

**Nest survival of South Island
riflemen (*Acanthisitta chloris
chloris*) following aerial 1080
(sodium monofluoroacetate)
predator control in South
Westland, New Zealand.**

Claire Kilner

A report submitted in partial fulfilment of the
Post-graduate Diploma in Wildlife Management

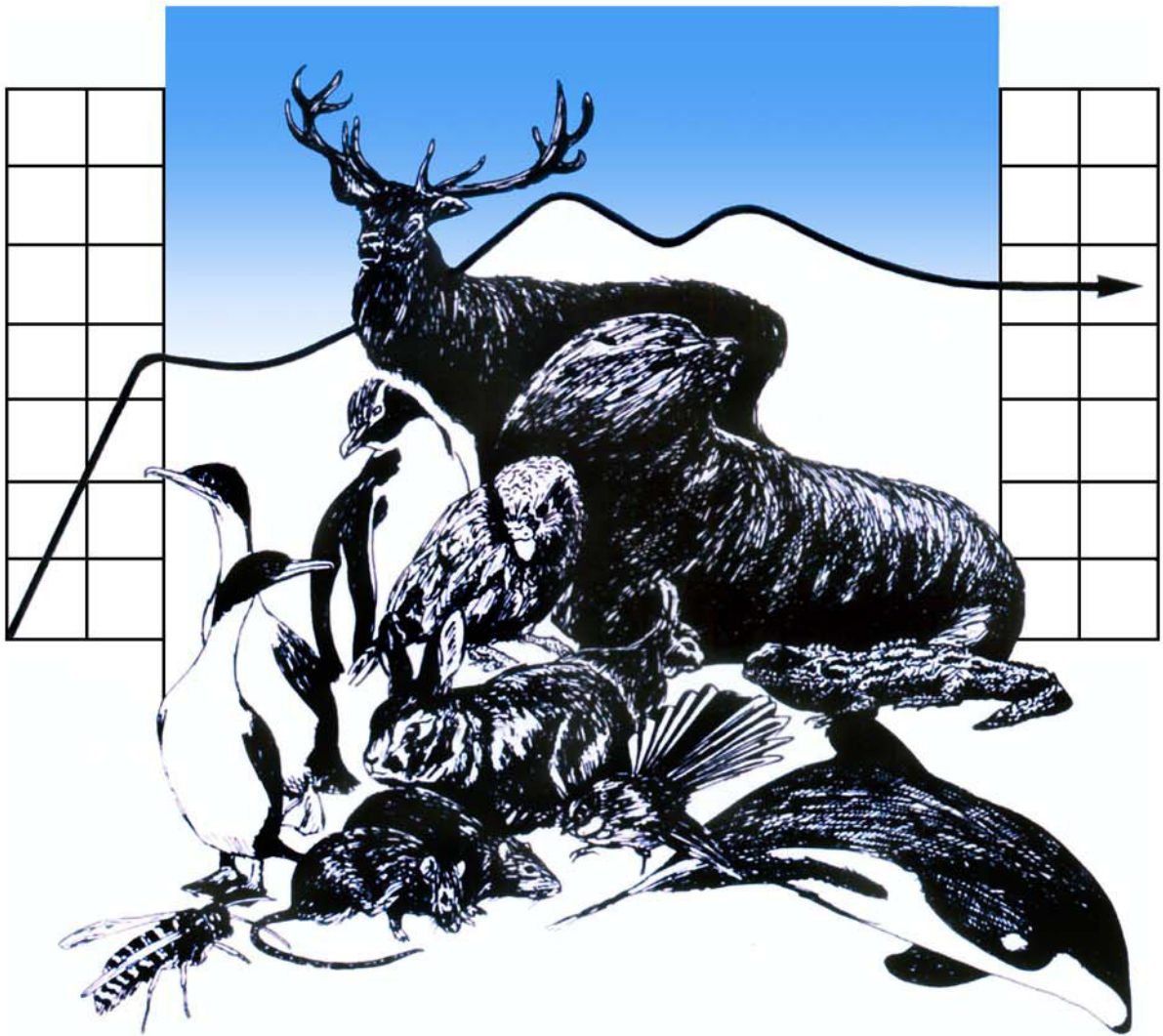
University of Otago

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DEPARTMENT OF ZOOLOGY



WILDLIFE MANAGEMENT

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Executive summary

New Zealand's fauna is vulnerable to introduced mammalian predators, therefore conservation in New Zealand has concentrated on predator control to protect endangered species. Aerial application of sodium monofluoroacetate (1080) toxin is a key method of achieving predator control over conservation land at a landscape scale. The use of aerial drops of 1080 is publically controversial, partly because of potential bird deaths, and quantitative research on the long-term effects of 1080 for forest birds has been limited. Similarly more research needs to occur on the results of multi-predator operations, which have come out of increased understandings of predator-prey interactions and the unintended consequences for native species of focusing predator control on one species.

The Department of Conservation (DOC) initiated research to fill these knowledge gaps in 2009. The aim of its project is to assess the impact of 1080 use on forest birds and to tailor the timing of 1080 operations to better target predators and more effectively protect forest birds. This paper reports on one aspect of this project, giving a preliminary analysis of the first two years nesting success data for the South Island rifleman (*Acanthisitta chloris chloris*) in South Westland. Rifleman nests were monitored over the summers of 2010/2011 and 2011/2012 at two treatment sites, and in 2011/2012 a control site was added. In the treatment areas, different methods of 1080 control are being compared: aerial 1080 control in response to possum numbers; and adaptive management, where aerial 1080 control occurs in response to multi-predator monitoring.

It was hypothesised that nest survival would be highest at sites when 1080 treatment occurred, and that multi-predator treatment would have better survival than treatment aimed at possums. Modelling of daily nest survival rates in the programme MARK found that site and a quadratic temporal trend were the best explanation of nest survival. The control site had significantly lower estimated nest survival than both sites where 1080 treatment had occurred, although models that included an effect due to the 1080 operations were not strongly supported. According to these findings, 1080 operations do not have a negative impact on rifleman, however rifleman may not be the best species to evaluate the relative impacts of the different 1080 regimes.

Introduction

New Zealand's avifauna, which evolved on islands free of mammalian predators, is well known to be vulnerable to predation and food competition from introduced mammalian predators (Clout 2001; Innes et al. 2010). These predators, including ship rats (*Rattus rattus*) and stoats (*Mustela erminea*), are the cause of many historical extinctions, and continue to be the key threat to the existence of many native birds (Miskelly et al. 2008; Innes et al. 2010). Possums (*Trichosurus vulpecula*) historically recognised as a threat to New Zealand vegetation, have more recently been found to be a significant predator as well (Moorhouse et al. 2003; Morgan 2004).

Conservation in New Zealand has focused on controlling these predators to protect threatened species. As conservation knowledge and techniques improve, attention has turned to ecosystem protection, and it has become increasingly apparent that landscape scale multi-predator control is the best way to protect many species (Saunders & Norton 2001). Aerial toxin drops are commonly used in such predator control, as they are more cost-effective and can reach areas that are difficult to access by other means (PCE 2011). Sodium monofluoroacetate (1080) is a toxin that has been used in New Zealand for over 50 years, primarily to control possums (Morgan 2004). Aerial 1080 drops were first investigated in the 1950s, and are the primary method of carrying out landscape scale predator control, particularly on mainland New Zealand (Morgan 2004).

However aerial 1080 use is publically controversial, and increasing attention has come on to proving the outcomes of 1080 control (PCE 2011). Of particular concern has been the impacts of 1080 use on forest birds, as there has been limited research quantifying the outcomes of 1080 operations at mainland sites for forest birds (Veltman & Westbrooke 2011). Veltman and Westbrooke (2011) advocate long term forest bird studies at toxin sites. They point out ongoing studies of passerines at mainland sites have not yet occurred (or been reported), and that rifleman are one such species reported to have died and are at risk as a species (Veltman & Westbrooke 2011).

Armstrong (2006a) argues that it has already been demonstrated that predator control can help New Zealand's threatened fauna, and now research needs to go into the levels of predator control to achieve desired outcomes. Conservation managers have become aware of complex predator-prey interactions following predator control, for example, stoat dietary changes from rats to birds following a 1080 operation

(Murphy & Bradfield 1992), increases in rat numbers following possum control (Sweetapple & Nugent 2007) and possibly stoat control (Dilks et al. 2003). The consequences of such unanticipated interactions can have negative effects on native birds (Veltman & Westbrooke 2011). These predator-prey interactions are particularly complex in beech (*Nothofagus* spp) forests, where irregular masting events produce huge amounts of seed, which naturally are a key food source for native invertebrates and birds (Wardle 1984; Alley et al. 2001). However masting years also fuel rodent population explosions, and in turn in the populations of their predators, stoats (Jones et al. 2011). This increase in predators in the breeding season, particularly stoats, has had serious consequences for native birds populations in beech forests (White & King 2006).

An increased awareness of the implications of predator interactions has led to multi-species predator control being undertaken. For example, 1080 is now used to control rats and stoats, as well as possums (Murphy et al. 1999; Alterio 2000). Although the value of researching and reporting on the results of multi-species predator control and ecosystem protection has been recognised (Saunders & Norton 2001), it is argued that little research has been published (Innes et al. 2010). This is particularly important for the use of 1080 given the controversy over its use.

In 2009, the Department of Conservation's Research and Development Division initiated research to fill these knowledge gaps. The aim of the project is to assess the impact of 1080 use on forest birds and to tailor the timing of 1080 operations to better target predators and more effectively protect forest birds. There are three research sites for this project: South Westland and Marlborough, in the South Island, and the Tararua Ranges in the North Island. In each of these areas, two different methods of 1080 control are being compared: aerial 1080 control in response to possum numbers; and adaptive management, where aerial 1080 control occurs in response to multi-predator monitoring. This paper reports on one aspect of this project, giving a preliminary analysis of the first two years nesting success data for the South Island rifleman (*Acanthisitta chloris chloris*) in South Westland.

Nesting success is a measure which has been used by wildlife managers both internationally and in New Zealand, for example, to assess the effects of predators and predator control (O'Donnell et al. 1996; Armstrong et al. 2006a, 2006b; Pieron & Rohwer 2010; Amundson & Arnold 2011; Potter et al. 2011; Cox et al. 2012), and the effects of habitat on nest survival (Amundson & Arnold 2011; Saab et al. 2011). Birds

are particularly vulnerable to predation during nesting (Innes et al. 2010; Cox et al. 2012), and as Armstrong et al. (2006a) argues, modelling vital rates such as nest success allows responses to predator control to be more quickly evaluated.

Methods of assessing nest survival have become increasingly sophisticated. A basic measure of nest survival is apparent nest success, which is a simple calculation of the number of successful nests (where at least one chick fledges) divided by the number of nests found. In New Zealand, for example, O'Donnell et al. (1996) calculated apparent mohua nest success to evaluate the effects of stoat control. Similarly Moorhouse et al. (2003) used apparent nest success to investigate the effects of toxin operations on kaka and kereru. However, apparent nest success is open to bias because it does not take into account that nests found are only a proportion of those originally in existence (Dinsmore et al. 2002). Other methods take such bias into account, for example, the Mayfield method (Mayfield 1961, 1975; Johnson 1979), which calculates daily nest survival. Subsequent methods and computer programmes have built on this method, allowing other important biological variables to be taken into account, for example, environmental factors (Dinsmore et al. 2002; Rotella et al. 2004). MARK (White & Burnham 1999) is one such programme, and was used to analyse the riflemen data in this report.

Study animal

Riflemen were chosen as a species to study because they are still numerous enough that sufficient sample sizes are possible, yet under the New Zealand Threat Classification system they are a species classified as at risk because of their declining population (Miskelly et al. 2008). Limited research has occurred on riflemen, the most in-depth research was carried out by Sherley in his PhD thesis on the breeding system of the South Island rifleman, using artificial nest boxes in kanuka (*Khunzeae ricoides*) forest at Kowhai Bush, Kaikoura (Sherley 1985). This research continues to be the key reference on riflemen.

The rifleman is New Zealand's smallest bird, weighing 5.5–7g (Sherley 1985), and is an insectivorous, cavity-nesting passerine that inhabits a wide range of habitats. Pairs form long term bonds (Gill 1980 unpublished data, in Cameron 1990; Sherley 1994) and are sedentary in their territories year round, which are held by mutual avoidance by neighbouring pairs rather than active defence (Cameron 1990; Sherley 1994). In South Westland, riflemen begin nestbuilding in mid-October, and nests

fledge in mid to late December. Riflemen have very long incubation and nestling periods (Franklin & Wilson 2003), even by New Zealand avian standards (Sherley 1985). A long incubation period is a factor known to increase vulnerability to predators (Innes et al. 2010). Sherley (1985) reported that the average incubation period was 19.6 days, and the nestling period 24.0 days. The research in South Westland used baselines of 20 days of incubation and 22 days to fledge to work out stage transitions, based on this literature and close observations in the first season (pers. comm. R. Cole 2011). Riflemen will raise second broods (Sherley 1985) although this was not commonly known to occur in South Westland.

New Zealand cavity nesting birds have been shown to be more vulnerable to predation than overseas cavity nesters (Elliott 1990). The nature of a cavity nest means incubating adults, as well as eggs and hatchlings, are vulnerable to predation (O'Donnell 1996; Innes et al. 2010). Although riflemen are cavity nesters with long incubation periods, they have persisted in areas for longer than other cavity nesting birds, such as mohua (*Mohoua oehrocephala*), for reasons that are unknown but may be related to size or behavioural traits.

Sherley found that predation was the most common cause of nest failure once rifleman eggs had hatched (>90%) (Sherley 1985). Ship rats are likely the main mammalian predator of rifleman and their nests. Ship rats are more common in lowland podocarp-broadleaved forests than beech forests, and they are also less common at higher altitudes (Innes 2005). Beech mast years, however, lead to rat population explosions (Innes 2005). Ship rats are arboreal, and are well known predators of eggs, chicks and the adult birds of small species (Innes 2005). For example, ship rats were responsible for 72% of nest predations of two species of small New Zealand passerines, tomtits (<20g) (*Petroica macrocephala*), and North Island robins (30g) (*P. australis*) (Brown 1997). In South Westland, camera footage showed rat predation of a rifleman nest. However a stoat was filmed preying on a nest in Marlborough (pers. comm. G. Elliott 2012), and a possum visited a rifleman nest in South Westland (pers. comm. J. Malham 2011). Ruru (*Ninox novaeseelandiae*) are probably the natural avian predators of rifleman. Competition for invertebrate food resources could come from mice (*Mus musculus*), rats, possums and stoats (Rickard 1996; Murphy et al. 2008).

As rifleman are insectivores, they could be vulnerable to 1080 through secondary poisoning if 1080 persists in invertebrates. 1080 has been found in tree

weta, cave weta and cockroaches following 1080 operations, but has not been found in spiders, beetles, centipedes or millipedes (Eason et al. 2011). Studies of invertebrates following aerial 1080 operations have found no effect on invertebrate populations (Powlesland et al. 2005). Eason et al. (2011) believe that secondary poisoning risk to insectivorous birds would be limited to within a short period after an operation as 1080 does not appear to persist for long in invertebrates.

Study area

The study area is near Lake Paringa in South Westland, in the South Island. This area of South Westland has an annual rainfall averaging 5280 mm yr⁻¹ and up to 6000 mm yr⁻¹, and mean monthly temperatures ranging between 8 to 18° Celsius (O'Donnell & Dilks 1994). The alpine fault runs through the area, and the terrain and vegetation in this area have been affected by glaciation (Wardle 1980). Podocarp forest and swamps can be found on the lowlands, and silver beech (*Nothofagus menziesii*) gradually increases with altitude to dominate above 500m (Wardle 1980). Introduced mammalian predators found in this area include stoats, rats, possums and cats.

Methods

Predator control

The riflemen study sites are within the 1080 study areas, see Figure 1. The 1080

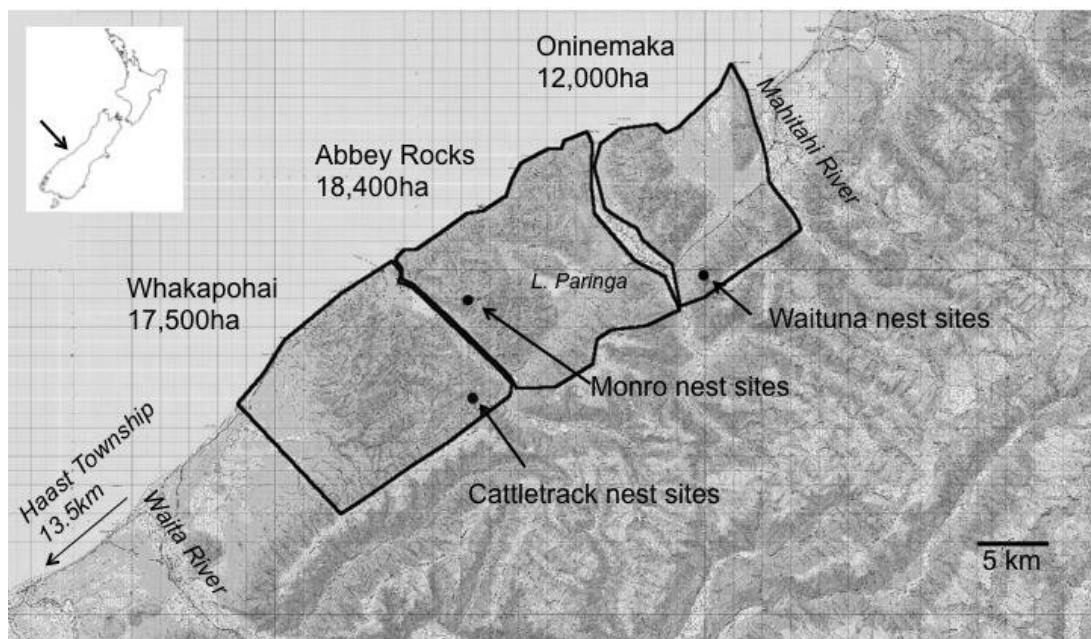


FIGURE 1. Map of 1080 study areas with rifleman nest sites marked (TerraView, DOC).

project uses a paired-catchment design over three areas, with one control area and two treatment areas with aerial 1080 applied aimed at different predator control outcomes. Historically the Abbey Rocks and Whakapohai blocks have been treated with 1080 for possum control, whereas no organised predator control has been carried out carried out in the control block (unpublished report, Elliott 2009). Two 1080 operations have been carried out since the project started, the Whakapohai block in 2010, and the Abbey Rocks block in 2011. It was initially estimated that the Whakapohai block would be treated approximately every six years, and Abbey Rocks every three years (unpublished report, Elliott 2009). Monitoring of predators is carried out using tracking tunnels and wax tags (unpublished report, Elliott 2009). See Table 1 for a summary.

TABLE 1. Summary of 1080 study areas in the Paringa District, South Westland. (unpublished report, Elliott 2009; pers. comm. J. Malham 2012). * Treatment occurred prior to this study.

Area	Target species	Size (ha)	Sow rate	1080 treatment
Whakapohai	Possum	17,500	1kg/ha of 6g	1 Dec 2010
Abbey Rocks	Rat, stoat, possum	18,400	1kg/ha of 6g	May 2009* 27 Oct 2010
Ohinemaka	–	12,000	–	–

Riflemen nest success

The nesting success of riflemen was investigated at sites situated in the control and treatment blocks described above. In general, only riflemen study sites will be referred to in this report. Riflemen were searched for in an approximate area on the designated ridge or saddle, generally starting from 400m in altitude, where riflemen were more easily found. The boundaries of the riflemen study sites were subsequently defined by where nests were found. All sites are beech forest, primarily silver beech, with Southern rata (*Metrosideros umbellata*), kamahi (*Weinmannia racemosa*) and some montane totara (*Podocarpus cunninghamii*). See Table 2 for summary.

Riflemen were studied in the treatment sites of Cattletrack and Monro in the 2010 and 2011 seasons. (Breeding seasons will be referred to as 2010 for the 2010/2011 season, and 2011 for the 2011/2012 season.) Riflemen were first studied in the control site, Waituna, in the 2011 season. Possums have been controlled in the

Monro area on an ongoing basis for the benefit of beech mistletoe (*Peraxilla colensoi*) and there is a possum trapping line running through the site.

TABLE 2. Summary of nest monitoring sites. Measurements are approximate and taken from the programme TerraView.

Nest site	Treatment	Size (ha)	Altitude (m)	Distance to sea (km)
Cattletrack (Whakapohai)	Possums	5.7	232-596	11.4
Monro (Abbey Rocks)	Multi-species	3.82	423-781	5.2
Waituna (Ohinemaka)	Control	5.66	442-675	10.6

Riflemen nests were found using recorded calls to attract riflemen to a ‘feather trap’, where white commercial feathers were laid out on a bush or the ground. Nesting riflemen were followed as they took feathers back to their nests. Nests were observed every 4–5 days, and the behaviour of adults used to determine the nest stage. Based on the literature and experience, 30 minutes observation was chosen as the maximum required to determine nest activity (pers. comm. R. Cole 2011). Banding of adults occurred in the 2010 and 2011 seasons to allow fledgling and adult groups to be identified with nests and therefore confirm nesting success. Some nests in the Waituna and the Cattletrack were monitored using infra-red cameras. The purpose of this monitoring was to determine the cause of any predation event, and to minimise the staff time required to visit nests.

Riflemen density

Density has been a factor in nest survival in other studies, for example Kelly et al. (2005). For this study, the closest available approximation for density is using the results of digital bird call counts occurring as part of the wider 1080 project. However only data for the 2010 season were available, therefore rifleman counts were excluded as a covariate for the purposes of analysis, and are included here for the purposes of description, see Figure 2. Riflemen density appears highest in the Cattletrack based on observer experience, however riflemen counts do not support this statistically.

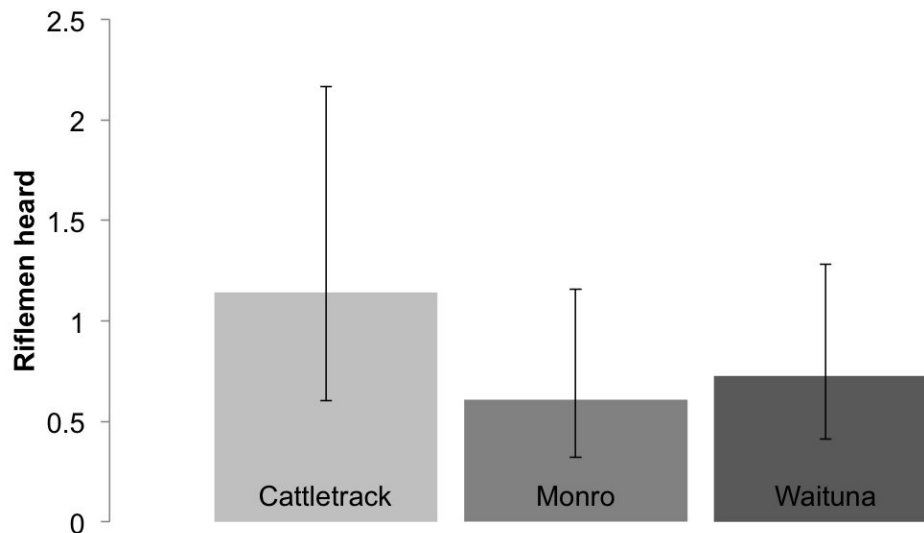


FIGURE 2. The average rifleman count in the study sites, estimated from a generalised linear mixed model of rifleman counts for the month of January between 423 and 558m in altitude, including terms for altitude and month, with a random effect from counting station. The units of measure are the number of riflemen heard in a five minute recording in the morning between one and three hours after sunrise (source: unpublished data, G. Elliott 2012). Counts did not necessarily occur within rifleman study areas, but in the wider study block. Error bars are 95% CI.

Rat monitoring Rat abundance was indexed using tracking tunnels. While this method cannot be used to provide rat population estimates, tracking indices have been used in other New Zealand studies to compare relationships between avian survival and predators

(Kelly et al. 2005; Armstrong et al. 2006a). Corflute tracking tunnels with an inked card to record rat prints were baited with peanut butter and were left out over a fine weather night. Rat prints recorded on the cards, indicate the presence or absence of rats. All lines were run within the course of approximately a week. A rat abundance index was calculated by dividing the number of tunnels positive for rat prints by the number of tunnels to calculate the percentage of tunnels entered.

As with riflemen counts, rat tracking results were only available for one period during the breeding season, and were not measured on an ongoing basis over the season, although in the Cattletrack block in 2010, two rat tracking events were carried out, pre- and post-1080 treatment. The control site, Waituna, did not have a tracking tunnel line, therefore the closest block most comparable with respect to vegetation and predator control history were used to estimate rat levels. As the graph shows, rat levels were rapidly increasing during 2011 in the Monro site in response to a masting event. The aerial 1080 predator control led to 0% rat tracking in the Cattletrack and Monro areas in 2010 and 2011 respectively, see Figure 3. Cattletrack riflemen should therefore have benefited from a partial season of rat control in 2010 and Monro riflemen, an entire breeding season of rat control in 2011. These results give an indication of rat levels in the wider project area but are not a direct measure of rat populations at nest monitoring sites.

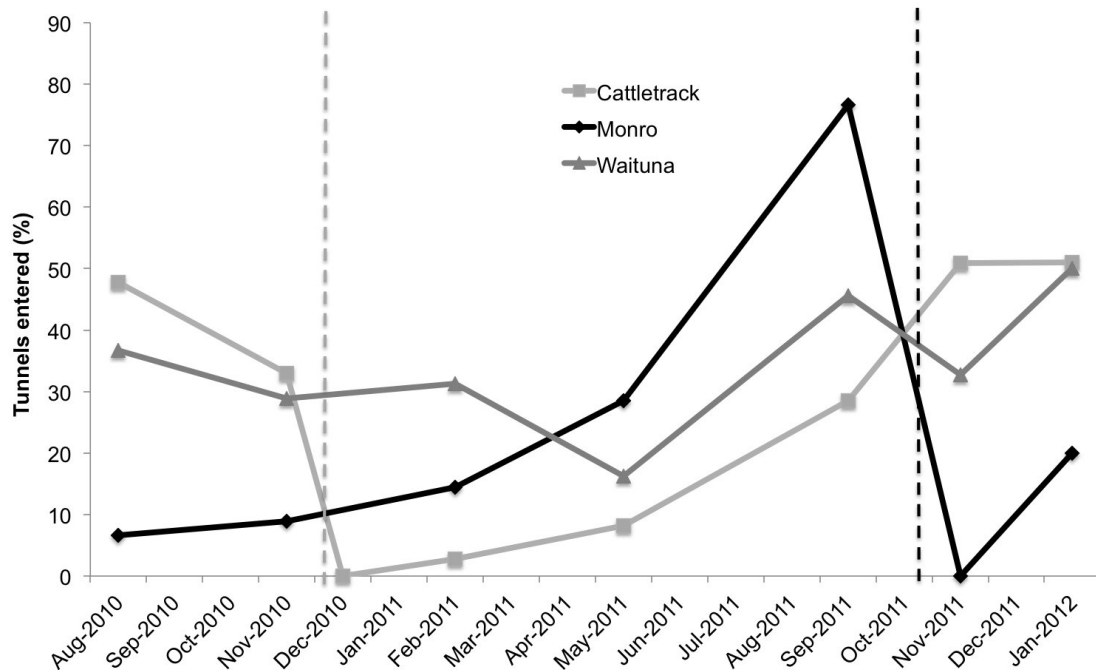


FIGURE 3: Changes in rat indices over time at or near the three riflemen nest monitoring sites. The dotted grey line indicates the 1080 operation in the Cattletrack area, and the dotted black line the 1080 operation in the Monro area (unpublished data, G. Elliott 2012).

Nest survival hypotheses

Six covariates were chosen to model daily nest survival for riflemen. These covariates were chosen by examining the literature on nest survival, both in New Zealand and internationally, and field workers' experience.

1. **Temporal.** Constant daily nest survival over the whole breeding season is unlikely (Dinsmore et al. 2002). Therefore two types of temporal trends that could be reasonably supported were fitted to detect responses to unmeasured variables. Firstly, a linear trend, to investigate the possibility that survival probabilities either declined or increased over the course of the season, which might be for a variety of reasons including increasing predator numbers or if more vulnerable nests are removed at the beginning of the season (Moynahan et al. 2007). Secondly, a quadratic trend was fitted to allow survival probabilities to fit a curvilinear model, because for example, it could be hypothesised that there is a mid-season increase in predators in response to increased resources (Cox et al. 2012). These are standard temporal models fitted by other researchers examining nest survival (Dinsmore et al. 2002; Borges & Marini 2010). No further time trends were included to avoid over-fitting the data (Dinsmore et al. 2002).
2. **Treatment.** The effect of 1080 treatment on rifleman nest survival is the primary concern of this analysis. The hypothesis is that the application of 1080 will improve the daily nest survival of riflemen, and secondly that of the two 1080 treatments, multi-species predator control will show the most positive response in riflemen nest survival.
3. **Site.** There may be site specific features affecting daily nest survival that were not able to be investigated, such as localised weather conditions or habitat composition.
4. **Calendar year.** There may be other characteristics of annual variation, for example, weather, that may affect survival.
5. **Elevation.** It was hypothesised that riflemen nest survival would increase with altitude as predator numbers drop (pers. comm. G. Elliott 2011). Rat numbers are lower at high elevations (Innes 2005).
6. **Camera use.** Climbing the nest tree to mount a camera within 30cm of the nest hole and re-climbing to replace batteries caused researchers to be in closer proximity to nests than at trees where observations were obtained at a distance.

Some other covariates cited in nest survival literature were not used for reasons of resources or nest access. For example, nest age when the nest was discovered was not used as a covariate. As nests and eggs were not physically accessible we were unable to determine with accuracy the age of nests. Nest height, tree species and nest position (Moors 1983), and nest concealment (Brown 1997) have not been found to be predictors of predation of passerines in New Zealand. As this data was only available for part of the dataset and the programme MARK cannot process datasets with missing covariables, these measurements were excluded from the analysis. In the interest of limiting parameters a covariate for rat density was not included as the covariate for treatment was effectively modelling the drop in rat numbers.

Modelling the nest survival of riflemen

The nest survival function in MARK was chosen to analyse this data and test the hypotheses proposed above. This function calculates the daily nest survival of each nest. The assumptions of these models carried out in MARK are: 1) homogeneity of daily nest survival rates; 2) nest fates are correctly determined; 3) nest fates are independent; and 4) nest discovery and subsequent nest checks do not influence survival (Dinsmore et al. 2002; Rotella et al. 2004).

Nest fates were able to be determined in this research, thereby satisfying assumption 2). However there is likely to be overdispersion in this data as a result of violations of assumption 3) and assumption 1). Overdispersion can be caused by random effects of individuals, sites and years, by heterogeneity in nest survival, and lack of independence of nest fates (Dinsmore et al. 2002; Rotella et al. 2004). There are likely to be differences in individual riflemen nest survival rates as these are probably affected by a variety of variables. However this assumption is not as important as it is if Mayfield's method is used (Williams et al. 2002) as these other variables can be modelled in MARK (Rotella et al. 2004). Nests fates from within the same site are not independent, for example, in the Cattletrack and Monro sites, some of the same riflemen pairs contribute to nest survival data in both years.

The literature notes the difficulties in determining and accounting for such overdispersion in MARK (Dinsmore et al. 2002; Rotella et al. 2004). Normally an overdispersion coefficient (\hat{c}) would be calculated to calculate overdispersion, however, no bootstrap goodness of fit tests are available in MARK for nest survival data. Furthermore, Dinsmore et al. (2002) argue that other methods proposed to

account for overdispersion in nest survival data are imperfect. Although these methods have been used in recent research, researchers continue to acknowledge Dinsmore et al.'s (2002) concerns with the efficacy of these calculations (Walker et al. 2005; Moynahan et al. 2007). This analysis follows Dinsmore et al.'s (2002) methods.

Observer effects while checking nests are possible. Sherley (1985) noted that banded birds were more wary of observers, whereas unbanded birds were unperturbed by observers. Both Sherley (1985) and Grey (1969) used artificial nest boxes at an accessible height. Sherley (1985) believed that there was some risk of desertion during laying and incubation periods, but his primary concern appeared to be about physical inspection of the nest box. In contrast, in this research riflemen at natural nests were observed from a distance, which were at an average height of 11m (SD = 6, n = 59). Therefore it seems unlikely that observer effects had an impact on daily nest survival rates.

The use of cameras at nests (n = 10) in 2011 is more likely to have affected nest fates. A study on tomtits and North Island robins found no connection between the use of cameras and predation, but some nest desertion occurred (Brown et al. 1998). In South Westland, no rifleman nests were abandoned as a result of camera installation, when disturbance would have been most invasive. It is possible that human contact with nest holes could affect nest survival, for example, by attracting predators (Major 1990). However, another New Zealand study, albeit in a braided river habitat, predators were not found to use scent trails to find nests (Keedwell & Sanders 2002). Cameras were only installed at the Waituna and Cattletrack sites in 2011, as these were anticipated to be the most likely sites to be predated. Therefore camera presence is confounded by site and year and was not included in the main analysis. The effect of cameras was considered separately in a reduced data set including only 2011 Waituna and Cattletrack nest survival data.

In MARK, three dates are crucial: the date the nest was confirmed active; the last day that the nest was checked successfully; and, the date of the nest's fledge or failure. As riflemen usually do not commence incubation until the final egg is laid check, it is difficult to calculate nest survival prior to incubation. Therefore following Dinsmore et al. (2002), the date that a nest is confirmed is the date that incubation is discovered. As discussed above, time from incubation to fledging was taken as 42 days.

The breeding season was slightly different between the two years. The 2010 season ran from 2 November 2010 – 1 January 2011, and the 2011 season from 29 October 2011 – 3 January 2012. Analysis in MARK requires that each day in the breeding season is numbered. The breeding season between these two seasons was standardised, as in Dinsmore et al. (2002) and Moynahan et al. (2007), so that 29 October was day one of the breeding season in both years, giving 67 days of breeding and 66 estimates of daily survival. Such coding enables both years to be analysed together rather than separately.

Site and year were grouped together in entering into MARK, providing five groups (two sites in 2010 and three sites in 2011). The daily nest survival of each group was initially analysed using MARK to provide a 42 day estimated nest survival rate. For modelling, the design matrix in MARK was used to investigate nest survival hypotheses. A logit link was used in modelling covariates for the reasons enumerated by Dinsmore et al. (2002) and Rotella et al. (2004). As the nest sample size in this research is small ($n = 69$), an effort was made to restrict the number of parameters, therefore no interactive terms were used, and the number of models was restricted.

Using MARK to carry out analysis, two rounds of modelling occurred based on Borges & Marini (2010) and Potter et al. (2011) methods. The initial round of modelling examined temporal variables, examining which temporal model best fitted the data 1) a null model ($S_{(.)}$), as in Mayfield's method, which does not take into account changes in survival over the breeding season; 2) a linear model (S_T); and, 3) a quadratic trend (S_{TT}). In the next round of modelling additional covariates were added to the best temporal model, these covariates were 1) 1080 treatment, as a dummy variable (as treatment occurred half way through the breeding season in 2010, two dummy covariates were created to code for before and after treatment;) 2) elevation of each nest were entered as individual covariates; 3) site as a categorical variable; 4) calendar year as a categorical variable; and, 5) camera use, using a reduced data set.

Small-sample corrected Akaike's Information Criterion (AIC_c) was used to rank models according to how they fitted the data. Burnham and Anderson (2002) give rough guides to assessing models. Following these guidelines, the best models in this study were considered to be those within two AIC_c units of the top model (Burnham & Anderson 2002). Inferences about the effects of the best models were made using model outputs, AIC_c weights (W_i), and slope parameters (Betas β) (Burnham & Anderson 2002; Dinsmore 2008).

Results

Nesting parameters

Seventy nests were located and monitored in this research. One nest was not included in the analyses as it did not progress to incubation. Monitoring occurred during a 67-day interval (29 October – 3 January) over two breeding seasons. All nests are believed to be first broods. Of all nests, apparent nesting success was 87%, see Table 3. Cause of failure could not be determined for most, although predation was proven at one nest by camera footage. It was not possible to accurately determine the nest age of these failed nests, but stage was generally able to be determined: three nests were at incubation, four nests had chicks and two nests were at either late incubation or early chick stage.

TABLE 3. Number of nests by year and site, and apparent nesting success for South Island riflemen in the Paringa district, South Westland. * 1080 treatment for predator control occurred.

Year	Site	Total nests	Exposure days	Failed	Nesting success (%)
2010	Cattletrack*	17	358	1	94
	Monro	12	418	1	92
2011	Cattletrack	17	509	1	94
	Monro*	13	436	2	85
	Waituna	10	233	4	60
Total		69	1954	9	87

Estimates of nest survival

Daily nest survival was a function of site and a quadratic trend in the best model. The next best model was within 2.00 Aikaike differences ($\Delta AICc$) and added a calendar year effect, see Table 4. The logistic regression equation (with standard error in parentheses below) for the best model was:

$$\text{logit}(\hat{S}_i) = 21.02 - 0.63(\text{Monro}) - 2.12(\text{Waituna}) - 0.86T + 0.012TT$$

(8.97) (0.92) (0.89) (0.50) (0.01)

The Waituna site had a negative effect on nest survival probabilities, the slope estimate on a logit scale in the best model was: $\hat{\beta}_{\text{Waituna}} = -2.12$ (1 SE = 0.89, 95% CL = -3.86, -0.39). See Table 5 for $\hat{\beta}$ values of the best model.

TABLE 4. Riflemen daily nest survival rates in three South Westland study sites in the 2010/2011 and 2011/12 breeding seasons modelled with main effects and a quadratic trend. Aikake differences (ΔAIC_c), Akaike weights (w_i), and number of parameters (K) and deviance are reported.

Model	ΔAIC_c	w_i	K	Deviance
$S_{\text{site+TT}}$	0	0.41	5	77.45
$S_{\text{site+year+TT}}$	1.80	0.17	6	77.24
$S_{\text{year+TT}}$	2.18	0.14	4	81.65
S_{TT}	2.23	0.13	3	83.71
$S_{\text{elevation+TT}}$	3.74	0.06	4	83.20
$S_{\text{treatment+TT}}$	4.22	0.05	4	83.69
$S_{(.)}$	5.56	0.03	1	91.04
S_T	7.53	0.01	2	91.01

TABLE 5. Maximum likelihood estimates (logit scale) for the best model $S_{\text{site+TT}}$ for riflemen daily nest survival in South Westland 2010-2011.

Label	Estimate	SE	95% CI	
			Lower	Upper
Site: Cattletrack	21.017	8.969	3.437	38.597
Site: Monro	-0.634	0.916	-2.429	1.162
Site: Waituna	-2.124	0.885	-3.858	-0.389
Linear trend	-0.858	0.504	-1.846	0.130
Quadratic trend	0.012	0.007	-0.002	0.025

A quadratic trend was supported over both the null or constant model, and a model with linear trend. The best model, with a site effect and a quadratic temporal trend are plotted in Figure 4. The figure shows a dip in nest survival probabilities in the middle of the breeding season. This effect is more strongly shown in Waituna, than in either the Cattletrack or Monro sites, where a difference in the probability of survival cannot be distinguished. A similar dip occurs in the next best model $S_{\text{site+year+TT}}$ although the dip is not as strong as in the best model where sites have been pooled. The probability of surviving the 42-day breeding cycle in each site by year is assessed without the quadratic trend in Figure 5. 1080 treatment and elevation were not well supported and did not feature in the top models. As treatment is an effect of

key interest in this paper, the beta value for the model $S_{\text{treatment+TT}}$ is reported here:

$$\hat{\beta}_{\text{treatment}} = 0.100 \text{ (1 SE = 0.727, 95\% CL = -1.325, 1.524).}$$

The effect of cameras on nest fate in the Cattletrack and Waituna sites in 2011 was analysed separately. At the Cattletrack site, five of 17 nests had cameras, as did five of 10 nests at the Waituna site. Three nests with cameras failed, all at the Waituna site, however no inferences could be drawn from a model considering the additive effects of site and camera presence.

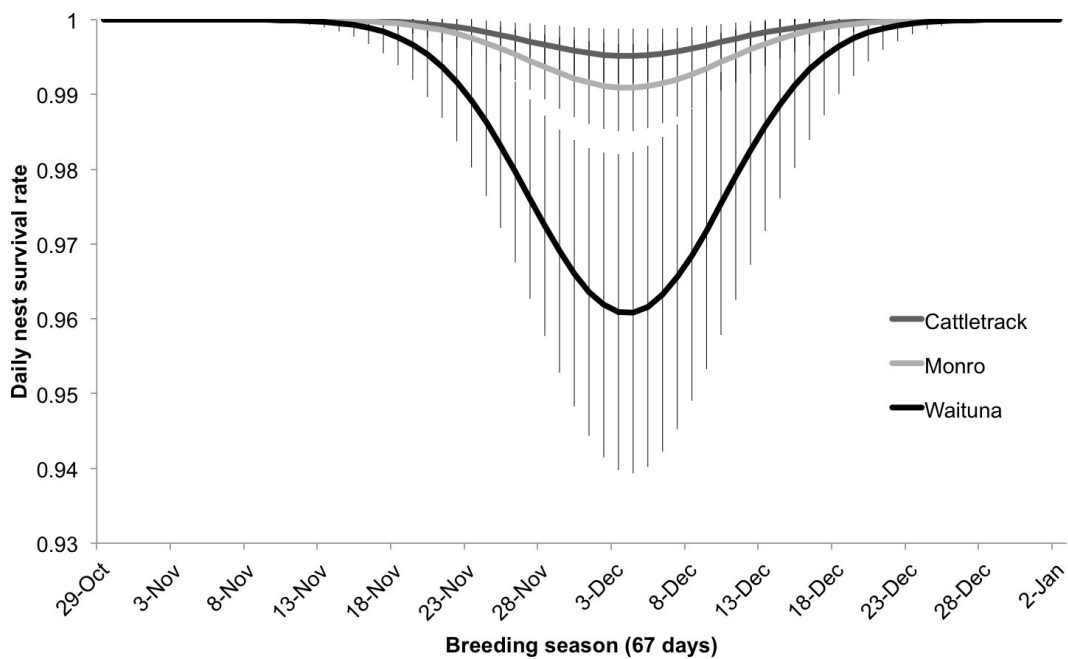


FIGURE 4. Daily nest survival rates plotted with site effect and quadratic temporal trend for rifleman in South Westland 2010–2011. Error bars are +/- one standard error.

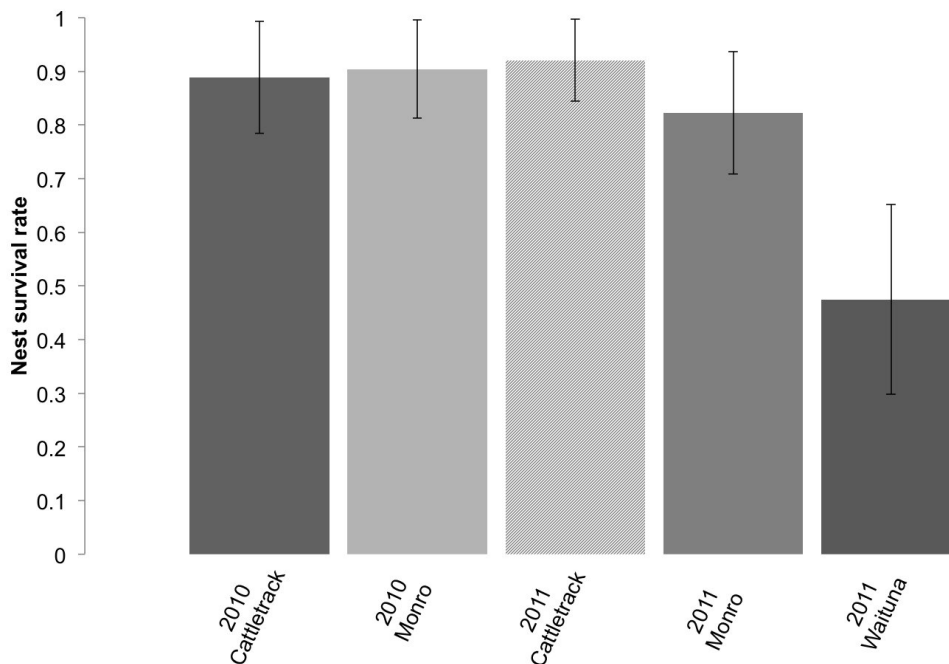


FIGURE 5. Estimated nest survival of riflemen over 42 days, assuming constant daily nest survival over the 67-day breeding season in South Westland. Error bars are +/- one standard error.

Discussion

This study has not been able to show that individual 1080 operations had an immediate effect on riflemen nest survival in South Westland. A treatment effect was not supported in the modelling, and this is reflected in comparing the nest survival probabilities of the two sites where treatment occurred. A drop in nest survival was expected in the Cattletrack site in 2011 as rat numbers were expected to be high for a mast year. However, as Figure 5 shows, nest survival does not vary significantly between the Cattletrack and Monro sites in either year. Both treatment sites had significantly better nest survival rates than the control site. The year effect supported in the second best model is probably caused by poor survival in the new 2011 control site.

Riflemen nest survival data was best explained by models that included a quadratic trend modelling a dip in survival mid season. The support for a quadratic trend may be identifying a vulnerable period in the nesting stage of riflemen. While it was not possible to age nests exactly, nests appeared to be failing in the late incubation to early chick stage. It is possible that chick vocalisations or increased parental visits attracts predator attention to nests at this stage (Leech & Leonard 1997;

Haff & Magrath 2011). A mid-season peak in predation has been found in other studies on nest survival (Cox et al. 2012). Having nest age as a covariate would enable such a stage vulnerability to be examined. This would require more frequent visits to nests if stages were to be identified by observation of behaviour.

Two other main effects were tested, elevation and camera use. Nests in this study are clustered between 400–650m in elevation and this may not be a sufficient spread in altitude to reflect a predator effect. If riflemen are easier to find at these elevations because predator numbers are reduced, no effect of elevation will be found. No conclusions could be drawn from the model investigating the effect of cameras on nest survival, although inferences may be limited by sample size. As abandonment may be an issue at certain times in the nesting cycle (Sherley 1985; Brown et al. 1998), this risk should continue to be taken into account when using cameras.

Modelling assumptions

The set of models assessed here was fairly closely grouped by $\Delta AICc$, and in particular the top three models are fairly close together, indicating that none are a convincing explanation of the data set. This could be because the data is insufficient to make strong inferences from (Burnham & Anderson 2002). The small sample size in each area makes the results vulnerable to connected events. The Monro site had two nests fail almost simultaneously in 2011. While no cause could be determined, these nests were unusually close together, the nest trees being five metres apart. It seems likely that their fates were connected. It should be noted that an inspection of nest failure dates cannot link these failures to the use of 1080 toxin. It seems highly unlikely that these nests failed as a result of the 1080 operation more than a month after the operation occurred, given Eason et al.'s (2011) analysis on the limited persistence of 1080 in invertebrates.

Project resources meant that a minimum of 10 nests was set in each area. Additional nests were found on an incidental basis at the Monro and Cattletrack sites. The ease of finding additional nests at these sites may indicate greater riflemen numbers than in the Waituna, and illustrates the problem of obtaining sufficient samples of a species that is under pressure. Pseudo-replication occurred in the Cattletrack and Monro sites between years, as pairs banded in 2010 also had nests included in the 2011 data. As not all pairs were banded, it is possible that pseudo-replication is higher than known. The terrain is such that it is not practical to move

sites every year. Pseudo-replication would not have negatively affected the investigation of the effect of 1080, as 1080 treatment changed between sites.

The factors behind the similarities in nesting success in the Cattletrack and Monro are not explained by the covariates entered into this model. While the sites in South Westland were superficially comparable in habitat and location, it is possible that there are other site specific covariates acting on nest survival, for example localised weather patterns or nest characteristics. Including rifleman data from the replicate sites in Marlborough and the Tararua Ranges will strengthen future analyses.

Implications for wildlife managers in New Zealand

One aim of the overall study is to determine whether targeting 1080 treatment at a suite of predators in response to predator numbers, rather than possums only, can benefit forest birds. Two seasons of monitoring rifleman nest survival has not been able to answer this question in South Westland.

An effect from 1080 treatment could not be inferred from modelling. This does seem to show that 1080 does not have a negative effect on rifleman, and the timing of most nest failures makes it unlikely they were linked to 1080 operations. A history of predator control at sites can be hypothesised to be contributing to the site effect modelled. The Cattletrack and Monro sites have a longer history of predator control than the Waituna, and better nest survival. New Zealand avian species are vulnerable to both mammalian predation and food competition, and New Zealand studies commonly find that predator control increases nesting success in other species (James & Clout 1996; Armstrong et al. 2002; Dilks et al. 2003; Moorhouse et al. 2003; Whitehead et al. 2008; Starling-Windhof et al. 2011). Predator control may be benefiting rifleman nest survival over subsequent years. In the future of this study, modelling ‘time since treatment’ (Saab et al. 2011) could assess this effect for rifleman.

It was initially assumed that rats were rifleman’s primary predator, however no link between rat numbers and nest survival could be made in this analysis. For example, although rat numbers were similar in the Cattletrack and Waituna, nest survival in Waituna was much lower. (It should be noted however that the rat data is not a specific measure at nest monitoring sites). If possums were a key predator, this might explain a long-term effect of predator control for rifleman as possum populations recover more slowly from predator control (pers. comm. G. Elliott 2012).

As in other studies, the complex interactions in beech forests caused by masting events may be complicating the analysis of rifleman responses to predator control, especially with only two years of data (Innes et al. 2010).

Conclusion

This study has found that the site where no predator control has occurred had significantly lower estimated nest survival than the sites where aerial 1080 treatment for predator control has occurred. It has been unable to distinguish a difference in nest survival between the two sites where 1080 treatment occurred alternately, even in a year where high rat numbers were expected. The covariates used in this analysis were unable to explain these differences in site effect. The complex food-web interactions that exist in beech forests may be affecting rifleman responses to 1080 treatment. Research into beech forests is steadily increasing our knowledge, and extrapolation can be made to rifleman from general avian responses to predator control. However, at this stage rifleman do not appear to be a useful species for investigating responses to the two different 1080 regimes.

Acknowledgements

Thank you must go to the Paringa team: Jason Malham, Ruth Cole, Mara Nydegger and Chris Bell for making me welcome. Jason and Ruth for finding information for me and for our useful discussions. Thanks to Dr Graeme Elliott for facilitating this project, getting me started, and for his continued help along the way. Also thanks to Dr Deborah Wilson for her assistance with modelling in MARK. Dr Elliott and Allan Kilner reviewed a draft version of this report.

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