation of at least one egg at 17% of the artificial nests. Mammalian predator trapping had no noticeable effect on artificial nest predation, but did reduce the probability an artificial nest was visited by a cat, possum, or hedgehog. Results suggest typical predator control efforts of gamebird hunters does not reduce mallard nest predation, but may reduce nest disturbance and consequently mallard hen predation and nest abandonment.

INTRODUCTION
Globally, introduced mammalian predators are implicated in the decline of biodiversity (Blackburn *et al*. 2004; Doherty *et al*. 2016). In New Zealand, feral cats (*Felis catus*), stoats (*Mustela erminea*), weasels (*Mustela nivalis*), ferrets (*Mustela furo*), brushtail possums (*Trichosurus vulpecula*), and European hedgehogs (*Erinaceus europaeus*) are all predators of native avifauna, negatively affecting their populations (Moors 1983; Sanders & Maloney 2002; Moorhouse *et al*. 2003; Jones & Norbury 2006). As a result, significant effort is invested into the control of these introduced predators using a variety of methods (Baber *et al*. 2009; O'Donnell & Hoare 2012; Fea *et al*. 2021). Numerous studies have documented the benefits of mammalian predator control for native forest bird species

(Baber *et al*. 2009; O'Donnell & Hoare 2012; Fea *et al*. 2021); however, no New Zealand studies have looked at the potential benefit of predator control for gamebirds, specifically the mallard duck (*Anas platyrhynchos*), New Zealand's most important gamebird.

Predation and disturbance of mallard duck nests has been well documented in New Zealand (Garrick 2016; Sheppard 2017; Sheppard *et al*. 2019). For example, Sheppard (2017) assessed mallard nest survival at two New Zealand study sites (Waikato and Southland) and found that almost 40% of nests were subjected to at least one predation event; predators completely removed or destroyed all eggs from 8% of nests. At the Southland study site, 9% of mallard hens were killed by predators whilst on the nest, resulting in the loss of the nest. If these nest failure rates are applicable across Southland, each year thousands of mallard nests are disturbed or fail due to predators.

Mustelids (stoats, ferrets, weasels) and cats (domestic and feral) are suspected predators of mallard nests and incubating hens in the Southland agricultural landscape (Sheppard 2017; Sheppard *et al*. 2019; Stewart *et al*. 2019; Southland Fish and Game *unpubl. data*); however, hedgehogs and possums may also prey on mallard nests as they are known to consume bird eggs (Brown *et al*. 1993; McDonald *et al*. 2000; Sanders & Maloney 2002). Swamp harriers (*Circus approximans*) and pukeko (*Porphyrio melanotus*) are native predators of avian nests (Boulton & Cassey 2006; Kross *et al*. 2013; Innes *et al*. 2015) and have been observed preying on mallard nests (Morgan *et al*. 2006; CS *pers. obs*.).

The predation and disturbance of mallard nests and the laying/incubating hen is of concern for gamebird hunters and managers. Due to the non-migratory nature of mallards in New Zealand (McDougall 2012), hunters are concerned that the loss of local nests or incubating hens may affect local hunting opportunities. Predators also have the potential to negatively affect the regional mallard population, which is of concern for gamebird managers because some areas have relatively low and/or declining mallard abundance (McDougall & Amundson 2017).

Amongst some hunters and landowners there is interest in undertaking mammalian predator control to improve local mallard nest and brood survival (CS *pers. obs*.). However, many trapping programs lack adequate trap densities and sustained effort (CS *pers. obs*.). International studies have documented improved mallard nesting success with predator control (Duebbert & Lokemoen 1980; Garrettson & Rohwer 2001; Amundson *et al*. 2013), but these studies are not comparable to New Zealand because of vast differences in landscape and predator guilds. Predator control

in these studies was also unrealistically intensive for the average landowner or hunter to conduct without support. Before gamebird managers advocate for and logistically support hunters to undertake predator control for improved mallard nest survival, there is a need to understand how control of New Zealand specific mallard predators, with realistic trap densities and effort, could affect localised mallard nest success.

This study used artificial mallard nests paired with motion detection cameras, and a Before-After-Control-Impact (BACI) study design, to (1) determine the most likely predators of mallard nests in the Southland agricultural landscape, and (2) test whether farm-scale predator trapping of mustelids, feral cats, hedgehogs, and possums affects the predation and predator visitation of artificial mallard nests during the spring breeding season.

METHODS
Study area
Two Southland dairy farms were selected and approximately 150 hectares of each farm were used as study sites. The treatment site (predator trapping site) was located near Roslyn Bush (46°20′35.4″S, 168°27′44.8″E) and the control site was located *c*. 20 km away near Lochiel (46°11′37.2″S, 168°17′57.8″E). Both sites had flat topography, were *c*. 35 m above sea level and surrounding land use consisted of intensive agriculture, specifically dairy cattle and sheep farmed on predominantly rye grass (*Lolium perenne*) pastures. Small streams, agricultural drains and five small (<1 ha) man-made waterfowl hunting ponds were present at both sites. The remaining land cover was limited to road verges, ditches, rank grass, and shelterbelts of typically macrocarpa (*Cupressus macrocarpa*), pine (*Pinus radiata*), gum tree (*Eucalyptus* spp.), or flax (*Phormium tenax*).

Artificial nest deployment
In 2019 and 2020, at each site, 17 artificial mallard nests (hereafter nests), spaced at least 145 m apart were deployed every 12 days, over three periods: late August – early September, early September – mid-September, mid-September – early October (a total of 51 nests per site, each year). These periods encompass the peak nest initiation (28th of August) and the peak nesting period (late-August – early October) for mallard ducks in Southland (Garrick 2016; Sheppard 2017). Nests were deployed for 12 days to mimic the average mallard laying period in Southland; the period whereby a mallard hen lays her eggs (one a day) before starting to incubate the whole clutch (typically 12 eggs) (Bellrose & Kortright 1976; Sheppard 2017).

The nests were constructed using methods adapted from Gunnarsson & Elmberg (2008) and Pasitschniak-Arts & Messier (1995). All nest bowls were constructed with dry grass to keep nest crypsis comparable for each nest. The dry grass was compressed into a bowl and fashioned into a nest with a *c.* 23 cm diameter and 8 cm depth. Three brown domestic hen eggs (length *c.* 55 mm) were added to the nest and covered with wild mallard hen down and breast feathers. Brown hen eggs are commonly used in artificial nest experiments (Padyšáková *et al.* 2010; Purger & Mužinić 2010) and artificial clutches baited with hen eggs have a survival rate comparable to those baited with mallard eggs (Kreisinger & Albrecht 2008). Four drops of Avery® mallard scent was also added to the nest.

Nests were placed on the ground, in hedgerows and shelterbelts, both of which are common mallard hen nesting habitat (Sheppard 2017). Each nest was paired with either a Browning® Spec Ops Advantage trail camera or a Moultrie® M-880i trail camera fastened to a stake *c.* 0.8 m from the nest. Cameras were set on a three trigger burst with a 30 second delay between bursts. The lowest trigger sensitivity was used for both camera types because wind can cause within-frame vegetation to move which can trigger the cameras (CS *pers. obs.*). Preliminary tests with the cameras indicated that both trail camera brands had comparable detection capabilities.

After 12 days of deployment, the nests were inspected, and nest fate recorded. Following nest assessment, each nest and camera were removed. A new nest was then redeployed with a camera and placed in a different location within the study site. In 2019, nest positions were marked with a handheld GPS and after the 12-day nest deployment period, a river stone painted bright pink was placed on the ground to help identify where the nest had been placed. The GPS waypoint and pink stone enabled nest locations to be replicated in 2020.

Reviewing trail camera photographs
Following collection of the cameras, the photographs were processed. Types of nest predators and predator visitation rates were recorded. A nest fate was recorded as preyed on if at least one egg was destroyed or displaced from the nest. If a nest was preyed on and then scavenged (remnants of a broken egg consumed), scavenging was not recorded as a predation event but was recorded as a nest visit.

When assessing nest disturbance, if a predator was photographed at a nest site multiple times within a ten-minute period, this was recorded as a single visit. If a predator was photographed at a nest site for more than ten minutes, without a break away from the nest of at least ten minutes, this was also recorded as single visit. However, if a predator was detected at a nest site, then was absent from the nest site for 10 minutes or more, then was again detected at the nest site, these were recorded as separate visits. Predator visits (disturbance) included predators touching the nest contents, smelling the nest, and walking in proximity (*c.* 1 m) to the nest. After recording the daily visitation rates for each predator, the total number of visits by each predator for the 12-day nest deployment period was determined.

The artificial mallard nests were not used to estimate survival rates of natural nests as mallard nest survival has already been assessed in Southland (Sheppard 2017; Sheppard *et al.* 2019). Furthermore, the survival rates of artificial nests often differ from natural nests due to the absence of an incubating female and differing predator abilities (Willebrand & Marcström 1988; Kreisinger & Albrecht 2008).

Predator control
Between 29 May and 28 August 2020, predator trapping was conducted at the Roslyn Bush site (treatment site). Small mustelids (stoats and weasels) and hedgehogs were targeted using four trap tunnels (length 800 mm, width 220 mm, height 180 mm) and two Mark IV Fenn traps baited with fresh chicken necks and placed alongside hedgerows or shelter belts. Chicken necks were selected as a bait because they are readily available and convenient. Larger mustelids (ferrets) and hedgehogs were targeted using two DOC 250 traps, also baited with a chicken neck. Trap tunnels were spaced 260–505 m apart and checked and re-baited weekly. Cats were targeted using six live capture treadle trigger cage traps. Prior to cat trapping, local landowners were contacted to determine whether they owned any pet or farm cats. Pictures or descriptions of these cats were collected so cats could be released if captured.

All traps were placed in hedgerows or shelter belts. To enable convenient trap checking and baiting, five of the six cage traps were paired (*c.* 10 m away) with a mustelid trapping tunnel and all traps were located near a paddock gateway. To acclimatise cats to the traps, they were pre-baited weekly with two chicken necks for at least three weeks. With each successive week of pre-baiting, the pre-bait was positioned further into the cage (closer to the treadle trigger). The bottom of the cage was covered in leaf litter, so cats did not feel the metal cage underfoot. Traps were only set when pre-baits were being constantly eaten and fine overnight weather was forecasted. The cages

were set overnight on six occasions throughout the three-month period and captured feral cats were euthanised.

Possum trapping was conducted over two nights (7–8 August, 2020) by recreational possum hunters. Prior to trapping, potential trap sites were pre-baited with a lure comprised of flour, icing sugar, and cinnamon. Following pre-baiting, over two consecutive nights, recreational hunters set thirty Victor ® #1 coil spring leghold traps (each night), baited with flour-based lure. The traps were set in hedgerows and shelterbelts, checked each morning, and captured possums were euthanised.

Statistical analysis

A BACI (Before-After-Control Impact) (Morrison *et al*. 2008) study design was used to assess the effectiveness of the predator control for reducing nest predation and disturbance. The number of predation events and nest visits were compared between sites. A single predation event or predator visit to a nest was treated as a success (Binomial distribution). To analyse the data, a Bayesian approach, similar to that of Conner *et al*. (2016) was used to assess the effect of predator control on nest predation and disturbance.

The probability of at least one encounter (or predation event) (*m*) in year *t* at the control site (*C*), or treatment site (*T*), is $Encounter_{t,T|C} \sim binom(m_{t,T|C}, Cameras_{t,T|C})$. The treatment site in year *t* was not

trapped but was trapped in year *t+1*. The relative change in encounters after trapping to before trapping is:

$$\frac{m_{t,T}}{m_{t,C}} = K_{Before}$$

$$\frac{m_{t+1,T}}{m_{t+1,C}} = K_{After}$$

$$\frac{K_{After}}{K_{Before}} = K_{BACI}$$

Where K_{BACI} is the relative change in nest visits/predation after trapping cf. before trapping. We used an uninformative prior to derive the posterior binomial distributions and analysed the relative ratios of the posterior distributions using Program R (3.5.1; R Core Team 2018), package R2OpenBUGS (Sturtz et al. 2005). We ran 10,000 iterations, 3 chains, and discarded the first 1000 as burn-in (Gelman & Rubin 1992). Trace plots were checked for convergence. The accuracy of the posterior estimates was checked such that the MC error/sample sd < 0.05. We used the step function to calculate the probability that $K_{BACI} < 1$ (i.e., that trapping resulted in less predator encounters/predation).

Table 1. Number of artificial mallard nests predated/destroyed by different predators, by study site and year in Southland, New Zealand (n = number of artificial nests).

Predator	2019		2020		
	Treatment (n = 48)	Control (n = 48)	Treatment (n = 45)	Control (n = 48)	Total (n = 189)
Cat	2	0	0	1	3 (2%)
Possum	1	0	0	1	2 (1%)
Hedgehog	2	0	3	0	5 (3%)
Weasel	0	0	0	0	0
Stoat	0	0	0	0	0
Ferret	0	1	0	0	1 (<1%)
Swamp harrier	1	15	1	16	33 (17%)
Rat	0	0	0	0	0
Australian magpie	0	0	0	0	0
Pukeko	0	1	0	0	1 (<1%)
Dog	0	0	0	0	0
Unknown	0	1	1	0	2 (1%)

Table 2. Number of artificial mallard nests visited on at least one occasion by different potential predators, by study site and year in Southland, New Zealand (n = number of artificial nests).

Predator	2019		2020		Total (both sites and years) (n = 189)
	Treatment (n = 48)	Control (n = 48)	Treatment (n = 45)	Control (n = 48)	
Cat	30 (63%)	19 (40%)	21 (47%)	25 (52%)	95 (50%)
Possum	30 (63%)	10 (21%)	30 (67%)	16 (33%)	86 (46%)
Hedgehog	30 (63%)	17 (35%)	27 (60%)	27 (56%)	95 (53%)
Weasel	1 (2%)	6 (16%)	2 (4%)	5 (10%)	14 (7%)
Stoat	3 (8%)	1 (2%)	0	4 (8%)	8 (4%)
Ferret	0	9 (19%)	4 (9%)	1 (4%)	14 (7%)
Swamp harrier	1 (2%)	15 (31%)	3 (7%)	16 (33%)	35 (19%)
Rat	4 (8%)	4 (8%)	1 (2%)	5 (10%)	14 (7%)
Australian magpie	4 (8%)	1 (2%)	0	0	5 (3%)
Pukeko	0	1 (2%)	0	0	1 (<1%)
Dog	2 (4%)	0	0	1 (2%)	3 (1%)
Unknown	19 (40%)	6 (13%)	16 (36%)	9 (19%)	49 (26%)

RESULTS

Nest predation and destruction

Overall, 204 nests were deployed at the two study sites over two years (n = 51 each site, each year). Data were obtained from cameras at 189 nests while data from 15 nests were lost due to camera malfunctions (n = 5), animals knocking over the cameras (n = 9) or vegetation obscuring the cameras (n = 1). Of the 189 nests for which data were collected, 47 (25%) were destroyed (at least one egg broken/displaced from nest) by predators (Table 1).

Swamp harriers were the most common nest predator and predated/destroyed 33 of the 189 (17%) nests (Table 1). Direct swamp harrier predation of at least one egg occurred at 31 nests. Despite observing swamp harriers at both sites throughout the study, most (94%) swamp harrier predation of the nests occurred at the control site (Table 1). During visits by swamp harrier, the eggs were typically removed from the nest and on some occasions were consumed 2–3 m away from the nest. The only other predators to actively prey on the eggs were pukeko (n = 1) and possum (n = 1). The pukeko moved eggs just outside the nest and consumed them over three visits (one egg consumed per visit). The possum kept the egg in the nest and removed a *c.* 3 cm by 3 cm piece of shell from the egg, but consumed little (if any) of the contents.

Cats, hedgehogs, and ferrets destroyed some nests by displacing the eggs from the nest bowl or damaging the eggs. However, these predators did not consume any eggs. Hedgehogs and a ferret displaced eggs outside the nest bowl (15–20 cm) by rummaging through the nest, while cats displaced eggs from the nest bowl or broke eggs by trampling on them.

Artificial nest disturbance

Predators visited 181 of the 189 nests (96%). Hedgehogs, cats, possums, and swamp harriers were the most common nest visitors (Table 2). Further, the frequency in which the potential predators disturbed the nests varied (Table 3). Possums were the most frequent nest visitors and would often disturb the nests by smelling the nest or walking in proximity of the nests. On average, across both study sites and years, possums visited a nest an average of 2.7 times (Table 3). Cats and hedgehogs were frequently observed smelling the nests but would seldom physically disturb the nest. Rats (*Rattus* spp.) walked over the nests but did not appear to affect the eggs or nest structure. Stoats, weasels, and ferrets investigated the nest by climbing over the nest bowl and eggs, but they did not consume the eggs.

Predator control

Six trapping tunnels were deployed for 87 days capturing 18 hedgehogs and two stoats. Six cage traps were set overnight on six occasions and captured seven feral cats and one farm cat that was captured and released on four occasions. During the two nights of possum trapping, 31 possums were captured.

Table 3. The number of times predators visited artificial mallard nests (frequency of disturbance) by study site and year in Southland, New Zealand (n = number of artificial nests).

Predator	2019		2020		Total (both sites and years) (n = 189)	Number of visits ($\bar{x} \pm 1$ se, range)
	Treatment (n = 48)	Control (n = 48)	Treatment (n = 45)	Control (n = 48)		
Cat	55	68	38	113	274	1.45 ± 0.25 (0, 40)
Possum	170	49	218	75	512	2.71 ± 0.36 (0, 28)
Hedgehog	121	46	82	93	342	1.82 ± 0.27 (0, 37)
Weasel	3	8	2	6	19	0.10 ± 0.03 (0, 3)
Stoat	3	1	0	12	16	0.08 ± 0.05 (0, 9)
Ferret	0	13	8	3	24	0.13 ± 0.04 (0, 4)
Swamp harrier	5	34	6	24	69	0.37 ± 0.07 (0, 5)
Rat	6	11	1	23	41	0.22 ± 0.07 (0, 9)
Australian magpie	12	1	0	0	13	0.07 ± 0.04 (0, 5)
Pukeko	0	3	0	0	3	0.02 ± 0.02 (0, 3)
Dog	2	0	0	1	3	0.02 ± 0.01 (0, 1)
Unknown	41	11	29	19	100	0.53 ± 0.10 (0, 13)
Total	418	245	384	369	1,416	6.87 ± 0.55 (0, 48)

Effect of predator trapping on artificial nest predation

Very few nests were preyed on or destroyed by cats, possums, hedgehogs, and mustelids at both sites and during both study periods (Table 1). An insufficient number of nests were preyed on by each mammalian predator to meaningfully test whether predator trapping had any effect on artificial nest survival, so it was inferred that small, farm-scale trapping of mammalian predators did not affect the nest predation rate.

Effect of predator trapping on disturbance at artificial nests

Predator trapping led to a decrease in the number of nests visited by feral cats, possums and hedgehogs. Nest visits of feral cats decreased by 40% (K_{BACI} = 0.60 (95% Bayesian Credible Interval (BCI) 0.316–1.016, median = 0.577) $P(K_{BACI} < 1) = 0.97$. Nest visits by possums decreased by approximately 27%, K_{BACI} = 0.73 (BCI 0.32–1.39, median = 0.68), $P(K_{BACI} < 1) = 0.85$. For hedgehogs, nest visits decreased by approximately 36%, K_{BACI} = 0.64 (BCI 0.34–1.05, median = 0.61), $P(K_{BACI} < 1) = 0.96$.

DISCUSSION

In New Zealand, mallard nest predation, partial predation and nest failure is often attributed to cats and mustelids (Sheppard 2017; Stewart *et al.* 2019; CS *pers. obs.*). However, this study suggests that effects of mammalian predation on mallard nests is relatively minor compared to predation by swamp harriers. It is therefore unlikely that current mammalian predator control efforts are achieving reduced mallard nest predation rates in Southland. Swamp harriers are known predators of bird nests throughout New Zealand (Boulton & Cassey 2006; Morgan *et al.* 2006; Kross *et al.* 2013; Innes *et al.* 2015), but this is the first study to illustrate that swamp harriers are probably the most important mallard nest predator in southern New Zealand.

Swamp harriers are abundant throughout New Zealand (Eakle 2008) and were frequently observed at both sites in this study. Under current legislation, swamp harriers are partially protected (Wildlife [Australasian Harrier] Notice 2012) and provision for control exists when they cause problems for domestic livestock. Predation of wild gamebirds on private land is not justification for swamp harrier control. The only way to reduce swamp harrier predation of mallard nests would be to establish initiatives to reduce their foraging success. Sheppard (2017) found that mallard nest survival was higher when hens selected more densely vegetated nesting sites. This may be because dense vegetation offers better nest crypsis, particularly for highly visual predators like swamp harriers. To enhance mallard nest survival, managers should encourage landowners to protect and create densely vegetated habitat (hedges and woodlots).

At both study sites, very few nests were preyed on or destroyed by cats, possums, hedgehogs, and mustelids both before and after trapping.

Therefore, farm-scale control of mammalian predators will likely have little effect on mallard nest predation rates. Limited predation of the nests by cats, stoats, and ferrets was unexpected because these predators are known to consume bird eggs in both real (Sanders & Maloney 2002; Stewart *et al*. 2019) and artificial nests (Smith *et al*. 2008; Kross *et al*. 2013). The reason for limited nest predation may be related to the availability of alternative prey. At both study sites, mice (*Mus musculus*), Eurasian blackbird (*Turdus merula*), song thrush (*Turdus philomelos*), and common starling (*Sturnus vulgaris*) appeared locally abundant and were frequently photographed by the trail cameras. Reduced predation pressure on mallard nests due to the availability of alternative prey has been observed in North America. Ackerman (2002) found that mallard nest success was positively correlated with rodent abundance and concluded that rodents provided predators with an alternative food supply. Furthermore, in Southland, passerines and their eggs have been identified as the most common prey item in the diet of stoats during the mallard breeding season (Stewart *et al.* 2019) which suggests they are highly available and/or selected for.

Very limited predation of the eggs by possums and no predation by hedgehogs may be explained by their typical foraging habits in agricultural environments. Although hedgehogs and possums have been documented consuming bird eggs in some habitats (Brown *et al*. 1993; Sanders & Maloney 2002), in agricultural habitat, hedgehog diets typically consist of vegetation and invertebrates (Campbell 1973) whilst possum diets are comprised of vegetation (Harvie 1973).

Despite limited mammalian predation, hedgehogs, possums, and cats were photographed visiting the nests with some nests receiving multiple visits within the 12-day nest deployment period. Predator visitation of real nests may have negative consequences for the laying/incubating hen and the nest. A nest visit from a cat for example, may result in the predation of the hen, and loss of breeding females is a key driver of mallard productivity in New Zealand (Sheppard 2017). Additionally, nest disturbance may cause the mallard hen to abandon her nest (Sheppard *et al*. 2019; CS *pers. obs*.). This could have profound impacts on the population because the probability of renesting decreases with successive nests and clutch sizes become smaller (Arnold *et al*. 2010). In this study, predator trapping reduced the number of nests visited by 27-40%, depending on predator type. This finding suggests that small scale trapping programmes can decrease nest disturbance, which may enhance breeding productivity. This finding should be communicated to landowners and gamebird hunters to help encourage the uptake of predator trapping programs on private land.

Results from this study indicate that swamp harriers are the most likely mallard nest predator and that small scale removal of cats, possums, and hedgehogs could reduce the number of mallard nests disturbed by these predators. However, it is acknowledged that this study has some limitations. Firstly, an obvious criticism of artificial nests is that they lack realism. There are unavoidable foreign scents associated with the construction of artificial nests and the absence of a female bird which may influence predation rates (Willebrand & Marcström 1988). Secondly, the presence of a trail camera at nests may influence predation rates (Richardson *et al*. 2009). Finally, this study has limited spatial and temporal replication (the study was conducted over two years at two sites) so the magnitude of the effect of the predator control on nest disturbance should be interpreted prudently. Despite these limitations, this study has still provided some insight into mallard nest predation, how predators may interact with nests and the potential effect small-scale predator control could have on mallard nest survival and disturbance. Future studies should use trail cameras to validate the identity of mallard nest predators and those causing nest abandonment and, assess the effect of predator control on duckling survival, as it is the most important variable governing mallard population growth in New Zealand (Sheppard 2017).

LITERATURE CITED

Ackerman, J.T. 2002. Of mice and mallards: positive indirect effects of coexisting prey on waterfowl nest success. *Oikos 99*: 469–480.

Amundson, C.L.; Pieron, M.R.; Arnold, T.W.; Beaudoin, L.A. 2013. The effects of predator removal on mallard production and population change in north eastern North Dakota. *The Journal of Wildlife Management 77*: 143–152.

Arnold, T.W.; Devries, J.H.; Howerter, D.W. 2010. Factors that affect renesting in mallards (*Anas platyrhynchos*). *The Auk 127*: 212–221.

Baber, M.; Brejaart, R.; Babbitt, K.; Lovegrove, T.; Ussher, G. 2009. Response of non-target native birds to mammalian pest control for kokako (*Callaeas cinerea*) in the Hunua Ranges, New Zealand. *Notornis 56*: 176–182.

Bellrose, F.C.; Kortright, F.H. 1976. *Ducks, geese and swans of North America*. Harrisburg (PA), Stackpole Books.

Blackburn, T.M.; Cassey, P.; Duncan, R.P.; Evans, K.L.; Gaston, K.J. 2004. Avian extinction and mammalian introductions on oceanic islands. *Science 305*: 1955–1958.

Boulton, R.L.; Cassey, P. 2006. An inexpensive method for identifying predators of passerine nests using tethered artificial eggs. *New Zealand Journal of Ecology 30*: 377–385.

Brown, K.; Innes, J.; Shorten, R. 1993. Evidence that possums prey on and scavenge birds' eggs, birds and mammals. *Notornis 40*: 169–177.

Campbell, P.A. 1973. Feeding behaviour of the European hedgehog (*Erinaceus europaeus* L.) in a New Zealand pasture. Unpubl. PhD thesis, The University of Canterbury, Christchurch, New Zealand.

Conner, M.M.; Saunders, W.C.; Bouwes, N.; Jordan, C. 2016. Evaluating impacts using a BACI design, ratios, and a Bayesian approach with a focus on restoration. *Environmental Monitoring and Assessment 188*: 1–14.

Doherty, T.S.; Glen, A.S.; Nimmo, D.G.; Ritchie, E.G.; Dickman, C.R. 2016. Invasive predators and global biodiversity loss. *Proceedings of the National Academy of Sciences 113*: 11261–11265.

Duebbert, H.F.; Lokemoen, J.T. 1980. High duck nesting success in a predator-reduced environment. *The Journal of Wildlife Management 40*: 428–437.

Eakle, W.L. 2008. Relative abundance of Australasian harriers (*Circus approximans*) in New Zealand. *Notornis 55*: 136–139.

Fea, N.; Linklater, W.; Hartley, S. 2021. Responses of New Zealand forest birds to management of introduced mammals. *Conservation Biology 35*: 35–49.

Garrettson, P.R.; Rohwer, F.C. 2001. Effects of mammalian predator removal on production of upland-nesting ducks in North Dakota. *The Journal of Wildlife Management 65*: 398–405.

Garrick, E. 2016. Duckling survival and habitat selection of brood-rearing mallard (*Anas platyrhynchos*) females in Southland, New Zealand. Unpubl. Masters thesis, The University of Otago, Dunedin, New Zealand.

Gelman, A.; Rubin, D.B. 1992. Inference from iterative simulation using multiple sequences. *Statistical Science 7*: 457–472.

Gunnarsson, G.; Elmberg, J. 2008. Density-dependent nest predation–an experiment with simulated Mallard nests in contrasting landscapes. *Ibis 150*: 259–269.

Harvie, A.E. 1973. Diet of the opossum (*Trichosurus vulpecula* Kerr) on farmland north-east of Waverley, New Zealand. *Proceedings of the New Zealand Ecological Society 20*: 48–52.

Innes, J.; King, C.; Bartlam, S.; Forrester, G.; Howitt, R. 2015. Predator control improves nesting success in Waikato forest fragments. *New Zealand Journal of Ecology 39*: 245–253.

Jones, C.; Norbury, G. 2006. Habitat use as a predictor of nest raiding by individual hedgehogs *Erinaceus europaeus* in New Zealand. *Pacific Conservation Biology 12*: 180–188.

Kreisinger, J.; Albrecht, T. 2008. Nest protection in mallards *Anas platyrhynchos*: untangling the role of crypsis and parental behaviour. *Functional Ecology 22*: 872–879.

Kross, SM.; McDonald, P.G.; Nelson, X.J. 2013. New Zealand falcon nests suffer lower predation in agricultural habitat than in natural habitat. *Bird Conservation International 23*: 512–519.

McDonald, R.A.; Webbon, C.; Harris, S. 2000. The diet of stoats (*Mustela erminea*) and weasels (*Mustela nivalis*) in Great Britain. *Journal of Zoology 252*: 363–371.

McDougall, M.B.; Amundson, C.L. 2017. Harvest dynamics and annual survival of mallards and grey ducks. *Journal of Wildlife Management 81*: 449–460.

McDougall, M. 2012. Toward adaptive management of parera (*Anas superciliosa*) and mallard (*A. platyrhynchos*) duck in New Zealand. Unpubl. Masters thesis, Massey University, Palmerston North, New Zealand.

Moorhouse, R.; Greene, T.; Dilks, P.; Powlesland, R.; Moran, L.; Taylor, G.; Knegtmans, J.; Wills, D.; Pryde, M.; Fraser, I.; August, A.; August C. 2003. Control of introduced mammalian predators improves kaka *Nestor meridionalis* breeding success: reversing the decline of a threatened New Zealand parrot. *Biological Conservation 110*: 33–44.

Moors, P.J. 1983. Predation by mustelids and rodents on the eggs and chicks of native and introduced birds in Kowhai Bush, New Zealand. *Ibis 125*: 137–154.

Morgan, D.; Waas, JR.; Innes, J. 2006. The relative importance of Australian magpies (*Gymnorhina tibicen*) as nest predators of rural birds in New Zealand. *New Zealand Journal of Zoology 33*: 17–29.

Morrison, M.L.; Block, W.M.; Strickland, M.D.; Collier, B.A.; Peterson, M.J. 2008. *Wildlife study design*. New York, Springer.

O'Donnell, CF.; Hoare, J.M. 2012. Quantifying the benefits of long-term integrated pest control for forest bird populations in a New Zealand temperate rainforest. *New Zealand Journal of Ecology 36*: 131–140.

Padyšáková, E.; Šálek, M.; Poledník, L.; Sedláček, F.; Albrecht, T. 2010. Predation on simulated duck nests in relation to nest density and landscape structure. *Wildlife Research 37*: 597–603.

Pasitschniak-Arts, M.; Messier, F. 1995. Risk

of predation on waterfowl nests in the Canadian prairies: effects of habitat edges and agricultural practices. *Oikos 73*: 347–355.

Purger, J.J.; Mužinić, J. 2010. Possible effects of nest predation on ground nest survival in the Neretva delta (Croatia). *Avian Biology Research 3*: 81–83.

R Core Team 2018. *R: A language and environment for statistical computing*. Vienna, R Foundation for Statistical Computing.

Richardson, T.W.; Gardali, T.; Jenkins, S.H. 2009. Review and meta-analysis of camera effects on avian nest success. *The Journal of Wildlife Management 73*: 287–293.

Sanders, M.D.; Maloney, R.F. 2002. Causes of mortality at nests of ground-nesting birds in the upper Waitaki Basin, South Island, New Zealand: a 5-year video study. *Biological Conservation 106*: 225–236.

Sheppard, J.L. 2017. Breeding ecology and productivity of mallards and mallard-grey duck hybrids in New Zealand. Unpubl. PhD thesis, The University of Auckland, Auckland, New Zealand.

Sheppard, J.L.; Amundson, C.L.; Arnold, T.W.; Klee, D. 2019. Nesting ecology of a naturalized population of Mallards *Anas platyrhynchos* in New Zealand. *Ibis 161*: 504–520.

Smith, D.H.; Wilson, D.J.; Moller, H.; Murphy, E.C. 2008. Using artificial nests to explore predation by introduced predators inhabiting alpine areas in New Zealand. *New Zealand Journal of Zoology 35*: 119–128.

Stewart, C.; Garrick, E.; McAulay, J. 2019. Do mallard ducks feature in the diet of stoats in an agricultural landscape? *New Zealand Journal of Zoology 47*: 206–219.

Sturtz, S.; Ligges, U.; Gelman, A. 2005. R2WinBUGS: A Package for Running WinBUGS from R. *Journal of Statistical Software 12*: 1–6.

Willebrand, T.; Marcström, V. 1988. On the danger of using dummy nests to study predation. *The Auk 105*: 378–379.