Short term effects of an aerial 1080 operation on mātātā (South Island fernbird, *Poodytes punctatus punctatus*) in a South Island wetland

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Abstract: New Zealand conservation managers use aerial 1080 (sodium fluoroacetate) to control invasive mammalian predators, often with the aim of protecting populations of threatened endemic birds. Mātātā (South Island fernbird, *Poodytes punctatus punctatus*) are endemic to New Zealand wetlands and are vulnerable to mammalian depredation. Mātātā populations might benefit from aerial 1080 predator control, but they also can suffer non-target poisoning losses. This study measured the short-term effects of an aerial 1080 operation on mātātā adult survival (i.e. non target mortality) and nest survival (over one breeding season) on the West Coast of South Island. The study utilised two sites, with an October (mid-breeding-season) aerial 1080 operation at one of the sites. We found no evidence of a negative short-term effect of aerial 1080 – none of fourteen colour-banded adult mātātā exposed to 1080 baits died of 1080 poisoning. Conversely, we found evidence of a short-term positive effect – aerial 1080 improved mātātā nest survival over one breeding season. The presence of a positive effect, in the absence of a negative effect, suggests that the net effect of the 1080 operation for the mātātā population was positive, at the end of the breeding season.

INTRODUCTION

Introduced mammalian predators are the primary reason for the decline of most New Zealand native avifauna (Innes *et al*. 2010; O'Donnell *et al*. 2015). Predator control, therefore, is a key activity for New Zealand conservation managers. However, tools and funding for predator control are limited and conservation interventions may not always deliver the desired outcomes. Designers of conservation programs require a sound knowledge base for deciding which control tools to use, and how to use them. Each tool must be tested in a systematic way to build confidence that the desired benefits will manifest.

Aerial 1080 (sodium fluoroacetate) baiting is commonly cited as a relatively cost-effective means by which invasive browsers and predators can be controlled in New Zealand landscapes. Indeed, aerial 1080 is the only invasive mammal control

method deployed in many New Zealand ecosystems, including forests and wetlands. Field studies underpinning this action are more commonly from native forests than from wetlands, despite New Zealand's wetlands ranking highly in national and international conservation prioritisation systems and despite wetlands being inhabited by a suite of threatened birds and invasive mammals (O'Donnell *et al*. 2015).

One such bird, mātātā (fernbird, *Poodytes punctatus*), is endemic to New Zealand at the species level. A North Island subspecies (*P. p. vealeae*) and a South Island subspecies (*P. p. punctatus*) are both classified as At Risk/Declining (Robertson *et al*. 2021). Mātātā populations have declined through various agents, including habitat loss as wetlands have been converted to pasture (Miskelly 2013). Rates of wetland drainage have slowed to near zero in recent decades, but mātātā continue to be impacted by introduced mammalian predators such as stoats (*Mustela erminea*), ship rats (*Rattus rattus*), mice (*Mus musculus*), and feral cats (*Felis catus*) (see O'Donnell *et al*. 2015). For example, mustelids (Mustelidae) and mice were implicated as primary agents of nest failure in a North Island saltmarsh (Parker 2002).

Ground-based insectivory, with a component of omnivory, is the primary foraging mode for mātātā. This can potentially lead to both direct and indirect ingestion of poison intended for predators, and thus to the deaths of some individuals, as has been reported for similar-sized forest passerines with similar foraging ecology – robins and tomtits (*Petroica* spp.) (Powlesland *et al*. 1999; Powlesland *et al*. 2000; Bell *et al*. 2021). For mātātā, the single published study on non-target 1080 poison risk reports a mortality rate of 9.4% for South Island mātātā (*Poodytes punctatus*) in South Westland (95% confidence interval 2.4–22.6%) (van Klink *et al*. 2013). Non-target poisoning rates of some bird species have varied significantly among aerial baiting operations (e.g. Veltman & Westbrooke 2011; Kemp *et al*. 2019). This suggests the need for measurements from several operations to enable sound conclusions about average risk levels.

The question of whether gains from aerial 1080 baiting, for mātātā, outweigh losses is not yet evaluated, largely due to absence of measurement. Here, we address this to some extent via a study of nest survival and non-target poisoning rates, conducted over a single mātātā breeding season. Our study utilises two wetlands, one of which was baited aerially with 1080 partway through the nesting season. We thereby contribute to the evidence base on the costs and benefits of aerial 1080 for wetland birds. We do not evaluate long term population outcomes, but in time our results may be useful for this.

METHODS
Study sites

Two wetlands, or 'pākihi', west of the Paparoa Range in the Buller district were utilised, one of which was subject to an aerial 1080 operation in the spring of 2017. Pākihi are open vegetated areas covered in tangle-fern (*Gleichenia dicarpa*), sedges (*Machaerina* spp.), and mānuka (*Leptospermum scoparium*), on infertile peaty soils. In the northwest of the South Island, pākihi are both natural and created by human disturbance (Williams *et al*. 1990). Both of our study pākihi were surrounded by beech forest and our treatment site, 'Tiropahi', was more than 1 km inside the boundary of the 1080 operation (Fig. 1).

Our non-treatment site, 'Costello Hill', was a readily accessible pākihi on the top of a rise at 70 m elevation. The sides of the rise were vegetated with beech, and surrounded by farmland, scrub, the
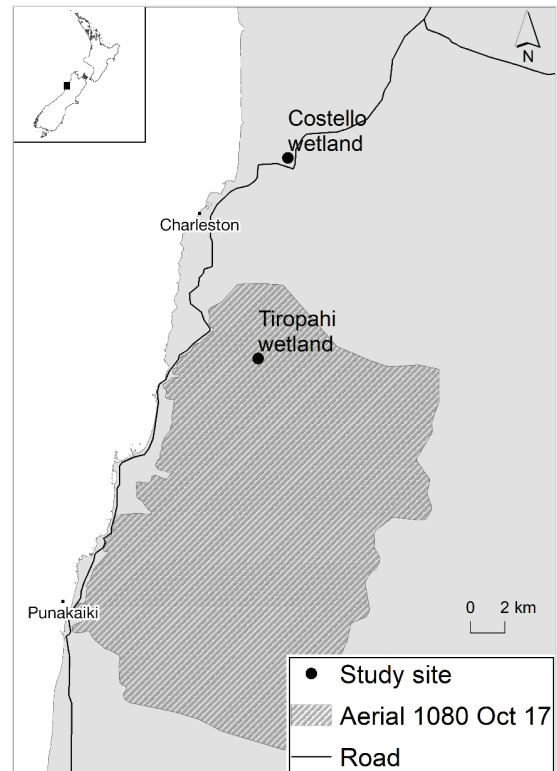
Figure 1. Locations, on the New Zealand West Coast of the South Island, of the two pākihi wetlands, 'Tiropahi' (aerial 1080 treated, 41'59"S, 171'28"E), and 'Costello' (untreated, 41'53"S, 171'29"E), used to measure short-term effects of aerial 1080 on mātātā (South Island fernbird, *Poodytes punctatus punctatus*) populations.

Little Totara River, and State Highway 1. Costello Hill had possum monitoring carried out annually, which included some kill-trapping (B. Waddell *pers. comm.*). The most recent organised pesticide used was ground-based poison baiting on farm edges about 1.2 km away, three to four years before this study (B. Waddell *pers. comm.*). The treatment site, Tiropahi pākihi, was at 180 m elevation. It had a cut-over pine (*Pinus radiata*) plantation on its northwest side, and beech-podocarp forest on the opposite side.

Study period
From September 2017 we visited both sites on an approximately weekly basis to capture adult mātātā (South Island fernbird, *Poodytes punctatus*) for marking with individually identifiable combinations of coloured leg bands, and to find and monitor mātātā nests. The Tiropahi site was treated with aerial 1080 on 28 October 2017, about a month after the first mātātā eggs were found, at which time we had already found 18 broods (nests containing eggs and/or young nestlings). We visitied the study sites until January 2018.

Predator monitoring
We monitored the abundance of mustelids and rats, using standard tracking tunnel transect methodology (Gillies & Williams 2013). We installed six tracking tunnels lines at each site, three on the pākihi and three in the surrounding forest. Lines were spaced at least 200 m apart. Overnight surveys for gauging rodent relative abundance were conducted on all installed lines. Peanut butter was smeared onto the ends of each tracking tunnel to attract rodents during overnight surveys. To gauge mustelid relative abundance, in addition to rodent abundance, further surveys lasting 8–9 nights were done, using three-four lines per site to maintain a spacing of >1 km between lines. Tunnels in these longer surveys were baited with salted rabbit meat to attract mustelids. Surveys were conducted simultaneously at the two sites. Both sites were surveyed twice for both rodents and mustelids – once prior to the aerial poison operation, and again afterward. We calculated the rat tracking as the mean proportion of tunnels per line that detected rats, and mustelid tracking as the proportion of lines that detected mustelids (Gillies & Williams 2013).

Colour banding of adult mātātā
We caught adults with mist nets and banded each with a unique combination of metal and colour bands. The resultant ability to identify individuals enabled measurement of non-target poisoning rate and assisted with nest finding and assessment of final nest outcomes, for measurement of nest survival.

Re-sighting surveys for non-target poisoning rate
On 26 October 2017, two days before the aerial 1080 operation, we surveyed for banded birds in their nesting territories (see below). We played pre-recorded mātātā vocalisations on portable speakers to attract birds, and allow colour-band combinations to be read with binoculars. Post-operation surveys were done on 31 October and again on 1 November, three and four days after baiting, respectively. Four consecutive days of heavy rain from 2 November to 5 November rendered the bait non-toxic, thus the 'risk period' of non-target poisoning was ended. Further re-sightings of banded individuals were recorded over the remainder of the nesting season.

Nest monitoring
Mātātā nests were found either by passive observation of adult birds, or by offering them feathers as nesting material and then following to the nest. Once located, nest fate was determined by weekly observer visits, and/or by trail cameras mounted on vegetation near the nest. Nest age was determined by comparing nestling appearance to a reference photo collection of known-age nestlings. Nests that failed at egg stage were assigned an age based on the median date of observer visits to that nest. Mātātā have a mean incubation period of 13 days and a nestling period of 17 days (Heather & Robertson 2005). For this study, we truncated observations at 28 days. Beyond this age we could not reliably distinguish nest failure from fledging (fledglings could not be consistently found to determine nest success).

Nest survival analysis
We constructed five alternative generalised linear models (GLMs) comprising various combinations of factors standing to affect nest survival. These models contained different combinations of Site and Time, within the Before-After-Control-Impact (BACI) experimental paradigm, plus all models included a quadratic effect for nest age, which allowed nest survival to vary across the nesting period, an effect which has been found in other New Zealand birds (Elliott 1996; Armstrong *et al*. 2002; Grant *et al*. 2005; van Heezik *et al*. 2020).
This last model was important, as the interaction explicitly tests for the treatment effect of aerial 1080 treatment, whilst controlling for site and time effects. The time parameter was a binary covariate which codes whether a nest encounter date was before or after the 1080 operation date, regardless of

site. It was therefore possible for a nest to experience both before and after time effects. We used GLMs with a binomial family to model daily survival rates (DSR) of nests (Rotella *et al*. 2004), with a complementary log-log (cloglog) link function (Bolker 2014). Exposure days were included as an offset in all models to account for variable-length nest monitoring histories (Rotella *et al*. 2004). Exposure was coded as one for each day a nest was active. If a nest failed, exposure was calculated as the number of days between the date the nest was last active and the date the nest was found failed.

Models were ranked by the Akaike Information Criterion corrected for small sample size (AICc). If the most parsimonious model was > 2 ΔAICc points above the next model, we took this as indicating strong support for that model (Burnham & Anderson 2002) and used this model to predict daily nest survival rates at each site before and after the operation. Nest success over 30 days, the average duration of a nest, was estimated by taking the product of DSR values from day 1 to day 30 (Dinsmore *et al*. 2002). Bootstrap 95% confidence intervals for nest success were estimated by running 500,000 bootstrap simulations (Cooch & White 2020). All analyses were run in program R (R Core Team 2021).

RESULTS
Predator abundance
Tracking tunnel surveys at the treatment site returned a small number of rodent prints before the operation and none after (Tables 1 & 2), while rodent tracking rates showed no clear pattern of increase or decline at the non-treatment site. Almost all mammal detections (i.e. footprints in tracking tunnels) at both sites were in forest adjacent to the

pākihi. The only detections *on* the pākihi were of mice, at the non-treatment site.

Nest monitoring
A total of 45 nests were monitored, of which 22 were at the treatment site and 23 at the non-treatment site (Fig. 2). The timing of nesting was very similar at the two sites, with early clutches laid in early October in both sites (Fig. 2). About ten nests at each site were initiated prior to the aerial 1080 operation. There were 21 cases of nest failure, four at the treatment site prior to the aerial 1080, and 17 at the non-treatment site (Fig. 2).

Failed nests were usually found empty although they occasionally contained broken eggshells, suggesting predation had occurred. We had limited success identifying nest predators with trail cameras. However, five predators were recorded visiting failed nests: four stoat visits were recorded at the non-treatment site, and one western weka (*Gallirallus australis australis*) visit at the treatment site. Field sign at these failed nests ranged from no remains, to shell fragments, and nestling remains. The weka removed all eggs and disturbed the camera equipment. Of the other three failed nests at the treatment site, two were empty, whilst nestling pin-feathers were found at the third.
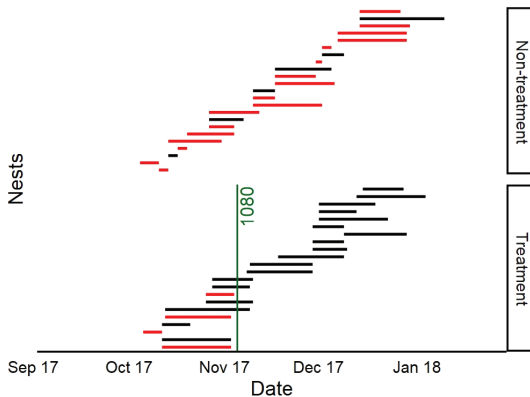
Nest survival
The "Site + Time + Site*Time + Nest age^2" model (i.e. the interaction model that explicitly tests the treatment effect) was the most parsimonious nest survival model, based on AICc. We present results based on this model, as the next best model, Site + Treatment + Nest age^2, was separated by >2 AICc points (Table 3). Overall, daily survival rates (DSR)

Table 1. Overnight survey tracking tunnel results at non-treatment and treatment sites before and after aerial 1080.

Site	Date	Rat (%)	Mouse (%)
Non-treatment before	17 October 2017	3	0
Non-treatment after	9 December 2017	5	2
Treatment before	17 October 2017	2	3
Treatment after	9 December 2017	0	0

Table 2. Extended survey tracking tunnel results at non-treatment and treatment sites before and after aerial 1080. The surveys occurred for eight and nine nights pre- and post-aerial 1080 respectively. Mustelid results calculated as proportion of transects with tracks.

Site	Date	Rat (%)	Mouse (%)	Mustelid (%)
Non-treatment before	18 October 2017	27	3	33
Non-treatment after	31 October 2017	33	0	33
Treatment before	18 October 2017	17	0	0
Treatment after	31 October 2017	0	0	0

Figure 2. Summary of mātātā (South Island fernbird, *Poodytes punctatus punctatus*) nest survival observations. Treatment = Tiropahi wetland; non-treatment = Costello wetland. Each horizontal line represents an individual nesting attempt. Line length indicates the number of days each nest was under observation. Nests that failed are coloured red.

Table 3. Model results of mātātā nest survival analysis. k = number of parameters, weight = model weight.

Model	k	AICc	ΔAICc	weight
Site * Time + Nest age^2	6	131.822	0	0.84
Site + Time + Nest age^2	5	135.373	3.55	0.14
Site + Nest age^2	4	139.021	7.2	0.02
Time + Nest age^2	4	150.714	18.89	0
Nest age^2	3	152.222	20.4	0

Survival of banded adults through 1080 baiting period

At the treatment site, 14 banded birds were confirmed as exposed to bait, via sighting within the treatment area just before and just after the operation. Significant rain occurred about a week after baiting, after which poison pellets were visibly disintegrated. All 14 exposed mātātā were resighted at least monthly until January 2018. That is, no mortality occurred among our sample birds during the period when toxic bait was present.
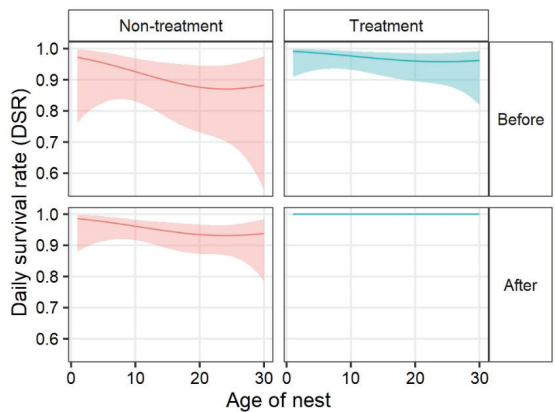
Figure 3. Mātātā (South Island fernbird, *Poodytes punctatus punctatus*) daily nest survival, by nest age, site (Treatment = Tiropahi wetland; non-treatment = Costello wetland) and time (Before and After aerial 1080 at Tiropahi wetland). Shading indicates 95% confidence bounds.
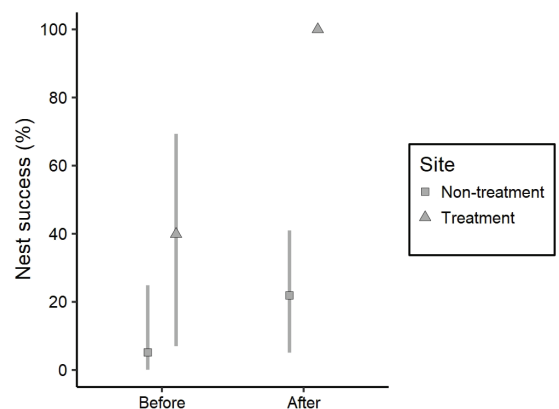
derived from the top model, 1) declined with nest age, 2) were higher at the treatment site than the non-treatment site, and 3) were higher during the 'After' phase of the study (Fig. 3). That is, both Site and Time effects were evident. However, the high ranking of the interaction model indicates a disproportionate increase in DSR at the treated site in the 'After' phase. Here, nest success over 30 days, calculated using DSR estimates from the best model ([lower 95% confidence interval, upper 95% confidence interval]), improved from 39.9% [7.0, 69.3] to 100% (a confidence interval could not be estimated for the treatment site after the 1080 operation as there were no nest failures) with aerial 1080 treatment (Fig. 4). At the non-treatment site, nest success over 30 days was 5.2% [0.1, 24.9] during the 'Before' phase and 21.9% [5.1, 41.0] afterward (Fig. 4).

Figure 4. Mātātā (South Island fernbird, *Poodytes punctatus punctatus*) nest success results with bootstrap confidence intervals. Confidence intervals could not be calculated for the treatment site after aerial 1080 as no nests failed.

DISCUSSION

We found no evidence of any non-target poisoning losses to our study population of mātātā from aerial 1080 baiting. Conversely, we found evidence for a productivity benefit, manifest via improved nest survival. Therefore, our study supports the notion that the poison operation had a positive effect for the Tiropahi mātātā population, over the timeframe of our study (one breeding season).

Our finding of improved nest survival is consistent with previous research that has found aerial 1080 within a breeding season improved the nest survival of native birds, including birds of similar size with similar foraging ecology (albeit in forest rather than wetland) (Powlesland *et al.* 1999; Armstrong *et al.* 2002; Kemp *et al.* 2018; Bell *et al.* 2021).

Measurement of long-term population trends is required to check that a short term benefit, such as we found, translates to increased mātātā density and population security over longer time frames. Longer time frames include out-years, more distant from control operations, in which benefits can be undone by repopulating predator populations (Bell *et al.* 2021). We recommend long-term population trend measurement at multiple managed and unmanaged sites, rather than further studies of short-term costs and benefits.

The nest survival rates we report here for the no-predator-control context are like those reported in previous studies of mātātā, which were both in no-predator-control contexts. Parker (2002) found nest success to be 22% from 21 koroātito (North Island fernbird, *P. p. vealleae*) nests. Harris (1986) found 31% nest success (no confidence intervals reported) for 41 mātātā nests. We found nest success rates of 5% to 40% without predator control.

We were not able to clearly relate predator interactions with mātātā nests to site and treatment. While trail cameras at nests confirmed stoats and weka as predators of mātātā, it was not possible to determine the reason for failure of most failed nests. A reduction in weka density after 1080 seems an unlikely explanation for the improved nest survival at the treatment site, as Tinnemans *et al.* (2018) report a very low weka mortality rate of 1.8% from 1080 baiting. Control of mammalian predators is a more likely mechanism, based on consistency with other studies and on our predator survey results. While overnight rodent tracking rates were uninformative (Table 1), the extended predator surveys we ran over 8–9 nights indicate effective rodent control (Table 2). This is likely to have caused the deaths of mammalian carnivores (i.e. stoats) by secondary poisoning (Murphy *et al.* 1998). Therefore, we strongly suspect that rats and mustelids were at reduced density in the treatment site after the 1080 operation. (The zero-mustelid tracking rate at the treatment site before treatment could be an artefact of the small number of tracking tunnel transects). Alternative explanations for the disproportionate increase in nest survival at Tiropahi after aerial 1080 bait are difficult to surmise, given that the two study sites were comparatively similar in geography, aspect, vegetation, and climate. We note that mātātā habitat varies and the extent of water coverage at a site or proximity to other ecosystems such as coastal dunes, or farms, could affect predator assemblages at a site, but our two sites were intentionally selected as generally similar.

Our mammalian predator detections on tracking surveys were almost exclusively in the forest adjoining the pākihi wetlands. This emphasizes the importance of considering predators in areas surrounding mātātā habitat as a source of risk both to nests and nesting mātātā on the pākihi, and to juveniles and unmated individuals residing in adjacent ecosystems (see Parker 2002). Our study pākihi were adjacent to beech forests. Beeches are masting species, irregularly producing massive seedfalls that support large increases in mammalian predators including mice, ship rats, and stoats (King 1983; White & King 2006). Our nest survival results were from a post-mast year, when we expected low rat density but high stoat density in the adjacent forests, possibly spilling over onto the pākihi. Rat relative abundance was as we anticipated, but stoat relative abundance appeared lower than anticipated. While our study supports an effect of predator reduction on mātātā nesting success in this context, our result may have been different in other contexts.

In summary, our analysis suggests that aerial 1080 improved mātātā nest survival, probably via the control of mammalian predators, with no losses of adult mātātā from non-target poisoning. This builds on existing evidence which collectively indicates that aerial 1080 can be a constructive part of conservation programmes for threatened species in New Zealand.

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