Kea (*Nestor notabilis*) survivorship through a 1080 operation using cereal baits containing the bird repellent d-pulegone at Otira, central Westland

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Abstract

The Nationally Endangered kea (*Nestor notabilis*) is a large parrot that is endemic to the South Island of New Zealand. There was concern about the potential population impact of kea mortalities observed at some aerial 1080 cereal operations, prompting a project to develop and register an effective bird repellent for use in aerial 1080 cereal operations. As part of this project, a population of kea was monitored before and after an aerial operation using cereal baits containing 0.15% 1080 and the bird repellent d-pulegone at Otira, central Westland, during winter 2013. Radio transmitters were attached to 49 kea within the Otira treatment area and 39 of these birds were tracked by radio telemetry during a Department of Conservation (DOC) brushtail possum (*Trichosurus vulpecula*) control operation. Of the 34 kea residing in the treatment area at the time of the operation, 5 died from 1080 poisoning, which equates to a mortality rate of 14.7% (5–31.1% CI). At this level, there is no evidence that repellent reduced the number of kea deaths in this study. The concentration of d-pulegone in the 1080 baits was c. 0.07% wt/wt at the time of the operation, which is less than half of the nominal concentration (0.17% wt/wt). D-pulegone may have been effective if used at a higher concentration or in combination with a secondary repellent.

Keywords: kea, *Nestor notabilis*, 1080, sodium fluoroacetate, bird repellent, d-pulegone, Otira treatment area

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1. Introduction

The kea (*Nestor notabilis*) is a large parrot that is endemic to the South Island of New Zealand. Kea were once considered a pest on high-country sheep runs, where they learnt to attack sheep which often then died from blood poisoning (Cunningham 1947; Anderson 1986). Consequently, they have a history of being persecuted by high-country farmers, with a bounty leading to over 150 000 kea being killed between 1860 and 1970. Spurr (1979) highlighted the fact that, for a long-lived, slowly reproducing species like the kea, even a small reduction in the otherwise high survival rates of juveniles and adults could result in significant population decline. However, it was not until 1986 that the kea became a fully protected species. In 2012, kea were reclassified from 'Not threatened' to 'Nationally Endangered' by Robertson et al. (2013), meaning that the population is estimated at 1000–5000 individuals and that an ongoing or predicted decline of 50–70% in the total population is expected over the next 10 years due to recruitment failure.

The ground-nesting habit of kea makes them vulnerable to predator species such as stoats (*Mustela erminea*) and brushtail possums (*Trichosurus vulpecula*). Predators are common and considered a serious threat throughout kea habitat, with stoats identified by Kemp et al. (2014) as the most significant predator. Therefore, effective large-scale predator control is required through this habitat, given the ecology of stoats (King & Murphy 2005) and the low density of kea nests (Bond & Diamond 1992).

Aerial application of bait containing 1080 (sodium fluoroacetate) is the main method of achieving large-scale pest control in New Zealand. It has been widely used to control possums since the 1950s (Montague 2000) and to target ship rats (*Rattus rattus*) since the late 1990s (Innes et al. 1995; Fairweather et al. 2013). TBfree New Zealand uses 1080 to control possums in order to protect the farming industry from the impacts of bovine tuberculosis, while the Department of Conservation (DOC) uses it to protect native forest ecosystems by reducing predation on native animals and herbivory on native trees and plants. Unfortunately, however, since 1080 is a vertebrate pesticide, there is also some mortality of non-target native species during such operations (Spurr & Powlesland 1997; Fairweather et al. 2013), and parrots are relatively sensitive to this toxin (McIlroy 1984).

Kea forage extensively on the forest floor where 1080 baits lie after aerial operations. Being opportunistic omnivores, kea have a tendency to investigate novel objects and sample novel foods, which may extend to sampling poison baits. Direct ingestion of 1080 baits is thought to be the primary risk for kea, but secondary poisoning from scavenging poisoned carcasses may also occur. Efforts have been made to quantify the risk to kea by carrying out intensive monitoring of bird survival both before and after 1080 operations (Veltman & Westbrooke 2011), including 116 kea monitored prior to this study. Kea deaths were observed in two of nine monitored operations. In 2008, 7 out of 17 kea died after an Animal Health Board (AHB, now TBfree New Zealand) aerial 1080 operation at Franz Josef and Fox Glaciers in South Westland (10-g Wanganui #7 bait, 3 kg/ha prefeed, 2.5 kg/ha toxic; Veltman & Westbrooke 2011). In 2011, 8 out of 37 kea died after a joint DOC/AHB aerial 1080 operation at Okarito in South Westland (6-g prefeed and 12-g toxic RS5 bait, 1 kg/ha prefeed and 2 kg/ha toxic; Kemp & van Klink 2014). Post-mortem examinations of the kea carcasses recovered from these two monitored operations revealed green contents and/or cereal matter in the gizzard or crop of 12 of the 13 kea examined (Kemp & van Klink 2014), suggesting that at least one pellet had been consumed by each bird. Conversely, all monitored kea survived at aerial 1080 operations in 2008 at Arawhata, in 2009 at Mt Arthur and Hawdon Valley, in 2011 at Abbey Rocks, and in 2012 at Copland Valley and Hawdon Valley. The bait specifications at Arawhata were similar to Franz Josef and Fox Glaciers, and the bait specifications for the other sites were similar to Okarito (Kemp & van Klink 2014).

In response to this risk, DOC introduced a compulsory baiting protocol for public conservation land where kea may be present in 2010. This protocol restricts the bait type (cinnamon-lured RS5) and sets a maximum application rate (2 kg/ha for 12-g baits and 1 kg/ha for 6-g baits). Sowing was initially prohibited in areas with low structural vegetation cover above the tree line. However, since June 2014, boundary decisions have been made as part of the DOC permission process, to allow for the risks and benefits of sowing above the tree line to be evaluated for each operation (DOC 2014).

DOC is also working with others to develop an effective bird repellent to protect kea during aerial 1080 operations (Orr-Walker et al. 2012; Cowan et al. 2013). To date, research has focussed on d-pulegone (a primary repellent, which repels birds reflexively through olfactory and gustatory cues) and anthraquinone (a secondary repellent, which birds learn to avoid due to gastrointestinal discomfort). As part of a repellent development project, DOC required that kea survivorship be monitored through one or more case study operations where green-dyed prefeed and repellent were used.

This paper reports on the first case study—an aerial 1080 cereal operation that was carried out in winter 2013 to control possums at Otira, which is 55 km southeast of Hokitika on the west coast of the South Island. During this operation, d-pulegone was used at a nominal concentration of 0.17% wt/wt in prefeed and toxic baits. D-pulegone was also used at a neighbouring TBfree New Zealand operation at Taipo as a precaution in case any of the monitored kea flew into this area during or after the TBfree New Zealand operation. Anthraquinone was not used in this operation because rats responded poorly to it in a pen trial on palatability and efficacy (Cowan et al. 2014); however, further information on this repellent can be found in Clapperton et al. (2014), who surveyed tomtit (*Petroica macrocephala toitoi*) abundance before and after an aerial 1080 carrot operation using 0.09% anthraquinone.

2. Methods

2.1 Bait manufacture

Prefeed baits were manufactured by Animal Control Products Ltd on 13 June 2013; these were dyed green, and included 0.15% wt/wt cinnamon lure and 0.17% wt/wt d-pulegone. Toxic baits were manufactured between 29 and 31 May 2013 (9 weeks prior to aerial application), and included 0.30% wt/wt cinnamon lure, 0.15% wt/wt 1080 and 0.17% wt/wt d-pulegone.

The nominal concentration of d-pulegone was set at a similar level to previous New Zealand studies investigating the use of bird repellents, including an aviary trial with kea that was carried out by Orr-Walker et al. (2012). A description of how the repellent was incorporated into baits by the manufacturer, Animal Control Products Ltd, can be found in Crowell et al. (2014).

Prefeed baits were dyed green to discourage kea from sampling prefeed and to reinforce the repellent strategy, using the same dye as is always applied to 0.15% 1080 cereal baits. In a choice feeding trial, Weser & Ross (2012) observed that green is the least preferred food colour for captive kea; therefore, kea may be less likely to consume green prefeed baits and subsequently have less interest in toxic baits. Consistency in bait appearance and smell has also been shown to reinforce the learned aversion between repellent prefeed and repellent toxic baits (Werner & Provenza 2011), and so use of the same green dye in prefeed and toxic baits could enhance the learned aversion for any kea that experience irritation or discomfort as a result of consuming the repellent in the prefeed baits.

2.2 Study site and sowing methods

The Otira treatment area covered 10 756 ha (Fig. 1). About two-thirds of this area is podocarp-broadleaf forest and one-third is mixed beech-hardwood forest. There is a belt of subalpine shrubland at c. 1000 m, which mainly consists of *Olearia* and *Dracophyllum* spp.

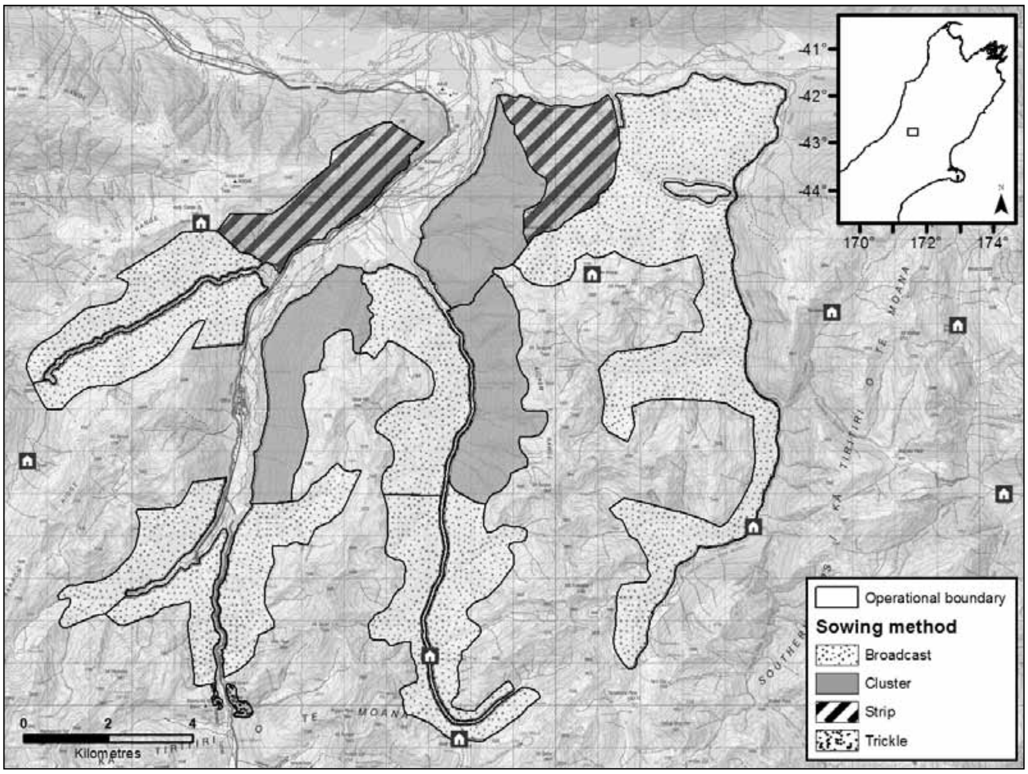

Figure 1. Aerial 1080 treatment area blocks at Otira, central Westland.

The DOC standard broadcast method and two experimental low-sowing methods (cluster and strip) were used across most of the block, with a small area at the southern edge of one block treated with trickle sowing (Fig. 1). The broadcast sowing method was applied to 7306 ha, and consisted of 6-g prefeed cereal baits being broadcast sown by helicopter at a rate of 1 kg/ha followed by 12-g toxic cereal baits being broadcast sown at 2 kg/ha. A cluster sowing method was used on 2180 ha, which consisted of 2-g prefeed cereal baits being sown in 40 m-wide swathes at 100-m flight path centres followed by 6-g toxic cereal baits being sown in clusters of baits aligned with the prefeed flight path centres; each cluster was 33 m apart and consisted of around 28 baits. A strip sowing method was used over 1175 ha, which consisted of 2-g prefeed cereal baits being sown in 40-m-wide swathes at 100-m flight path centres, and 6-g toxic cereal baits being sown in a 40-m-wide swath and aligned with the prefeed flight path centres. The approximate sowing rate for the cluster and strip sowing was 500 g/ha, for both the prefeed and toxic cereal baits. Trickle sowing occurred on 95 ha at the edge of one block and consisted of 6-g prefeed cereal baits trickle sown on flight paths ca. 50–80 m apart at a sowing rate of 1 kg/ha and 12-g toxic cereal baits trickle sown along flight paths aligned with pre-feed lines at a sowing rate of 2 kg/ha.

All prefeed was sown on 29 July 2013 and all toxic bait was sown 3 days later on 1 August 2013. Three nights was considered the minimum period necessary for bait foraging by pests to consume at least 85% of the prefeed, as determined in a field trial in an adjacent area (Terry Farrell, DOC, pers. comm., May 2013), whereas seven nights was considered the maximum period for effective low sowing methods. Toxic baiting was timed to coincide with a clear weather forecast.

2.3 Kea monitoring

2.3.1 Capture and radio tracking

Kea occupy the entire Otira treatment area. Kea habitat ranges from podocarp-broadleaf forest and mixed beech-hardwood forest to subalpine scrubland and alpine tussock grasslands. Kea were mostly caught in open areas that were easily accessed, which tended to be slips, creek beds, and subalpine scrublands and tussock grasslands.

Pairs of kea handlers were flown into alpine tops on seven occasions between January and June 2013, in order to capture wild kea and fit them with radio transmitters. Birds were caught using hand nooses, noose lines or a net gun. Kea were attracted to catching areas using amplified kea calls played through a FOXPRO player. All birds were marked with a unique combination of one metal and two colour plastic bands to allow individual identification.

Radio transmitters (short life juveniles, long life juveniles and egg timers obtained from Sirtrack Ltd) were attached to all kea caught using flying-bird harnesses, which have a weak link to ensure the eventual shedding of the transmitter, even if birds cannot be recaptured (Karl & Clout 1987; DOC 2011). The radio transmitters had an inbuilt mortality 'Time Since Death' measurement function, and were specified to have an average battery life of 112 weeks (c. 2 years).

Monitoring of radio-tagged kea took place on 29 July 2013, in order to confirm which kea were in the treatment area and therefore potentially at risk. Monitoring resumed on the day after 1080 cereal baits were sown and continued for at least the period when kea could be exposed to 1080, defined as the timeframe until 1080 cereal baits on the ground were deemed to be non-toxic. Section 2.4.2 describes the monitoring undertaken to determine this timeframe. Four weeks of post-operational monitoring was planned.

During the post-operational monitoring period, radio-tagged kea were monitored as often as was logistically possible. This ranged from daily for some birds that were close to State Highway 73 (SH73) to weekly for others. Monitoring was carried out on foot using ground-based observers who tracked the birds using a Telonics TR-4 receiver and a hand-held Yagi antenna. Aerial tracking by helicopter or fixed-wing light aircraft was undertaken on six occasions for birds that were inaccessible from SH73. Known as Sky Ranger tracking, the aircraft carries a tracking receiver that scans to detect the radio transmitters while flying systematically over the treatment area. The location of each kea was estimated by observers by checking telemetry signals from known locations and recording the direction (magnetic bearing), signal strength and approximate distance for each radio-tagged kea. Each attempt to obtain a radio signal was recorded, and if a signal was obtained the bird was recorded as alive or dead and inside or outside the Otira 1080 treatment area.

Survival was estimated simply as the proportion of radio-tagged birds that survived until 1080 cereal baits on the ground were non-toxic, with a binomial 95% confidence interval estimated using the exact method.

2.3.2 Autopsy

Samples of breast muscle tissue from all dead kea that were found were sent to Landcare Research Toxicology Laboratory (Gerald Street, Lincoln, Canterbury) to be tested for the presence of 1080. Post-mortem examinations of kea carcasses were undertaken by the Institute of Veterinary, Animal and Biomedical Sciences at Massey University.

2.4 Bait analysis

2.4.1 Concentration of d-pulegone and 1080 on receipt and following storage

Three bags of the 12-g 1080 pellets were sent by the manufacturer to the Landcare Research Toxicology Laboratory. Baits were analysed for d-pulegone on receipt, and then stored for further sampling and analysis (the analysis method for d-pulegone has an uncertainty (95% CI) of ± 4%). Baits were also analysed for 1080 concentration on receipt and after 2 months (the analysis method for 1080 has a method detection limit of 2 mg/kg and uncertainty (95% CI) of ± 9%).

2.4.2 Effect of rainfall on 1080 concentration

Two 150 mm-capacity wedge rain gauges were set within the Otira treatment area beside SH73. Daily rainfall was recorded under forest canopy at Mt Barron track (gauge 1) and in the open near the Deception road end (gauge 2). Toxic bait samples were placed in a cage adjacent to the rain gauge at Mt Barron track to monitor physical breakdown and the reduction in 1080 concentration to determine when baits could be considered non-toxic. Weathered bait samples were collected on days four and seven following the application of 1080 baits to test their toxicity, and on day seven to determine d-pulegone content. All samples were tested at the Landcare Research Toxicology Laboratory.

3. Results

3.1 Kea monitoring

Forty-nine kea were captured within the Otira treatment area, with all except one kea caught between January and June 2013 and the final kea caught during monitoring on the day toxic baits were sown. In the months leading up to the 1080 operation, ten of these kea were lost from the monitored population: nine lost their transmitters and one died from an unknown cause. Telemetry signals were obtained from the remaining 39 radio-tagged kea in the weeks prior to the distribution of 1080 bait (Fig. 2).

Five of the 39 monitored kea had territories that included areas outside the poison treatment area and therefore these birds were considered to be only 'partially exposed'. Due to their isolated territories, close-order tracking was not used to verify their actual daily locations and therefore the amount of exposure these individuals had to 1080 cannot be quantified. Consequently, 34 radio-tagged kea were considered to be within the treatment area and potentially exposed to 1080 baits.

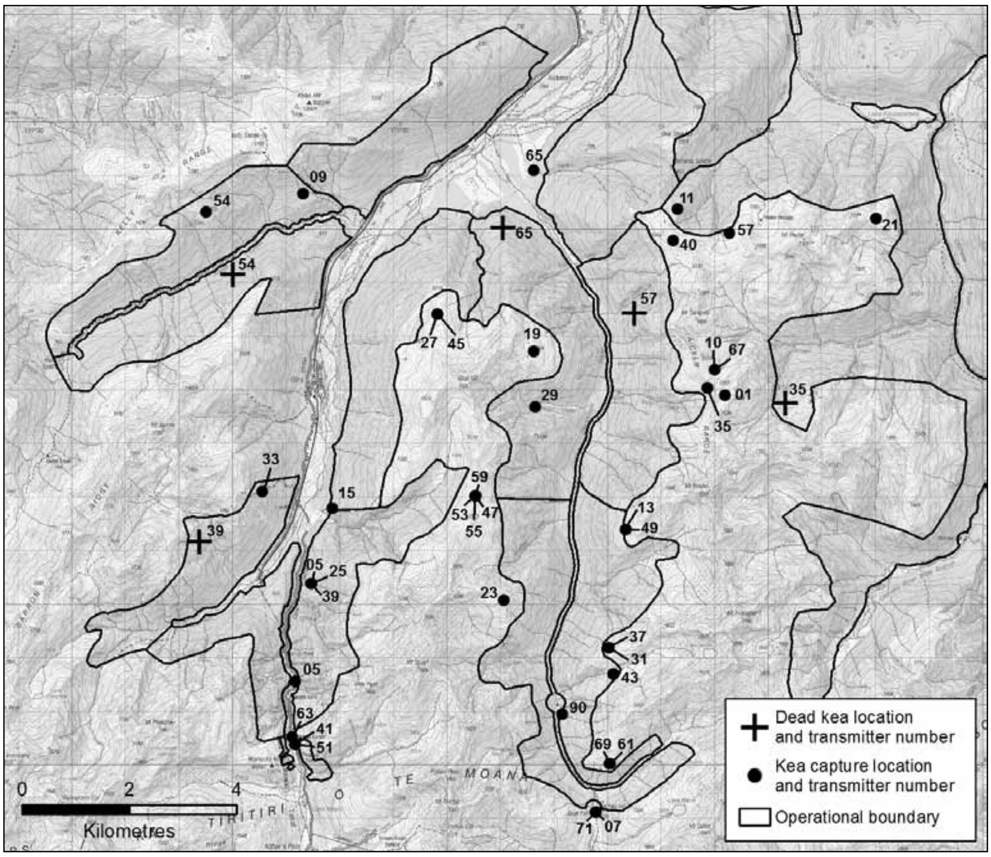

Figure 2. Kea (*Nestor notabilis*) locations in the Otira aerial 1080 treatment area. Circles indicate the locations and radio transmitter numbers of 39 kea caught between January and July 2013 and monitored before and after the aerial 1080 operation. Crosses indicate the locations and radio transmitter numbers of five dead kea that were found after the Otira 1080 operation, August 2013.

3.2 Kea mortality

The carcasses of five kea were recovered on days 2, 7, 11 and 12 after the application of toxic baits, and the 'Time Since Death' output from each of the radio transmitters confirmed that all five birds died in the first 3 days following the 1080 operation (Fig. 2; Table 1). Laboratory assays confirmed the presence of 1080 in the breast muscle tissue of all five of these birds (Table 1). Post-mortem examinations of the five kea were also undertaken to look for any abnormalities and test for lead levels; however, none of the kea were found to have abnormalities and lead levels were

Table 1. Results of laboratory assays on five kea (*Nestor notabilis*) carcasses from the Otira treatment area, including location, transmitter number, 1080 concentration in breast sample and pathology report. Cause of death for all birds was diagnosed as 'presumptive sodium monofluoroacetate (1080) poisoning'.

LOCATION	SEX	NUMBER OF DAYS AFTER 1080 APPLICATION THAT BIRD DIED	1080 CONCENTRATION IN BREAST SAMPLE (μg/g)	PATHOLOGY REPORT
Deception River	M	1	1.20	The bird weighed 947 g (pectoral muscle had already been removed on one side), and was in moderate to good condition, with no external lesions or feather defects. Bright green pasty material was found loose in the coelum, which is likely the remnants of crop and gizzard contents that were removed previously. The koilin layer lining the gizzard was bright green. No other gross abnormalities were seen.
Whaiti Stream, Otehake River	M	1	2.19	The bird weighed 927 g (pectoral muscle was already removed on one side) and was in moderate to good body condition. The crop contained bright green pasty content. The gizzard contents were bright green, consisting of plant-based material and seeds. The koilin layer was also bright green. No further gross abnormalities were noted.
Deception River	F	2	2.30	The bird weighed 975 g (one pectoral muscle was already removed) and was in good body condition. The crop was empty. The gizzard contents consisted of plant material and were bright green. The koilin layer lining the gizzard was also bright green. No further gross abnormalities were noticed.
Holts Creek, Otira River	M	2	3.44	The bird weighed 942 g (pectoral muscle was already removed on one side) and was in good body condition. The crop contained bright green pasty content. The gizzard contents were bright green, consisting of plant-based material and seeds. The koilin layer was also bright green. No further gross abnormalities were noted.
Kellys Creek	F	3	0.95	The bird weighed 861 g and was in moderate condition. The crop contained seeds. The plant-based gizzard contents and koilin lining were a bright green colour. No further gross abnormalities were found.

very low in each. Bright green contents (1080 cereal bait remains) were found in the gizzard of all five birds and in the crop of three birds (Table 1), and so the cause of death for all of these birds was diagnosed by the pathologist as 'presumptive sodium monofluoroacetate (1080) poisoning'.

The remaining 29 radio-tagged kea survived for at least 30 days after the aerial application of 1080, by which time the poison risk period had passed. Therefore, the kea survival rate was 85.3% (95% CI = 68.9–95%) and the mortality rate from 1080 poison (calculated as 1 – survival) was 14.7% (95% CI = 5–31.1%).

3.3 Concentration of bird repellent and 1080

On receipt from the manufacturer (12 June 2013, 12–14 days after manufacture), baits were found to contain 0.11% wt/wt d-pulegone, which is c. 65% of the nominal concentration (Table 2). Toxic baits were sown 9 weeks after bait manufacture and further dissipation of d-pulegone occurred during the period of storage. Five days after the operation, the concentration of d-pulegone in toxic baits was 0.07% wt/wt d-pulegone (Table 2), which is less than half of the nominal concentration. Analysis of baits collected from the field during the first week after the operation suggests that d-pulegone dissipated more in the field than in storage (Table 2).

Sampled baits contained 0.13% wt/wt 1080 on receipt and 0.15% wt/wt 1080 11 weeks after bait manufacture, indicating that baits contained about the nominal concentration of 0.15% 1080.

Table 2. D-pulegone concentration in 1080 baits manufactured for the Otira operation. The shaded rows indicate bait samples that were collected in the field after the operation. Other samples came from baits stored at Landcare Research since the time of manufacture.

DATE ANALYSED	WEEKS SINCE MANUFACTURE	NUMBER OF DAYS AFTER 1080 APPLICATION WHEN BAITS WERE ANALYSED	D-PULEGONE CONCENTRATION (% wt/wt)	NUMBER OF DAYS AFTER 1080 APPLICATION THAT BAITS WERE SAMPLED IN THE FIELD
12 Jun 13	2.0	–	0.11	–
06 Aug 13	9.5	5	0.07	–
12 Aug 13	10.5	11	0.06	–
12 Aug 13	10.5	11	0.05	4
13 Aug 13	10.5	12	0.04	7

3.4 Effect of rainfall on 1080 concentration

The weather at Otira remained dry from day 0 (the toxic sowing date) to day 3 after toxic baiting. By day 4, 5.5 mm (gauge 1) and 11.0 mm (gauge 2) of rainfall were recorded. The first weathered bait samples collected on day 4 were c. 20% less toxic than the original toxicity of the 1080 baits (i.e. 0.12% wt/wt; Fig. 3). After day 4, rainfall was recorded daily, and by day 7 the gauges recorded 110.5 mm and 170 mm, respectively. The second weathered bait samples collected on day 7 were c. 95% less toxic than the original toxicity of the 1080 baits (i.e. 0.0075% wt/wt; Fig. 3). After day 7, all remaining baits were assumed to be non-toxic and so no further testing was carried out.

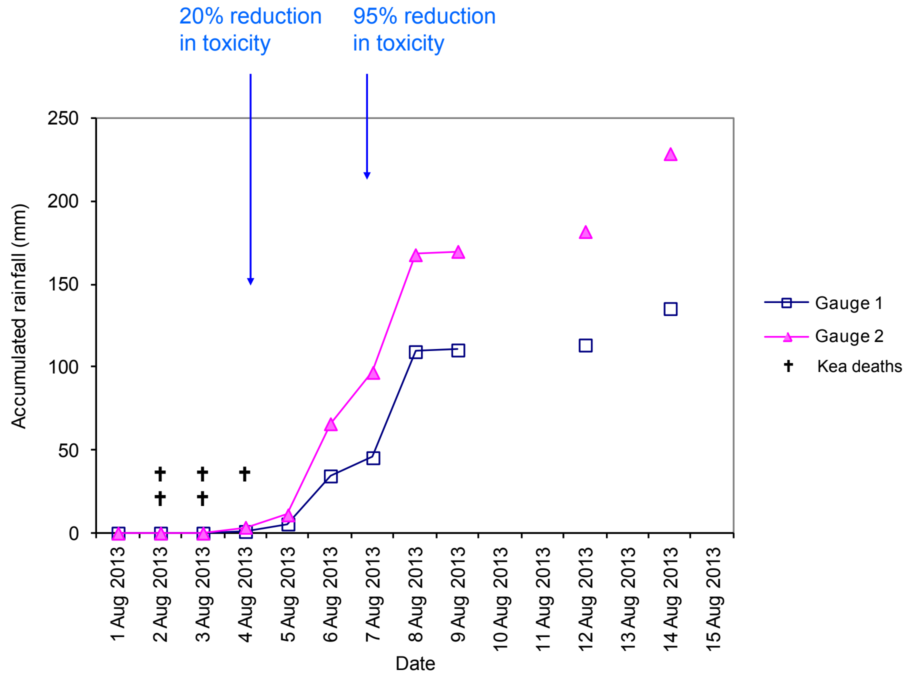

Figure 3. Accumulated rainfall (gauges 1 and 2), kea (*Nestor notabilis*) mortality events and weathered bait toxicity following the aerial application of 1080 on 1 August 2013 in the Otira treatment area.

4. Discussion

This study is the first to monitor the survival of individual radio-tagged kea through an aerial application of 1080 baits that include the primary bird repellent d-pulegone. The Otira treatment area provided an ideal site for this study. Not only was kea habitat easily accessed by foot from SH73 and by helicopter, but aerial tracking data captured by Sky Ranger also proved to be very beneficial, despite the post-operational monitoring phase being hampered by poor weather. The moderate to high numbers of kea within the treatment area also allowed for a statistically robust sample of kea to be caught for monitoring.

4.1 Kea mortality

Although d-pulegone was included in the prefeed and 1080 baits during this operation, there was still 14.7% mortality in the sample of 34 monitored kea at Otira, indicating that 0.072% wt/wt d-pulegone was insufficient to repel all kea from eating 1080 baits. This level of mortality is lower than observed at Franz Josef and Fox Glaciers in 2008 (41% mortality, 95% CI = 18.4—67.1%) but similar to that observed at Okarito in 2011 (21.6% mortality, 95% CI = 9.8%—38.2%). Given that no kea deaths were observed at the other seven monitored operations, there is no evidence that the use of d-pulegone reduced the number of kea deaths in this study. It may have been more effective at a higher concentration or in combination with a secondary repellent (i.e. one which causes discomfort or illness after consumption). These possibilities are discussed in Section 4.2.

The risk of kea death at aerial 1080 operations appears to be highly variable between sites. A statistical model is being developed that estimates risk at risky and non-risky sites, although it does not predict location or nature of risky sites. (J. Kemp, DOC, pers. comm., 14 August 2014). The current model includes the Otira observations and gives an estimate of 22% mortality at risky sites (95% CI = 13–33%) and 0% mortality at safe sites (95% CI = 0–5%).

It is not clear why kea appear to have been more susceptible to 1080 poisoning at Franz Josef and Fox Glaciers, Okarito, and Otira than at the other monitored sites. There are some theories but none are proven. There has been some interest in the 'junk food' theory—that experience foraging at car parks potentially makes kea more inclined to investigate novel foods, such as 1080 cereal pellets lying on the forest floor after aerial 1080 operations. However, three of the monitored kea at Otira (transmitters 05, 15 and 25) investigated sheep nuts during a kea behavioural trial at a car park within the operational area (Otira Viaduct-Deaths Corner Lookout) 4 months prior to the aerial 1080 operation (C. Veltman, DOC, pers. comm., 2 May 2014). These three birds survived the operation, suggesting that they did not investigate toxic baits. Prior exposure to 1080 has also been considered a possible factor. Interestingly, four of the kea that died from 1080 poisoning at Otira were adults and so theoretically may have been exposed to 1080 during the last aerial operation in 2005.

During a 1080 operation, kea may be killed through primary poisoning (eating baits directly) or secondary poisoning (eating poisoned carcasses). There is strong evidence to suggest that most kea die from primary poisoning. Across the three operations where monitored kea have died, half (10 of 20) of all kea deaths occurred the day after 1080 baits were sown, six occurred within 2–5 days and three occurred within 10–14 days. (Although one bird died 35 days after the operation, 1080 poisoning could not be confirmed by the time the corpse was recovered.) Further, 17 out of 18 autopsied kea from these operations had bright green cereal bait remains in their digestive systems.

Aerial 1080 operations are an effective landscape-scale method for directly controlling possums (Montague 2000) and rats (Innes et al. 1995) and for beneficial by-kill of stoats by secondary poisoning (Murphy et al. 1999). Kemp et al. (2014) investigated the potential benefit of such operations to kea survival and productivity by monitoring kea and predator dynamics at a number of forest sites. Their evidence indicated that aerial 1080 poison operations can benefit kea survival and productivity where stoat populations are effectively controlled, and that stoat by-kill occurs where rats are widespread. Kemp (2014) estimated the acceptable proportion of kea mortality in different pest control scenarios, defined as the mortality rate where the treated kea population grows faster than an untreated population. Where aerial 1080 is applied in a mast year, the model estimates an acceptable kea mortality rate of 37–39% (with the range dependent on mast recurrence frequency). In the year following a mast, the acceptable kea mortality rate was estimated at 29–30%. Between masts (when the Otira operation occurred), the model estimated that the acceptable kea mortality rate between masts at 18–25%. These three estimates assume that kea nests are protected from predation for 2 years. When the observed 14.7% mortality rate is compared with this benchmark, the model suggests the Otira kea population still grows faster than it would have without the aerial 1080 operation. Kemp (2014) cautions that the threshold for the kea mortality rate would be lower if nest protection only lasts 1 year, estimating an acceptable mortality rate of 10–14% for aerial 1080 operations between masts if nests are unprotected after 1 year.

4.2 Bird repellent

Baits were found to contain only 65% of the nominal concentration of d-pulegone on receipt from the manufacturer and likely less than half the nominal concentration at the time of sowing, due to dissipation during storage. Therefore, the inclusion of d-pulegone in 1080 baits may have been more effective at reducing kea mortality if the repellent had been at the nominal concentration of 0.17% wt/wt when it was sown. Two previous studies with birds in New Zealand have had positive results using this nominal concentration in a surface spray/dip (Day et al. 2003) or mixed in non-toxic cereal baits (Orr-Walker et al. 2012), when used in conjunction with 0.1% anthraquinone. Other d-pulegone concentrations have also been tested as solutions for soaking non-toxic wheat or dough baits (1–2 g/kg—Clapperton et al. 2012; 0.05%—Clapperton et al. 2014; 0.05–0.2%—Day et al. 2012) in conjunction with anthraquinone; however, none of these studies analysed the actual d-pulegone concentration at the time of the trial. An important next step is to investigate methods for stabilising the concentration of d-pulegone during the manufacture and storage of RS5 cereal baits.

It is also possible that d-pulegone does not act as a repellent for kea, but only as a salient cue for the conditional learning from anthraquinone, which is generally used as a secondary repellent. Orr-Walker et al. (2012) had promising results from feeding trials with captive kea using non-toxic Wanganui #7 cereal baits, simulating a strategy whereby prefeed baits contained 0.17% wt/wt d-pulegone and 0.10% wt/wt anthraquinone, and toxic baits contained 0.17% d-pulegone wt/wt only. They observed that mean daily consumption rates decreased significantly between untreated cereal baits and both of the subsequent repellent treatments, and concluded that learned aversion took place, which is more likely to have been a consequence of the anthraquinone than the d-pulegone. Therefore, if a method for stabilising d-pulegone is found, we could then determine whether d-pulegone is acting as a repellent or a cue through a controlled feeding trial with kea using cereal baits containing only d-pulegone.

4.3 Effect of rainfall on 1080 concentration

Rainfall reduces the exposure risk for non-target species by rendering the 1080 cereal baits non-toxic. Thomas et al. (2004) observed that almost all 1080 was leached from RS5 baits after 100 mm of simulated rainfall (Thomas et al. 2004). The five kea mortalities at Otira all occurred within the first 3 days after 1080 baits were sown, prior to any rainfall occurring. Bait samples analysed on day 4 (when rain began) and day 7 (after significant rainfall) showed that the 1080 concentration in the baits declined markedly, with only 5% of the original concentration found on day 7. This demonstrates a rapid reduction in primary poisoning risk for kea and other native species when rainfall occurs soon after operations. By contrast, it is plausible that operations that are followed by extended dry spells, as seen at Franz and Fox Glaciers in 2008, would have greater impacts on kea because the baits remain toxic for a longer period (Kemp & van Klink 2008).

5. Recommendations

This study confirms the need to continue research to better understand and reduce kea mortality during 1080 operations. Coordination between DOC and TBfree New Zealand should continue in order to undertake research into the risks and benefits of aerially applied 1080 for non-target native wildlife. Given that stoats are the major predator of kea, research is required to increase the scale, frequency and effectiveness of stoat control in order to improve kea productivity and survival.

The research into bird repellents should continue with a coordinated approach. Research priorities for d-pulegone are recommended by Crowell et al. (2014) and recognise that it was not an effective sole repellent at Otira. These include investigation of means to stabilise d-pulegone in cereal baits and development of potential strategies to use it at higher concentrations or in conjunction with a secondary repellent.

Crowell et al. (2014) also advocate for investigation of repellents other than d-pulegone and anthraquinone. Ideally, the pest efficacy of repellents should be investigated (as they were by Cowan et al. 2014) prior to testing with kea, as opportunities are limited for controlled observations of kea with repellent baits. A positive assessment of pest efficacy impacts is required to develop a repellent for native bird species other than kea.

When a repellent strategy is available that has been evaluated for pest efficacy and avian repellency, the monitoring methods used in the Otira operation should be repeated in a future case study.

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Note: DOCDM numbers refer to DOC's internal electronic file repository. For copies of these reports, please contact the authors.

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