A critique of the research used to justify kea poisoning

J.C. Pollard (BSc (Hons), PhD), 30th August 2026

Background: The number of kea (*Nestor notabilis*) remaining in NZ is unknown - estimates as low as 1000 have been made since 1986 (1, 2). The kea's official threat status has been worsening and reached Endangered in 2017 (2, 3). Declines and disappearances of kea have been very noticeable in the north and east alpine areas of the South Island (4). Kea have Absolute Protection under the Wildlife Act (1953), meaning it is illegal to kill or capture them or interfere with their nests (5).

A major cause of kea mortality, for decades, has been poisonous food bait distributed by aircraft to control unwanted mammals. Deaths of kea following aerial poisoning with 1080 (sodium monofluoroacetate) were noted in 1963 (6). Monitoring began in 2008 at Fox Glacier, where 7 of 17 kea were poisoned, indicating that 41% of the local kea had died (7). Recorded poisoning rates include: in 2020, 50% at Matukituki (8), also 50% at the remote Wet Jacket Peninsula (9); and in 2022, 22% at Arthurs Pass and 29% west of the pass at Otira-Taipo (10).

NZ's Department of Conservation (DOC) claims that kea populations benefit from poisoning, because it kills nest predators: **"*Without pest control, typically about 60% of kea nests fail -mostly due to being preyed on by stoats or possums, and in some areas, feral cats*" (11).** The following three brief sections examine the evidence for this claim. Further details are provided in the Appendices. Lastly, the Addendum provides more on the history between kea and humans (written by the late Bill Benfield).

1. Radiotelemetry

Radiotelemetry is the basis of DOC's, and charity (Kea Conservation Trust, KCT), studies on kea. The birds are caught and have a long-term backpack harness carrying a transmitter attached to them (335 kea reported by DOC up to 2021 (4); the KCT accounts for many more (12); animal control company Zero Invasive Predators is also now using the devices (13)).

In birds generally, those wearing backpack harnesses and transmitters are much more likely to die (14), e.g. annual survival rates of nearly 90% were found in falcons that managed to shed their backpacks compared to around 50% in birds that did not (15). Wearing telemetry equipment was found to affect most aspects of a bird's life, and markedly increased energy expenditure (14) - in the flightless takahe, this was attributed to heat loss, and the risk to alpine birds was pointed out – they may have little scope to forage more in winter to compensate (16); in pigeons (17) and ibises (18), flying was more difficult. Another effect of adding this equipment to birds, in general, is a marked decrease in nesting (14).

Reports from DOC's use of this equipment on birds in general include: deaths through capture and handling stress, aspergillosis (a fungal disease brought on by capture and stress), hypothermia, entanglement and predation; loss of body condition; lack of breeding; and disappearances (Appendix I); plus injuries from long-term wear (19).

The only sign of consideration from the people using them, of effects of putting harnesses on kea, appears to be a feasibility study on GPS monitoring (20). Casual observations were made on 14 newly harnessed birds (mostly) recaptured after a median of 11 days – although no negative effects were reported it was noted the birds responded by trying to remove the harnesses (20).

Bird researchers were asked to consider whether their radio telemetry studies are worthwhile if they collect biased data from disadvantaged birds, which are being harmed as well (14).

2. Nest monitoring

Using the transmitter-wearing kea, low-flying aeroplanes, ground searches and playing recorded kea calls, DOC and KCT have been finding kea nests to monitor (196 reported by DOC from 1992 up to 2023 (2); many more by KCT (12, 21)). Humans have been climbing into the nest cavities, handling chicks (measuring, taking blood and feather samples, applying leg rings, putting telemetry gear on older ones), adding cameras in and outside nests and re-visiting frequently (Appendix II, (12)).

The above manipulations are in direct conflict with collecting meaningful data on threats to kea, and the keas' breeding opportunities. In the U.K. it is illegal to interfere at all with the nests or young of rare birds because of the high risk of causing failure (22). Even brief desertion can leave eggs cooling or chicks vulnerable, and the sights/noises/scents created and left behind (e.g. cameras) attract curious and opportunistic animals (23, 24, 25); a nest researcher in NZ observed that stoats were following her around (25). Disturbing older chicks can cause them to leave the nest early, when survival is poor (26). Using bird calls to find nesting adults is also condemned due to the distraction it causes (27). Aircraft are known to disturb breeding birds and were banned by DOC from the air space above nesting terns (28); they are likely to distract kea (29). Leg bands also harmed kea: "*The large number of band injuries were caused not by the band being put on improperly but because a band prevents normal swelling of the leg, following a foot injury* (29).

Studies on kea at Arthurs Pass by J.R. Jackson in the 1950s-60s revealed the nests were worked on for years by the hen, then used for a lifetime. Nesting began in mid-winter: "*July: Heavy falls of snow cover much ground and Keas feed in the forest and on the forest floor. First eggs laid ... October: Peak of laying. Adults very shy and quiet*" (30). Jackson found that upset parent birds, other kea, gulls and falcons were all threats to eggs and chicks (31). Not rats, stoats or possums: "*During the last hundred years Keas have shared their environment with rats Rattus spp. And stoats Mustela erminea. I have found no evidence of these animals affecting Keas … Twice I have found a dead possum Trichosurus vulpecula within five yards of a Kea nest. The opossum frequently chooses holes similar to a kea nest as a den and perhaps these two opossums prospected the Kea nests*" (29).

In 1999 (32) and 2004 (33), DOC's G. Elliott and J. Kemp confirmed Jackson's assessment of a very low risk of predation at kea nests. Later, Kemp (with funding from the Animal Health Board (AHB), now OSPRI; a significant user of aerial poison to control bovine tuberculosis), began approving of ongoing poisoning of kea "to kill nest predators", despite the very poor evidence he had (Appendix III). Even cats, noted as invading Arthurs Pass National Park from about 2015 onwards, left the <u>nesting</u> (but not the other) kea alone. Again, kea were put in harnesses with telemetry gear to see whether the cats would catch them: "*This project aims to substantiate the importance of feral cats as a driver of native species declines for ground dwelling*[1] *birds in eastern forests*" (34). It could be suggested that this study was unashamedly biased research and therefore has little merit but it is another clear example of a poor method being used and placing endangered species at significant risk. Records from decades of kea nest monitoring repeatedly show great disruption: abandonment, disappearances, and unexplained deaths, and yet, little evidence of predation by mammals (Appendix II), (12)). An Official Information Act query to DOC in 2026 drew the reply that over the many years a total of 8 instances of predation of these disadvantaged kea had been caught, on in-nest cameras -involving a rat, a possum, and six stoats (35).

---

[1] This plan and the published results (4) repeatedly refer to kea as "ground dwelling"; however "*Young leaves and buds of forest trees form the main food of Keas. At all seasons they spend much time in the tree-tops (at Arthurs Pass in mountain beech) steadily and slowly picking buds …"* (30).

3. The experiment: Kemp et al., 2018

DOC's kea review (2) and website (36) cite Kemp et al. (2018) (37) as **the** evidence that predator control increases kea nest survival. This study of kea nests, stoats and rodents in an area that was poisoned (Okarito) and one that was not (Fox-Paringa) ran from 2008-2013 and a final report was produced in 2015 (38, Appendix IV). Truncated (2009-2012), modelled data was used in the 2018 publication (in the NZ Journal of Ecology (37)).

The scientific rigor of the study was poor – the monitoring predisposed kea to trouble – but also, bias was clear from the outset, with Kemp stating in his 2011 Milestone Report to the AHB, "*For nest survival in the treated area to be significantly higher at the p<0.05 level, then about 80% of the nests need to fledge at South Okarito during the 2011 season following aerial 1080 treatment. This is within the realms of possibility*" (39). There was no replication (an attempt was abandoned), there was non-random assignment of treatment to area (the AHB intended to poison Okarito), and the observers were open to bias because they knew of the treatment (38, Appendix IV).

The results from the study (preliminary in Table 1 below; final in Table 2 below and Appendix IV; published as truncated modelled data by Kemp et. al., 2018 (37)) are **<u>the</u>** evidence used to back the claim (2, 36) that kea nest survival benefits from poisoning. (Neither of DOC's other measures of kea productivity in the study (nest initiation and fledglings per nest) were considered to show any effect of the poisoning treatment.) The number of kea poisoned was not mentioned; in North Okarito, seven of nine monitored kea were killed (78% (41)).

Table 1. Results to 2012 from Milestone Report to the AHB (Kemp, 2012 (40)): Survival of kea nest contents throughout regular monitoring, in 2 areas, one (Okarito) poisoned in 2011.

Table I.

	n nests		n exposure days		n failures		% survival		95% CI	
Season	Fox-Paringa	Okarito	Fox-Paringa	Okarito	Fox-Paringa	Okarito	Fox-Paringa	Okarito	Fox-Paringa	Okarito
2008-2009		3		155		0		100%		23%-100%
2009-2010		5		285		3		29%		4%-74%
2010-2011	7	6	329	479	4	4	25%	48%	4%-65%	15%-83%
2011-2012	6	9	312	664	3	0	33%	100%	5%-76%	71%-100%

Table 2. Final results to 2013: Survival of kea nest contents throughout regular monitoring, in 2 areas, one (Okarito) poisoned in 2011 (see Table 3, Appendix IV, (Kemp et al., 2015 (38)), for full details).

Site	Season	No. Nests observed	No. nests reared a chick
Okarito	2008	3	3
Okarito	2009	5	2
Okarito	2010	7	3
Okarito-poisoned	2011	9	9
Okarito	2012	7	5
Okarito	2013	4	3
Fox-Paringa	2010	7	3
Fox-Paringa	2011	6	3
Fox-Paringa	2012	7	0
Fox-Paringa	2013	5	1

Note: The rodent graphs from the 2015 report (38, Appendix IV) show why aerial 1080 is spread repeatedly: a large rise in mouse numbers occurred within three months, followed by steeply increasing rats, then stoats (truncated from the 2018 paper). This pattern involving a large rat irruption is a standard response to broadcasting 1080, fuelled by the resources left unused by dead animals (42-45). Poisoning then needs to be repeated frequently to control the rats (46).

Conclusions: There is no scientifically obtained evidence that supports poisoning kea to improve their reproduction. Studies have found remarkably little evidence of nest predation by mammals, given the opportunities created by monitoring.

Due to the unknown, but likely precarious state of the species, an urgent halt to killing, capture and all interference[2] is strongly indicated. The kea's Absolute Protection status is not being acknowledged. Neither is its vulnerability to weather conditions, and starvation, which was the biggest natural killer of kea in Jackson's studies (25):

"*In the autumn as nesting finishes adult Keas may die, as they go into moult, perhaps in poor condition. The greatest mortality for all Keas is June to September when food is most scarce … tables show the large loss of Keas in their first year, especially soon after banding. Some of these Keas were inexperienced, recently fledged Keas. Others were banded and died in the spring when there is a large moving population, spurred by hunger …* "*The bad Season - October 1957-May 1958 ... in each month the rainfall was greatly above average, especially from October to March, probably the significant months for the Kea ... December was the worst month ... There were frequent storms ... This period caused a great reduction in the Kea population. Perhaps it was reduced to two thirds normal ... Chicks were found dead in their nests, eating of eggs was first noticed, and many parent Keas disappeared. Usual foods failed ... That summer there was little nectar, and the following winter few berries. Starvation was the immediate cause of death of many Keas that summer*"(25).

References

1 Anderson, R., 1986. Keas for keeps. Forest and Bird 17: 2-5

2. Weston, K., Kemp, J., McInnes, K., Aley, J., Orr-Walker, T., Dearlove, T., McAulay, J., & Young, L. (2023). Kea (*Nestor notabilis*): A review of ecology, threats, and research gaps for conservation. *Science for Conservation No. 339*. Department of Conservation, Wellington, New Zealand. https://www.doc.govt.nz/globalassets/documents/science-and-technical/sfc339entire.pdf "*In lowland podocarp forest in South Westland, aerial 1080 improved the odds of daily nest survival by a factor of 9.1 … Following the application of 1080, nest survival increased to 85%, whereas it declined to 12% in the untreated site ... "This positive effect of aerial 1080 on kea nest survival was attributed to the effective control of mammalian nest predators, particularly stoats*."

3 https://datazone.birdlife.org/species/factsheet/kea-nestor-notabilis

4 Kemp, J. R., Young, L. M., Mosen, C., Bolitho, L., Orr-Walker, T., & Elliott, G. P. (2023). Irruptive dynamics of invasive carnivores and prey populations, and predator control, affect kea survivorship across the Southern Alps. New Zealand Journal of Zoology, 50(4), 279–304. https://doi.org/10.1080/03014223.2021.2021249

[2] Includes KCT: Decades of blood sampling for lead; genetic sampling (500 samples taken); bait aversion trials; ZIP: bait aversion trials; communal feeding (which alters behavior and creates a disease transmission risk).

5 Wildlife Act 1953, s 3, New Zealand Legislation. Wildlife Act 1953, Public Act 1953 No 31, s 3 ("Wildlife to be protected").

6 Environmental Risk Management Authority Agency Evaluation and Review Report, Reassessment of 1080 (HRE05002) (2007). Appendix N. Table N7. Environmental Risk Management Authority, Wellington, New Zealand. https://www.epa.govt.nz/assets/FileAPI/hsno-ar/HRE05002/9aaecae154/HRE05002-059.pdf *"NZ land birds susceptible to non-recovery if subject to significant impacts and recent monitoring after 1080 … Species: Kea; Risk of non-recovery: high; Research priority in 1997 and rationale: High priority- infrequent exposure but will eat carrot bait...Monitoring...after aerial 1080operations...Dobson Valley 1963 - 4 dead Kea.*"

7 van Klink, P., Crowell, M. (2015*).* Kea (*Nestor notabilis*) survivorship through a 1080 operation using cereal baits containing the bird repellent d-pulegone at Otira, central Westland. DOC Research and Development Series 344. Department of Conservation, Wellington. 13 p.

8 DOC, 2020a. https://www.doc.govt.nz/news/media-releases/2020-media-releases/kea-cause-of-death-confirmed/

9 DOC, 2020b. https://www.doc.govt.nz/news/media-releases/2020-media-releases/predator-control-for-kiwi-survival-informs-kea-research/

10 Young, L. M., Whitehead, A. L., Handley, L. M., Yockney, I. J., Watson, M. B., Hickson, M., Benson, J. W., Giacon, I. D., & Weston, K. A. (2025). Aversion training wild kea with anthraquinone repellent in non-toxic baits prior to 1080 operations does not improve survival outcomes. New Zealand Journal of Ecology, 49(1), Article 3599. https://doi.org/10.20417/nzjecol.49.3599

11 DOC3 https://www.doc.govt.nz/our-work/national-predator-control-programme/monitoring-results-for-native-species/kea/https://www.keaconservation.co.nz/projects/nest-monitoring/

12 https://www.keaconservation.co.nz/projects/nest-monitoring/

13 https://www.keaconservation.co.nz/projects/perth-catchment-zip-research-site-kea-monitoring/

14 Barron, D., Brawn, J., Weatherhead, P. (2010). Meta-analysis of transmitter effects on avian behaviour and ecology. Methods Ecol. Evol. 1, 180–187. doi: 10.1111/j.2041-210X.2010.00013.x

15 Steenhof, K., Bates, K.K., Fuller, M.R., Kochert, M.N., McKinley, J.O., Lukacs, P.M. (2006). Effects of radiomarking on prairie falcons: Attachment failures provide insights about survival. Wildlife Society Bulletin 34 (1):116–126. https://doi.org/10.2193/0091-7648(2006)34[116:EOROPF]2.0.CO;2

16 Godfrey, J.D., Bryant, D.M. 2003. Effect of radio transmitters on energy expenditure of takahe. In: Williams, M. (Comp.). Conservation applications of measuring energy expenditure of New Zealand birds: assessing habitat quality and costs of carrying transmitters. Science for Conservation 214: 69–81. Department of Conservation, Wellington, New Zealand. https://www.doc.govt.nz/Documents/science-and-technical/sfc214e.pdf

17 Gessaman, J. A., Nagy, K. A. (1988). "Transmitter Loads Affect the Flight Speed and Metabolism of Homing Pigeons. Condor 90 (3), Article 17. https://digitalcommons.usf.edu/condor/vol90/iss3/17

18 Pennycuick, C. J., Fuller, M. R. (1987). Considerations of effects of radio-transmitters on bird flight. In H. P. Kimmich & M. R. Neuman (Eds.), Biotelemetry IX: Proceedings of the Ninth International Symposium on Biotelemetry, pp. 327–330. Braunschweig, Germany.

19 Michael, S., Gartrell, B.D., Hunter, S. 2013. Humeral remodelling and soft tissue injury of the wings caused by backpack harnesses for radio transmitters in New Zealand takahē (*Porphyrio hochstetteri*). Journal of Wildlife Diseases 49(3): 552–559. https://doi.org/10.7589/2013-1-006 "*Of the 16 birds that had worn a harness, 10 (63%) had superficial soft tissue injury to skin or patagium or more severe injury, such as remodeling of the distal humerus at the harness cord-wing interface, or pathologic fractures*."

20 Kennedy, E. M., Kemp, J. R., Mosen, C. C., Perry, G. L. W., & Dennis, T. E. (2015). GPS telemetry for parrots: A case study with the kea *(Nestor notabilis).* The Auk: Ornithological Advances, 132(2): 389–396. https://doi.org/10.1642/AUK-14-196.1

21 https://www.keaconservation.co.nz/projects/monitoring-threats-to-kea-in-the-matukituki-valleys-mt-aspiring-national-park/

22 RSBP. Protective legislation for wild birds in the UK. https://www.rspb.org.uk/birds-and-wildlife/wildlife-and-countryside-act

23 Major, R. (1990). The effect of human observers on the intensity of nest predation. Ibis 132 (4): 608-612. https://doi.org/10.1111/j.1474-919X.1990.tb00285.x

24 Hein, E.W., Hein, W.S. (1996). Effect of flagging on predation of artificial duck nests. Journal of Field Ornithology 67(4): 604-611. DOI: 10.2307/4514163

25 Ellenberg, U., Edwards, E., Mattern, T., Hiscock, J.A., Wilson, R., Edmonds, H. (2016). Assessing the impact of nest searches on breeding birds - a case study on Fiordland crested penguins (*Eudyptes pachyrhynchus*). New Zealand Journal of Ecology 39(2): 231-244. https://newzealandecology.org/nzje/3231

26 Cornell University - Cornell Lab of Ornithology (2011). NestWatch project. http://watch.birds.cornell.edu/cub/data

27 The Association of County Recorders and Editors (2014). The birdwatchers' code. Surfbirds.com22a https://www.aviation.govt.nz/about-us/media-releases/show/Airspace%2520breaches%2520threaten%2520critically%2520endangered%2520birds/

28 https://www.aviation.govt.nz/about-us/media-releases/show/Airspace%2520breaches%2520threaten%2520critically%2520endangered%2520birds/

29 Jackson, R. (1969). What do keas die of? Notornis 16, 33-44 https://www.birdsnz.org.nz/wp-content/uploads/2011/03/Notornis_16_1_33-44.pdf "*And when in the open on a river flat or above the bush line they carefully watch any large bird flying high above. To do this it is necessary for them to twist the head sideways and while in this stance all the Kea's attention is occupied*."

30 Jackson, J.R. (1960). Keas at Arthurs Pass. Notornis IX, 39-58 https://www.birdsnz.org.nz/wp-content/uploads/2025/02/Notornis_9_2_September_1960_whole_volume.pdf

31 Jackson, J.R. (1963). The nesting of Keas. Notornis X, 319-326 https://www.birdsnz.org.nz/wp-content/uploads/2025/02/Notornis_10_7_December_1963_whole_volume.pdf

32 Elliott, G., Kemp, J. (1999). Conservation ecology of kea (Nestor notabilis). WWF-NZ Final Report 1 August 1999, 64 pp. www.yumpu.com/en/document/view/5550938/conservation-ecology-of-kea-kea-conservation-trust-website "*This study is designed to assess the likelihood that nest predators are causing an ongoing decline in kea abundance*" … "*Kea nests appear to be relatively immune to predation from introduced mammals...Our results agree with a previous study of kea nesting at Arthur's Pass, where no evidence of significant nest predation was found (Jackson 1963)*."

33 Elliott, G., Kemp, J. (2004). Effect of hunting and predation on kea, and a method of monitoring kea populations. Results of kea research on the St Arnaud Range. NZ Dept of Conservation Internal Science Series 181, 17 pp. https://www.doc.govt.nz/globalassets/documents/science-and-technical/dsis181.pdf?utm_source=chatgpt.com *"To use the destruction of kea as a tool in their management we would need to be confident that the population was stable or increasing and safe from extinction. … The significant effect of predation and hunting suggests that kea populations declined following the introduction of mammalian predators and hunting in the 1800s, but that the decline has slowed or even stopped."*

34 Kemp, J., Young, L. (2021). Westward species-range contraction of kea. Landscape predator control research plan. Annual report 2020/2021. Department of Conservation, Wellington. 6pp

35 DOC (2026). OIAD-9280 – Response July 7 2026

36 https://www.doc.govt.nz/our-work/national-predator-control-programme/monitoring-results-for-native-species/kea

37 Kemp, J., Mosen, C., Elliott, G., Hunter, C. (2018). Effects of the aerial application of 1080 to control pest mammals on kea reproductive success. New Zealand Journal of Ecology 42, 158-168. doi: 10.20417/nzjecol.42.28

38 Kemp, J., Cunninghame, F., Barrett, B., Makan, T., Fraser, J., Mosen, C., 2015, unpublished. Effect of an aerial 1080 operation on the productivity of the kea (*Nestor notabilis*) in a West Coast rimu forest. Department of Conservation report. 15 pp. (Appendix IV.).

39 Kemp, J., 2011. R-80716, Effects of aerial 1080 operations on kea populations. Animal Health Board Milestone Report, 1/4/2011.

40 Kemp, J. (2012). R-80716, Effects of aerial 1080 operations on kea populations. Animal Health Board Milestone Report, 31/3/2012

41 Graf, C. 2011. Seven of Nine Tagged Kea Killed in Okarito Kiwi 1080 drop. http://www.scoop.co.nz/stories/PO1109/S00139/seven-of-nine-tagged-kea-killed-in-okarito-kiwi-1080-drop.htm

42 Byrom, A.; Banks, P.; Dickman, C.; Pech, R. Will reinvasion stymie large-scale eradication of invasive mammals in New Zealand? Kararehe Kino 2013, 21, 6-7.

43 Caut, S.; Casanovas, J.; Virgos, E.; Lozano, J.; Witmer, G.; Courchamp, F. Rats dying for mice: Modelling the competitor release effect. Austral Ecol. 2007, 32, 858-868. doi: 10.1111/j.1442-9993.2007.01770.x

44 Ruscoe, W.; Ramsey, D.; Pech, R..; Sweetapple, P.; Yockney, I.; Barron, M.; Perry, M.; Nugent, G.; Carran, R., Warne, R., Brausch, C., Duncan, R., 2011 Unexpected consequences of control: Competitive vs. predator release in a four-species assemblage of invasive mammals. Ecol. Lett. 14, 1035-1042. doi: 10.1111/j.1461-0248.2011.01673.x

45 Griffiths, J., Barron, M. (2016) Spatiotemporal changes in relative rat (Rattus rattus) abundance following large-scale pest control. N.Z. J. Ecol. 2016, 40, 371-380. doi: 10.20417/nzjecol.40.33

46 Wright, J. Evaluating the use of 1080: Predators, poisons and silent forests. Office of the Parliamentary Commissioner for the Environment, Wellington, New Zealand, 2011. https://pce.parliament.nz/media/pwthbbah/evaluating-the-use-of-1080.pdf

Appendix I. Quotes from DOC staff on the use of telemetry equipment in conservation of birds (note, some quotes relate to newly released birds under multiple stressors.)

Ref.	Quote
1	"All radio-tagged and banded rock wrens were sighted alive each day for eight days after the 1080 operation. Between 1 December and 9 December 2019 there was a prolonged period of heavy rain, with a total of 282 mm recorded at a nearby rain station. This rainfall event prevented birds being re-sighted for nine days. From 10 December 2019 (18 days after the operation) we managed to relocate all radio-tagged and banded birds except for one bird, whose radio-tag had exceeded its battery life. Two of the radio-tagged rock wrens were found dead (both female).One was found dead on its nest, but no 1080 was detectable in the muscle tissue. A second bird was preyed upon, with insuffcient remains to test for 1080.This bird was most likely preyed upon by a falcon …"
1	"We had some welfare concerns for the rock wrens wearing radio-tags during this study …Two of the first four birds fitted with full length radio-tag aerials showed sign of entanglement from the aerial, after which we shortened the aerial … We also observed higher than expected nest abandonments in birds fitted with radio-tags. From the 15 birds which had either radio-tags or colour bands attached, we found seven nests with known outcomes. Of these nests, three continued as normal, two failed because one of the parent birds died, and two pairs abandoned the nest, with one of these pairs re-nesting only to also abandon their second attempt."
2	"Using mist nets a total of 34 ruru were captured and radio-tagged ... However only 11 were known to be alive at the time of the poison operation, due to transmitter failure, predation, and 18 birds dying during a prolonged period of extremely cold weather 2 weeks prior to the operation."
2	"...plans to collect such data during the Waitutu operation were abandoned for ethical and operational reasons. Use of 'backpack'-type harnesses ... for attaching transmitters to kereru has been restricted by the Department of Conservation following concerns over instances of harness entanglement and resultant deaths …"
3	"... kereru sometimes suffer post-handling shock (become grounded and unable to fly) following transmitter attachment ... S-80578 was found on the ground in a weakened state on the fourth day after transmitter attachment … Of the four kereru used in this study, the one that had never been handled before responded negatively to handling and transmitter attachment … In most studies that have involved radio-tagging kereru the occasional bird has suffered from post-capture trauma, with some kereru becoming grounded within a few days of having a transmitter attached …"
4	"The remaining 22 females and 14 males were released on 10th September. Ten birds had tail-mounted transmitters attached and were monitored weekly. Two weeks after release, four transmittered saddleback were found dead following a week of extremely cold southerlies which brought snow to the higher parts of Boundary Stream. Necropsies of two birds found they died of aspergillosis, a common fungal disease that can become fatal when the bird is under stress. One bird had a broken neck, but mammalian predation was ruled out. The fourth bird was too decomposed to necropsy, but no obvious signs of predation were found. A survey six weeks after release estimated 21 birds present, giving a 57% minimum survival rate. There are five known pairs that are courtship feeding, but none are known to have attempted to nest."
5	"Blue duck in Egmont National Park: The planned transfer of further wildhatched and captive-raised birds has been postponed owing to poor productivity of both wild and captive populations this season. Survivors from last year's release are still encountered, but the birds had transmitters removed because of weight loss problems so monitoring is much more labour intensive. We plan to refit modified transmitters on birds based on findings from the

	takahe energetics study ..."
5	"Of the 13 Operation Nest Egg releases put back into Tongariro Forest, only 5 to date still carry functioning transmitters. One chick dropped its transmitter and 4 have had gear failure meaning we have lost track of them. One bird has been killed by a pig, another by a ferret, and 1 died from a ruptured liver after what we can only describe as misadventure because the bird was in perfect health otherwise – there were no visible sign of predation. Although the total of confirmed deaths from the 13 released chicks is only 3, there is the possibility of more among the 5 'missing' birds."
6	"The Pureora Field Centre is monitoring radio tagged kaka in the Waipapa Restoration Area to assess the effectiveness of pest control on a species sensitive to mustelid predation. Female kakas are followed to nests which are monitored. A sample of chicks have transmitters fitted to find out how many survived and where they disperse to ... A dramatic increase in fledgling mortality has been noted coinciding with a change to the pest control regime. Seventeen female chicks were monitored since the breeding season and excluding missing birds, eleven of fourteen fledglings have died. Nine of these were probably (some certainly) killed by stoats. And just to show that the predators are not targeting birds wearing radio transmitters, one observation included finding the remains of two untagged kaka within the same den as a dead tagged bird. So the results of a productive nesting season for kaka in the Waipapa has very much been let down by poor fledgling survival. The pest control regime was an aerial 1080 pollard operation in October. While this did offer protection during the time birds were nesting, as pest numbers increased, the level of protection decreased toward the end of the season when fledgling kaka become vulnerable."
7	This project['s] objectives include determining the costs (mortality as a result of the poison operation) and benefits (reduced mortality and increased breeding success after the poison operation as a result of poisoning introduced mammalian predators and competitors) of an aerial 1080 possum poisoning operation to kereru and kaka in Whirinaki Forest Park. This requires the radio-tagging and monitoring of kaka and kereru in a treatment area (Otupaka Ecological Area) and in a non-treatment area (Oriuwaka Ecological Area). The project began in October 1998. To date, 63 kereru have been captured and survived at least a fortnight after being radio-tagged. Of these, 28 (44.4%) have died ... the following are the assumed causes: 1 died on a nest, 2 collided with vehicles, 5 killed by cats, 6 killed by mustelids, 5 killed by falcon/ harrier, 2 killed by poachers, and 8 killed by unknown predators. Most of the deaths were in autumn (43%) and winter (29%) ... One of the birds had been caught by a cat while feeding a couple of metres above the ground. Fifty-three kaka have been captured and survived at least a fortnight after being radio-tagged. Of these, 3 (5.7%) have died, giving a mean life expectancy of 20.5 years. All 3 kaka that died were females killed by unknown predators."

Appendix I References

1 Rawlence, T., Squire, K. (2024) Survival of rock wrens (*Xenicus gilviventris*) using radio-tags,through an aerial 1080 pest control operation. New Zealand Journal of Ecology 48: 1–5. DOI: 10.20417/nzjecol.48.35742
2 Greene, T.C., Dilks, P.J., Westbrooke, I.M., Pryde, M.A. 2013. Monitoring selected forest bird species through aerial application of 1080 baits, Waitutu, New Zealand. New Zealand Journal of Ecology 37(1): 41–503
3 Powlesland, R.G., Moran, L.R., Wotton, D.M. 2011. Satellite tracking of kereru (Hemiphaga novaeseelandiae) in Southland, New Zealand: impacts, movements and home range. New Zealand Journal of Ecology 35(3): 229–234
4 Rare Bits Newsletter 55, 2004 https://www.doc.govt.nz/Documents/science-and-technical/RareBits55.pdf5
5 Rare Bits Newsletter 40, 2001 https://www.doc.govt.nz/documents/science-and-

technical/RareBits40.pdf
6 Rare Bits Newsletter 36, 2000 https://www.doc.govt.nz/globalassets/documents/science-and-technical/rarebits36.pdf
7 Rare Bits Newsletter 47, 2002 https://www.doc.govt.nz/documents/science-and-technical/RareBits47.pdf
8 Rare Bits Newsletter 38, 2000 https://www.doc.govt.nz/Documents/science-and-technical/RareBits38.pdf

Appendix II. Quotes from nest monitoring of kea 2009-2014 from KCT website, 2014 (see https://www.keaconservation.co.nz/projects/nest-monitoring/ for on-going observations)

Ref.	Quote
1	"Kea are caught up where possible, biodata collected, bloods taken (to test for avian diseases and/or lead levels) and identification bands and transmitters attached (depending on sex and life stage). Females are attached with egg-timer transmitters to aid in detection of nesting behaviour"
2	"January is a busy time for us with our annual summer surveys running throughout January. This year we will have our workers and keen KCT volunteers up the mountains counting kea at Kiwi Saddle (Kahurangi National Park) and Kowhai Saddle (in the Kaikoura Mountains). Corey Mosen, our field co-ordinator will be directing both sites which will see up to a dozen people at each site locating transmittered kea, attaching transmitters to any new birds and recording sightings and calls of kea early each morning and early evening for 10 days at each site."
3	"Four of these nests contained eggs at that time while the other three contained chicks (exact numbers unknown). By the end of November 3 of these nests had failed with the 4 active nests containing a total of 7 chicks evenly spread between Nelson Lakes and the Hawdon Valley in Arthurs Pass.
4	"At the start of the 2011 season there were twenty-one kea radio tagged in the Hawdon valley, Arthurs Pass, to be monitored. Six transmitters were found to be in mortality mode (4 of which were adult breeding females). The loss of these birds significantly reduces the possible sample size of nests to monitor. Additionally, nine transmittered birds remained unaccounted for resulting in only six kea able to be followed. Three of these kea are adult females of which only one has been identified as attempting to breed (Queen Pow Pow). The other two females showed no indication of having active cavities or notable courtship or nesting behaviour. Nest cameras set up at the Queen Pow Pow's nest showed that this nest was abandoned with an egg intact and this pair moved to another nest site which also did not produce chicks. Information gleaned from this nesting season appears to indicate that the high number of deaths of both adult and sub-adult birds may now be affecting productivity. A case in point is the late 2010 nesting by Mrs Moon (one chick fledged at the end of April 2011). Mrs Moon died one month later on 8 June 2011.
5	"Nest monitoring cameras placed in Nelson Lakes and Arthurs Pass clearly show possums visiting kea nests raising concerns about chick survivorship this year."
6	"...a light aircraft was used to radio track birds (thanks to in-kind support from DOC). Seven kea are present radio tagged in Nelson lakes- two of these are adult females, Ceejay (mate Kelly recently deceased) and Aphrodite...The three identified breeding pairs (confirmed through the 2000-2011 summer survey and 2010 nest monitoring efforts) were followed and their nest cavities identified. Out of a seven possible nest sites, three cavities were confirmed by September 2011. Cameras were set up inside and outside each nest area and images taken throughout the breeding season. Only one of the breeding pairs, Ceejay and Kelly, successfully fledged chicks as follows: Nest site 3 successfully fledged three chicks early in December 2011; Nest site 26 most likely failed due to possum predation; Nest Site 8 was found to be infertile. Unfortunately, Kelly, Ceejay's mate, was recovered dead during the nesting period (necropsy report cause of "sudden death" - unknown)"
7	"Corey Mosen revisited our survey nest sites during October and November. Here's a quick comparison of each of the nests sites from his first visits in August/Sept...Nelson Lakes...2 nests now have 3 chicks total. Beryls nest has failed (with the loss of 2 chicks and one egg), Queen Pow Pow's nest has been reduced from 3 chicks to two chicks and How's nest has reduced from 1 chick and 1 egg to 1 egg and 1 chick. Pest visitation seems to be the main

	factor for nest failure."
8	"Today, we went to the Hawdon valley to check on two nests and attach satellite transmitters, weigh, measure, band, and take bloods from the birds... "Kea parents in the wild behave just like keas in captivity! They make the same call when their nest is disturbed; they show the same postures and behaviours like throwing things at you; and they are very curious"
9	"I ended up helping Erin, a PhD student, with trying to catch and remove some satellite transmitters. However with so much rain, we only saw 3 birds, 2 of whom were very bedraggled!"
10	"Day 4 was a trip up to CeeJay's nest, which was empty - she seems to be only nesting every second year. We also saw and attempted to catch a male that was hanging around the nest, but he wasn't having a bar of that! CeeJay has a transmitter attached as she is a breeding female, however today her transmitter was doing a lot of crazy things which made for some fun for Cory to figure out what was going on!"
11	"We weren't expecting a chick, as there is no predator control in this area and her last two nests have been raided. But to our surprise, there was a wee chick there! I say wee but he weighed over 1000g. Cory got him out and we weighed, banded, took bloods and feathers and measured him. We attached a satellite transmitter as part of Erin's work."
12	"When we were checking the nest, I got to crawl inside. It was really interesting, as the cavity was a lot different to what I expected! It was long- I crawled more than my whole body length in - and it was narrow! I had to go in a bit like superman with my arms out in front of me …"It was the cutest thing I've ever seen, his head was really fluffy with baby feathers and was very soft...I also had a first while I was there, I got to take the blood from the chick! Very very cool experience"
13	"When we have been visiting all the kea nests, they have each had motion sensor trail cameras outside them and we get to see the pictures that are taken outside the nests. The possums that the 1080 are targeting are frequent visitors to most of the Kea nests we checked."
14	"On Monday, we travelled back to Nelson Lakes National Park to check out two more nests. Unfortunately one had been raided by predators, but the other nest was exciting - with two chicks and Dad in the cavity …"We attached transmitters, weighed, measured, took feathers and blood and banded these chicks too".
15	It has great been in the bush. We stopped regularly while Fanny and Brent released their pre-recorded birdsong on the jungle … The kea was then "processed", you know, like processed food. Out of Franny's bag of tricks came a radiotransmitter, with nylon string to attach it, a beak-measuring device, scales and other fandangos...Oh yeah, I was going to talk about 1080 and keas. Well the story as far as I can make out is that despite years of scepticism from DOC scientists, recent studies of mortality following an aerial 1080 drop have shown keas dying from 1080 poisoning...One point it is always worth making is that much of the 1080 poisoning in NZ is undertaken by the Animal Health Board in its ongoing battle with TB...But whatever way this does seem to be a big problem. Don't quote me on this, but about 1/3 of the keas habitat is under rotational TB control. Alarm bells seem to be ringing and DOC has teamed up with Landcare Research to investigate an effective bird repellent. It will be interesting to see what happens and if the planned drop in Okarito forest goes ahead"
16	"7 paired field researchers/observers per site will survey a minimum of 4 ridges each ... over an 8 day period in mid-January. This will be timed to co-incide with fledglings leaving the nest ... Observers will ... capture and band all kea where possible. Associated with satellite and radio tracking of individual birds, banding will be used ... collection and storage of blood samples at the time of capture will provide samples for other organisations …”

17	"We made regular visits to the ski field car park during June to October ski season each year between 1992 and 1999 to capture, radio-tag and band kea ... we also banded and radio tagged nearly fledged chicks from any accessible nests we found, particularly in January 1998 and 1999"
17	"During the breeding season (July-January) we repeatedly searched for every radio-tagged adult in our study until we found its nest, were confident it was not nesting, found its body, or concluded it had migrated out of our study area...Once it was found, we checked each nest every 2-3 weeks until it either failed or the chicks had fledged"
17	"We radio-tagged eleven near-fledgling chicks during three summers of our study and in three subsequent summers we flew at 2500-3500 m, in a radio-telemetry equipped fixed wing aircraft over all forested mountains within a 50-km radius of the nests. Following the flight, we visited all of the birds on foot to see if they were alive. We assumed the birds we could not find from the air had migrated out of our search area..."
17	"We captured and radio-tagged 39 kea which we monitored for an average of 2.5 years each. We found 44 nests in 25 sites and were able to assess the nesting success of 40 of them."
17	"Eggs and chicks disappeared from 35% of the nests we monitored and at two of these nests definite sign of stoat predation was found"
17	"The main potential predators of kea nests in montane beech forests in the northern South Island are stoats and possums...The only nest failure we can confidently attribute to a specific predator was caused by a stoat"
17	"However our failure to identify the cause of most nest failures means that predator control could easily be focussed on the wrong predators. The highest priority for future kea research should be to identify the causes of nest failure"
17	"Nest predation did not increase in the breeding season following full beech mast-seeding in 1995, when stoat (Mustela erminea) numbers were beginning to rise"

Appendix II References (from www.keaconservation.nz in 2014)

1 Orr-Walker, T. (2013). Inspiring communities to protect kea, the world's only mountain parrot www.keaconservation.co.nz

2 Kea Conservation Trust. 2013. Kea Conservation Trust Update, 16 December 2013. Kea Conservation Trust, New Zealand.

3 Kea Conservation Trust. 2013. Kea Conservation Trust Update, 16 December 2013. Kea Conservation Trust, New Zealand.

4 Orr-Walker, T., 2012. Nest monitoring- Arthurs Pass. Nestor Notabilis 6: 12 https://www.keaconservation.co.nz/wp-content/uploads/2013/10/KCT_newsletter2012_F.pdf

5 Orr-Walker, T., 2012. 2011- 2011- The highs and lows in brief April-May. Nestor Notabilis 6.

6 Orr-Walker, T., 2012. 2011- Nest Monitoring - Nelson lakes. Nestor Notabilis 6.

7 Orr-Walker, T., 2012. Field Projects - Nest monitoring updates. Kea Conservation Trust Updates Dec 2012.

8 van Herpt, S. 2012. Part Three - Learning on the road. Wellington Zoo blog.

9 van Herpt, S. 2012. Part Four - the days are just packed! Wellington Zoo blog.

10 van Herpt, S. 2012. Part Four - the days are just packed! Wellington Zoo blog.

11 van Herpt, S. 2012. Part Four - the days are just packed! Wellington Zoo blog.

12 van Herpt, S. 2012. Part Four - the days are just packed! Wellington Zoo blog.

13 van Herpt, S. 2012. Part Five - Telemetry and transmitters

14 van Herpt, S. 2012. Part Five - Telemetry and transmitters

15 Stewart, J. 2009. Kea catching. The adventures of PK Maebo & Jimjam 9/2/09

16 Roberts, L., 2014. Population estimates of wild Kea. (*Nestor notabilis*). Academia

Appendix III: Internal reports on kea predation

The following reports were obtained in response to requests made to DOC under the Official Information Act (1987), for research showing kea predation:

Kemp, J., 2014, unpublished. Battle for our birds kea tracking plan 2014-2015. 7pp.

Kemp, J., Orr-Walker, T., Elliott, G., Adams, N., Fraser, J., Roberts, L., Mosen, C., Amey, J., Barrett, B., Makan, T., 2014, unpublished. Benefits to kea (*Nestor notabilis*) populations from invasive mammal control via aerial 1080 baiting. Department of Conservation. 29 pp.

Kemp, J., Cunninghame, F., Barrett, B., Makan, T., Fraser, J., Mosen, C., 2015, unpublished. Effect of an aerial 1080 operation on the productivity of the kea (*Nestor notabilis*) in a West Coast rimu forest. Department of Conservation report. 15 pp.

Kemp, J., Hunter, C., Mosen, C., Elliott, G., 2016, unpublished. Draft: Kea population responses to aerial 1080 treatment in South Island landscapes. Department of Conservation, 14 pp.

Kemp's 2014 kea tracking plan states:

" This year (2014-15) the DOC is gearing up to broadcast 1080 to poison pests over about 500,000 hectares of beech forest inhabited by kea under the Battle for our Birds campaign. These operations are ***approved on the basis*** *that benefit derived to kea from stoat and possum control will outweigh the non target risk..."* (Bold emphasis added.)

The research identifying predators in the remaining internal documents follows.

Kemp *et al.*, 2014:
Predation by stoats was inferred from 5 kea nest visits by stoats, caught on motion-triggered still images outside nests which "assisted in identification of predators." Further details of identification were not provided, instead it is stated "analysis of predator photographs ... is presented elsewhere" (no reference was given). Nests had multiple visits from stoats and other species.

Predation by a stoat was inferred from DNA testing of saliva as the cause of death of one kea in one study, and in another study, 7 kea were inferred to have died due to stoat predation due to the signs "*corpse cached underground*" and/or "*puncture wounds on the skull*". However identifying predators is very difficult (1). The facts that rats as well as stoats cache food (2) and kea may have been dying or dead from other causes, were not considered.

Kemp *et al.* 2015:
This document is discussed in the main text of the current document. The authors stated that their experiment suffered from a lack of replication, non-random assignment of the treatments and non-blind observers (p. 12).

Kemp *et al.* 2016:
Deaths of 20 of 271 kea monitored with radio-harnesses between 1994 and 2015 were assessed against an unexplained binary index of plague or normal stoat numbers assigned to each year of recording. It was claimed the analysis showed survival was substantially lower in plague years. Nine of the 20 deaths occurred in stoat plague years, while 11 of the 20 deaths occurred in normal years.

Outcomes of 164 heavily monitored nesting attempts by kea (of which 77 failed) recorded between 1993 and 2015, were assessed against a three-point yearly predator scale (low, moderate, or high predator year) and it was concluded that nesting success of the monitored birds was inversely related to the predator scale. No scientific basis for the scale was provided but it "*relied largely on seed rain assessments.*"

The authors stated the *"best example"* of aerial 1080 improving productivity of kea and preventing mortality from stoats was the operation at Okarito in 2011 (Kemp et al., 2015 (above), published as Kemp et al., 2018).

Note: Even if stoats *were* a major predator of kea, then research shows poisoning with 1080 is a poor method of controlling them for many reasons, including: highly variable kill rates; stoats are unlikely to be poisoned by preying on rodents, because mice do not normally eat 1080 pellets and alpine areas have very few rats; stoats that remain after poisoning can "prey-switch" to eat more birds than beforehand; and the escalations in rodents which follow 1080 operations are likely to fuel increases in stoat numbers (see (3) for references).

References to Appendix III

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

2 Innes, J. 2005. Ship Rat. Pp. 187-203. In. C.M. King (Ed.). The Handbook of New Zealand Mammals (2nd Edition). Oxford University Press, Melbourne.

3 Pollard, J. Response to the Department of Conservation's reply to "Aerial 1080 poisoning in New Zealand: reasons for concern". https://1080science.co.nz/wp-content/uploads/2017/03/Response-to-DoC.pdf

Appendix IV

EFFECT OF AN AERIAL 1080 OPERATION ON THE PRODUCTIVITY OF THE KEA (*NESTOR NOTABILIS*) IN A WEST COAST RIMU FOREST

Josh Kemp, Francesca Cunninghame, Brent Barrett, Troy Makan, Joseph Fraser, Corey Mosen

June 24, 2015

ABSTRACT

The effectiveness of aerial 1080 as a tool for improving the productivity of the kea (*Nestor notabilis*) was assessed in a lowland rimu (*Dacrydium cuppresinum*) forest on the West Coast of New Zealand's South Island. Rates of nest initiation, nest survival and fledgling production were studied within a before-after-control-impact experiment using a 30,000 hectare 1080 treated forest and adjacent untreated areas. The 1080 operation had a strong and statistically significant effect on kea nest survival. The best two models contained the 1080 effect (coded as a Site x Time interaction), and the 95% confidence intervals around the Site x Time beta estimates did not overlap zero. We used model averaging to estimate kea nest survival with respect to three levels of predators; 1. 43.1% (95% CI = 21.4 - 63.2%) in low-stoat-years without control; 2. 6.7% (95% CI = 0.2 - 31.4%) in high-stoat-years without control and 3. 72.2% (95%CI = 38 - 89.6 %) during the three years post-1080. 58% of adult females nested each year (95% CI = 0.42 - 0.74) and successful nests produced on average 0.9 new fledglings; the aerial 1080 did not affect either of these rates. Kea productivity over the three years post-1080 is calculated to be 3.9 times higher in the 1080-treated area than in the untreated area (0.6 cf. 2.3 fledglings per mature female). We conclude that aerial 1080 can provide a meaningful productivity boost to the kea through the control of nest predators. Repeated operations will be required to sustain this benefit and to avoid unintended consequences of predator control.

INTRODUCTION

The kea (*Nestor notabilis*), a large parrot endemic to the South Island mountain ranges, is Nationally Threatened (Robertson et al. 2012). Evidence is mounting that the persistence of threatened and endangered bird species on mainland New Zealand depends on effective predator control (Wilson et al. 1998, Innes et al. 1999, 2010, Powlesland et al. 2003, Whitehead et al. 2008, Hegg et al. 2013). For sparsely distributed species, such as the kea, predator control must occur over large areas (i.e.>10,000 ha) to encompass a meaningful number of individuals. However, the range of tools available for use over such large areas is very limited. Aerial 1080 frequently ranks highly when considering options for the South Island back country, due to being all-terrain, scaleable, relatively cheap and remarkably reliable.

Aerial 1080 consistently controls populations of the australian brushtail possum (*Trichosurus vulpecula*) (Morgan et al. 2000, Coleman et al. 2007, Nugent et al. 2011). Ship rats (*Rattus rattus*) too are consistently controlled provided that non-toxic pre-baiting is carried out prior to poison baiting (Nugent et al. 2011). A secondary kills of stoats (*Mustela erminea*), via bait-eating vectors such as rodents, has also been reported (Murphy et al. 1999). The aforementioned predators are ubiquitous in kea habitat and are potentially hastening the species' decline. Hence, the use of aerial 1080 may slow or reverse the decline of the kea.

Aerial 1080 usage in forests inhabited by the kea commenced in the 1950s (Livingstone 1994). The extent of use has increased over the years such that about 25% of kea habitat is now under some sort of aerial 1080 regime (DOC Unpublished data). The possum has traditionally been the primary target and hence 1080 return times at sites have usually matched possum repopulation rates (5-8 years). However, aerial 1080 is also registered for the control of rats and has been increasingly used as such since the 1990s (e.g. Innes et al. 1999). Multi-pest control regimes with aerial 1080 on faster return times (e.g. 2-3 yearly), or on mast-driven ones, are now commonplace (e.g. O'Donnell and Hoare 2012). As such, the range of potential beneficiaries has expanded from possum-sensitive plants, land snails and agriculture to include a wide range of rat-sensitive and stoat-sensitive vertebrates and invertebrates.

Weighing against the potential benefits to the kea of aerial 1080 is a level of non-target risk (i.e., death by consumption of poison baits). Non target risk has been identified (Veltman and Westbrooke 2011), though it has varied greatly among aerial 1080 operations from zero to c. 20% (DOC Unpublished data).

The sustainability of the aerial 1080 programme for the kea population obviously requires careful assessment. This requires quantification of the 'costs' and of the 'benefits' to kea populations from aerial 1080. This study presents an experimental test of the hypothesis that benefits to kea populations are accrued via improved productivity following aerial 1080 predator control. Costs are addressed elsewhere.

Methods

Study area

Our study area was located on the West Coast of the South Island, between Paringa and Whataroa, on glacial moraines between the Tasman Sea and the Southern Alps (Figure 1). The forest is dominated by tall emergent rimu trees over a canopy of kamahi (*Weinmannia racemosa*) and southern rata (*Metrosideros umbellata*).

Our study area was split into two sites. The first, which we call 'Okarito', comprises the North Okarito and South Okarito forests plus the forested foothills east of State Highway 6. The site was delineated by the boundaries of a c. 30,000 ha aerial 1080 operation proposed by the DOC and TbFreeNZ. Prior to the start of our study, a stoat trap network was run in South Okarito forest from 2001-2006 (Robertson et al. 2011) and one aerial 1080 operation occurred here in 1998. We considered it likely that residual effect of these would be negligible, which was verified by predator abundance surveys (see results).

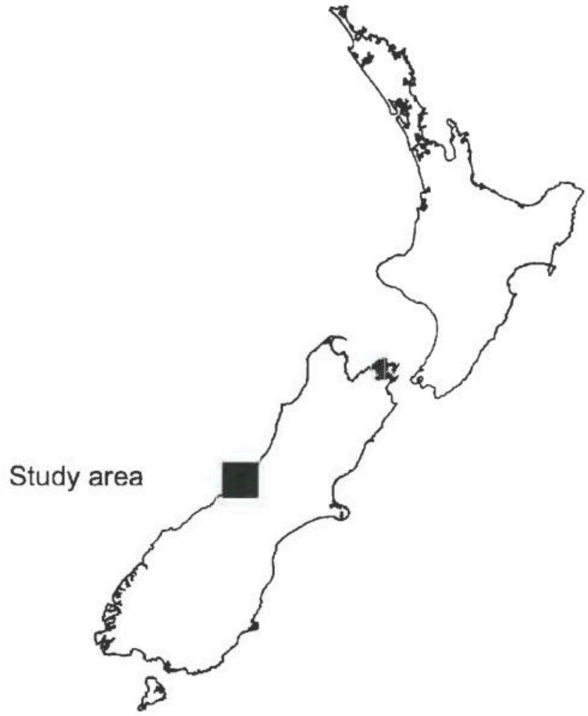

Figure 1. Map showing the location of the study area on the West Coast of South Island.

The Okarito site was treated with aerial 1080 partway through our study period, early in the 2011 kea nesting season, in response to a rimu mast. The rimu mast heralded a potential rat irruption for 2011 and a stoat irruption for 2012. The aerial 1080 covered c. 30,000 hectares of forest and scrub. Pre-baiting with non-toxic cereal pellets (6g pellets spread at 1kg/ha) occurred on August 18, 2011, followed by poison baiting (12g pellets spread at 2kg/ha) on September 4. The poison pellets contained 0.15% active ingredient (wt/wt). All baits, toxic and non-toxic, were laced with cinnamon oil, which supposedly acts as an attractant to possums and rats and a deterrent to birds.

The second site, which we call 'Fox-Paringa', is the bounded by the Fox and Paringa rivers, the Tasman Sea and the Southern alps, excluding the Copland Valley. The site was delineated by the absence of any predator control and the extent of the beech-forest free landscape known as the West Coast beech gap. Fox-Paringa has had no previous aerial 1080, nor stoat trapping, and received none during our study.

Field study of kea productivity commenced at Okarito late in the 2008 kea nesting season and continued until 2013. The Fox-Paringa site was introduced in the 2010 nesting season. From 2009 onward our field seasons commenced in July and ended in about January to cover the kea nesting season.

Predator indexing

The relative abundance of rats, mice and mustelids was indexed quarterly using tracking tunnels (King and Edgar 1977) according to the industry-standard protocol (Gillies and Williams 2013) which generates the Footprint Tracking Index (FTI). Possum relative abundance was measured using the Residual Trap Catch Index (RTCI) with raised sets (NPCA 2011). By these indices we classified rodent and stoat irruption years, assessed the effectiveness of the predator control operation and measured repopulation by rodents and mustelids after control.

Kea productivity measurement

Data on kea productivity was obtained by monitoring of radio-tagged adult female kea, by following radio-tagged male kea to the nests of their untagged mate and by monitoring known nest cavities. We located kea (for radio tagging) by cruising the landscape, intermittently broadcasting recorded kea calls, until kea were seen or heard. Once birds were seen or heard, a catch site was selected on the basis of local features, utilising clearings, slips, and prominent features on which kea might perch such as fallen logs or rock outcrops. The keas were attracted to the catch site by recorded kea calls and lured for capture in nooses and net guns. Stuffed kea decoys were often used to attract kea into nooses. As the study progressed, additional captures were made at previously-known nest sites, sometimes to change an existing radio tag for one with a fresh battery, sometimes to fit a radio tag for the first time.

Radio tags weighed c.24 grams, were purchased from Sirtrack® and Kiwitrack Ltd®, and were fitted using a backpack harness made of 2mm braided nylon (Karl and Clout 1987). The battery life was 38 - 46 months. The harnesses have a biodegradable link, which allows the eventual shedding of the transmitter. Kea were also fitted with a permanent, numbered, stainless steel leg ring, size V. Prior to 2011, coloured metal leg bands were fitted to enable identification of individuals from a distance. In 2011 we switched to dual-colour plastic wraparound Interrex® leg bands engraved with alpha-numeric symbols.

Productivity was calculated as the product of three components: 'Nest Initiation', 'Nest Survival', and 'Fledgling Production' (at successful nests). These parameters were measured as follows.

Nest initiation

We define the nest initiation rate as the proportion of radio tagged adult females observed tending a brood (i.e., seen with eggs or nestlings in a nest cavity) per year. Only those females tagged prior to start of the breeding season were included in our nest initiation sample. The radio tagged females were tracked repeatedly, at intervals of 2-3 weeks, from July to December, to detect the onset of nesting.

To avoid potential bias in the sample of radio tagged adult females we excluded those birds first tagged at known nest sites. That is, females located by the tracking of an adult male to a nest, or through routine checks of previously-used nest cavities, were excluded. If propensity to attempt nesting is not random among adult females, (e.g. nesting in a given year predisposes a female to nest in subsequent years), then inclusion of females captured because they were nesting would result in over-estimation of the nest intitiation rate.

We modelled nest initiation rate using logistic regression in program R (R core development team) using the package lmer (*ref*).

Nest survival

We established a lay date for active nests based on egg counts and/or by cross referencing photos and descriptions of nestlings to a reference collection of known-age nestlings. Nest survival was monitored by repeated visits at intervals of approximately 3 weeks. We considered nest survival as the persistence of at least one egg or nestling to 100 days. We did not consider partial nest failures because we could not distinguish partial predation from natural brood reduction. If the entire brood (eggs or nestlings) was absent at less than 100 days of age, the nest was regarded as failed. This gave a 16 day buffer against misclassification of early-fledged nests (the average nesting period is 116 days). Automatic cameras inside and outside the nest cavity augmented our personal observations. Internal cameras were programmed to take still photographs at 30 minute intervals to detect egg laying and determine dates of fledging or failure. They were not intended to photograph predators. External cameras aimed at the cavity entrances enabled late-stage nest failure to be distinguished from early fledging and assisted in identification of predators. (An analysis of predator photographs taken by automatic cameras at nests is presented elsewhere). Radio tags were fitted to near-full-grown nestlings to monitor their survival after fledging (reported elsewhere) and these assisted in determination of final outcomes of nest attempts.

We modelled the daily nest survival rate (DSR) using the methods of Dinsmore et al. (2002) implemented in program MARK (White and Burnham 1999, Rotella 2009) via the data analysis package RMark (Laake 2013) in program R (R core development team). The DSR approach was chosen because nests were found at various stages (Mayfield 1961). We estimated nest survival as DSR^{116} (116 being the time it takes to raise a brood).

Fledgling production at successful nests

The number of fledglings produced at successful nests was simply counted by observers just prior to fledging. The count was re-confirmed after fledging by radio tracking the fledglings and/or the adults. We modelled fledgling count with respect to aerial 1080 and stoat irruptions using zero-truncated poisson regression in program R using package VGAM (Yee 2010).

Statistical methods

For each of the above analyses, we compiled an *a priori* list of models to express possible combinations of factors affecting the dependent variable. The model sets comprise various combinations of the covariates 'Site' (control/untreated versus impact/treated), 'Time' (before versus after aerial 1080) and 'Stoat Year' (high versus low). Null models included the 'Constant' model, with no covariates, plus other null models such as 'Season' where appropriate.

The level of support for the Site x Time interaction is of key interest because it reflects the implementation of the aerial 1080 predator control operation. We assessed the relative importance of the Site x Time interaction by comparing the models' explanatory power using Akaike's Information Criterion, or AIC (Akaike 1973) corrected for small sample sizes (AICc) (Burnham and Anderson 1998). Models that differed in their AICc by <2.0 were considered to have similar support (Johnson and Omland 2004). The importance of the Site x Time interaction in the models was further assessed by comparing the 95% confidence intervals for the beta coefficients to zero.

RESULTS

Predator indexing

Rat relative abundance increased at both sites during 2011 after the 2011 rimu mast (Figure 2). After the 1080 at Okarito, mustelid relative abundance increased at the untreated site from summer 2011/2012 and remained high through 2013. Thus, we classified the years 2012 and 2013 as High Stoat years in West Coast rimu forests (Table 1, Table 3).

The aerial 1080 at Okarito reduced the relative abundance of rats, mice and mustelids to zero (Figure 2). Mustelids remained near zero for two kea nesting seasons (2011 and 2012), before becoming moderate-high during the third post-1080 nesting season.

Mouse relative abundance at Okarito increased following the 1080 operation and then declined again as rats repopulated. Rats at Fox-Paringa showed a natural post-irruption decline, or crash, during the winter of 2012 and remained low through 2013. In contrast, rat abundance at Okarito increased during 2012 and stabilised at moderate-high levels during 2013.

The possum RTCI at Fox-Paringa was 5.9% (120 trap nights on six transects) in February 2010. At Okarito prior to the 1080 it was 6.3% (240 trap nights on twelve transects, December 2009). These rates are moderate in a New Zealand context, reflecting the relatively infertile soil and dominance of unpalatable species in Westland rimu forests. After aerial 1080 at Okarito, 20 transects (200 trap nights) returned at RTCI of 0.5%, indicating successful control.

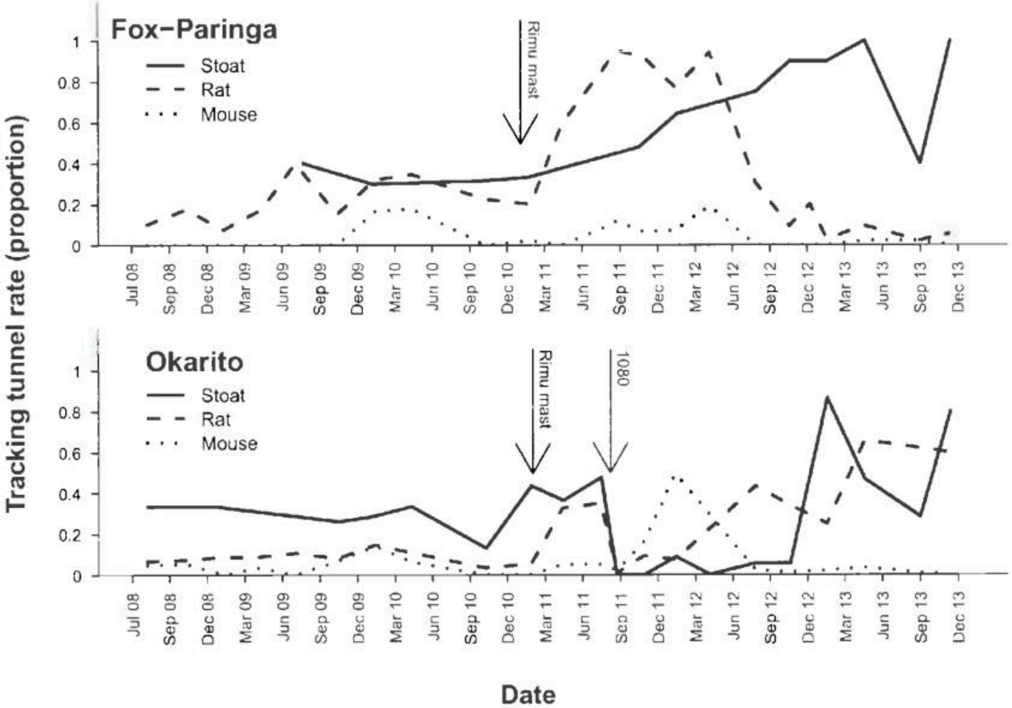

Figure 2. Footprint tracking index (FTI) results for stoats (solid line), rats (dashed line) and mice (dotted line), in the absence of predator control at Fox-Paringa and with an aerial 1080 operation at Okarito. Stoat tracking rates are reported as the proportion of transects with mustelid tracks. Rodent tracking rates are the average proportion of tunnels with rodent tracks.

Nest initiation

A nest initiation dataset of 36 adult-female-radio-years was accumulated (Table 1) from 17 adult female keas. Of the 17 females, 3 were tracked for one nesting season, 10 were tracked for two seasons, 3 were tracked for three seasons and 1 was tracked for four seasons. The variation was due to occasional transmitter harness failure, bird death or unresolved loss of radio signal. The bird tracked for four seasons was recaptured for a second transmitter deployment during a random capture survey. Nest initiation (i.e. evidence of egg-laying) was detected in 21 of the 36 adult-female-radio-years.

Table 1: Number of radio-monitored adult females (n), and the fraction of these detected with an active brood of eggs or nestlings (Nest), by Site (Okarito/Fox-Paringa), Time (Before/After 1080), Season and Stoat year (High = stoat irruption year in West Coast rimu forests). Note: there are no 2013 data due to no adult females qualifying for the sample that year (see methods).

Site	Season	Time	Stoat year	n	Nest
Okarito	2008	Pre	Low	2	1
Okarito	2009	Pre	Low	3	1

Site	Season	Time	Stoat year	n	Nest
Okarito	2010	Pre	Low	7	4
Okarito	2011	Post	Low	7	6
Okarito	2012	Post	High	3	0
FoxParinga	2010	Pre	Low	6	4
FoxParinga	2011	Post	Low	4	3
FoxParinga	2012	Post	High	4	2
Total				36	21

There was no support for an effect of the aerial 1080 on the probability of nest initiation (Table 2). There was weak support for a depressed nest initiation rate during the stoat irruption years, but the 95% confidence interval for the beta parameter spans zero so we do not consider it further. The mean nest initiation rate is 0.58 (95% CI = 0.42 - 0.74).

Table 2: Model ranking and weighting table, using AICc, for competing models of factors affecting the probability of radio tagged adult female kea laying eggs in a given year. Site = Okarito/Fox-Paringa, Time = Before/After 1080, Stoat year = Low/High.

Model	No. parameters	Delta AICc	Model weight
Constant	1	0	0.399
Stoat year	2	1.455	0.193
Site	2	2.195	0.133
Time	2	2.243	0.13
Site + Stoat year	3	3.745	0.061
Time + Stoat year	3	3.828	0.059
Site x Time	4	7.117	0.011
Season	5	7.828	0.008
Site x Time + Stoat year	5	8.978	0.004

Nest survival

A total of 3652 exposure-days of survival data were collected from 60 different nesting attempts (25 at Fox-Paringa and 35 at Okarito)(Table 3). Within this sample, 28 cases of nest failure occurred.

Table 3: Numbers of kea nests, nest failures, and days of nest exposure data obtained in our West Coast study area from 2008-2013.

Site	Season	Stoat year	Nests	Failures	Exposure
Okarito	2008	Low	3	0	155
Okarito	2009	Low	5	3	285
Okarito	2010	Low	7	4	518
Okarito	2011	Low	9	0	791
Okarito	2012	High	7	2	617
Okarito	2013	High	4	1	260.5
FoxParinga	2010	Low	7	4	339
FoxParinga	2011	Low	6	3	358.5
FoxParinga	2012	High	7	7	179.5
FoxParinga	2013	High	5	4	148.5

Site	Season	Stoat year	Nests	Failures	Exposure
Total			60	28	3652

Model selection using AICc revealed a best model containing the aerial 1080 effect (coded as the Site x Time interaction) and Stoat year (Table 4). The 1080 effect was also present in the second-best model (Delta AICc = 1.755) . The Site x Time beta estimate 95% confidence intervals do not overlap zero in either model (Table 4), indicating statistical significance of the 1080 effect. *Likelihood ratio tests could be used here if people would prefer that*

The 'Stoat year' beta estimate confidence interval very slightly overlaps zero (Table 4) and as such warrants further consideration.

Nest survival estimates from the top two models, raised to the power of the nesting period (i.e., DSR^{116}), are shown in Figure 3.

Table 4: Model ranking and AICc model weights for competing models of factors affecting kea nest survival.

Model	No. parameters	Delta AICc	Model weight
Site + Time + Site*Time + Stoat year	5	0	0.387
Site + Time + Site*Time	4	1.755	0.161
Site + Stoat year	3	1.865	0.152
Site	2	2.043	0.139
Site + Time + Stoat year	4	2.58	0.107
Site + Time	3	3.971	0.053
Stoat year	2	15.84	0
Constant	1	15.93	0
Time + Stoat year	3	16.7	0
Time	2	17.9	0

Table 5: Beta coefficients for the two models of kea nest survival containing the 1080 effect (coded as the Site x Time interaction)

Model	Factor	Beta	se	lcl	ucl
Model 1	Intercept	4.52	0.461	3.616	5.423
	Site	0.641	0.589	-0.514	1.796
	Time	-0.126	0.578	-1.259	1.007
	Stoat year	-0.872	0.452	-1.758	0.013
	Site x Time	1.784	0.873	0.072	3.495
Model 2	Intercept	4.384	0.45	3.502	5.266
	Site	0.672	0.589	-0.482	1.825
	Time	-0.535	0.531	-1.576	0.505
	Site x Time	1.71	0.872	0.001	3.418

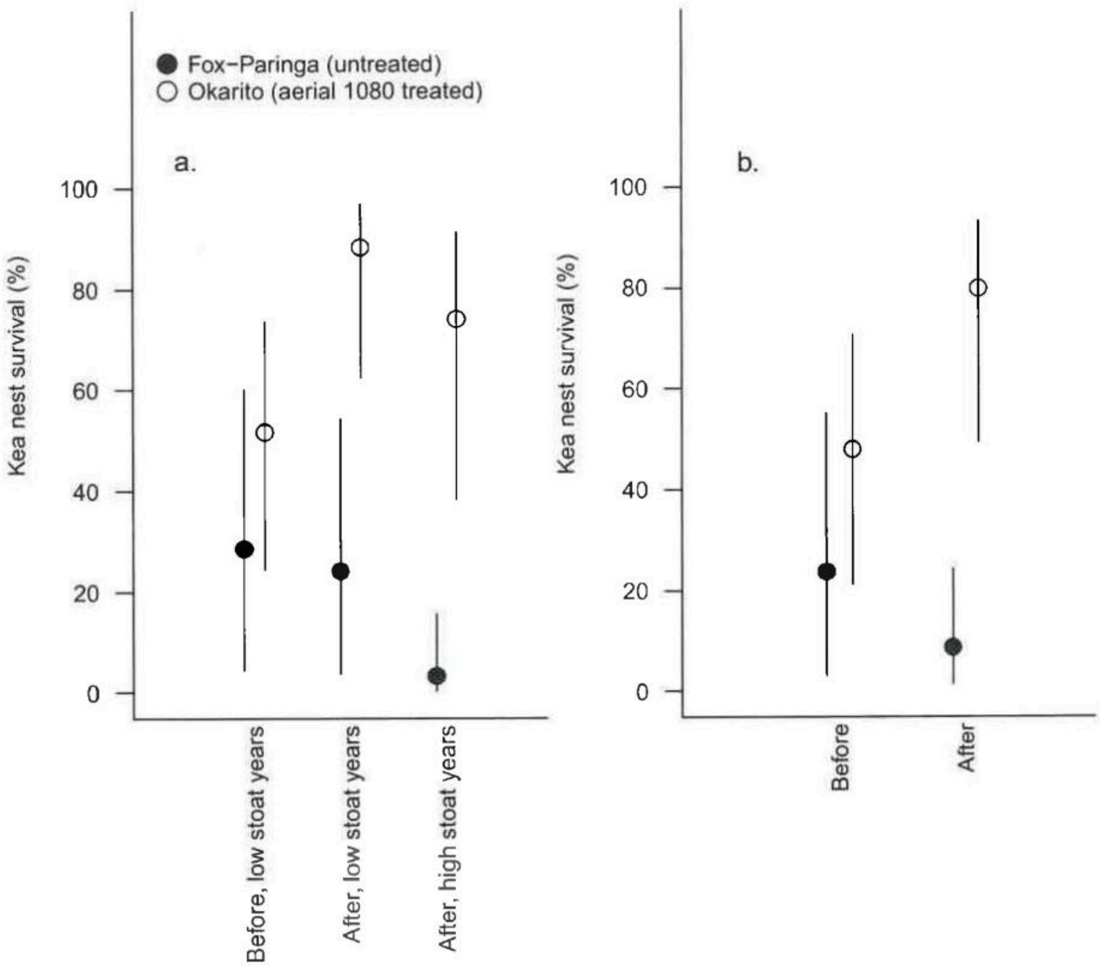

Figure 3. Estimated kea nest survival from the two models containing the aerial 1080 effect (a. = Model 1, b = Model 2). Error bars are 95% confidence intervals.

Fledgling count

We made accurate fledgling counts at fledging time (i.e. day 116) for 0 successful broods (Table 6).

Table 6: Numbers of 116 day old kea chicks fledged from 31 successful nests in our West Coast study area from 2008-2013.

NestID	Site	Season	Time	Mast	nfledged
1	Okarito	2008	Before	0	1
2	Okarito	2008	Before	0	1
3	Okarito	2008	Before	0	2
4	Okarito	2009	Before	0	2
5	Okarito	2009	Before	0	2

NestID	Site	Season	Time	Mast	nfledged
6	Okarito	2010	Before	0	2
7	Okarito	2010	Before	0	1
8	Okarito	2010	Before	0	2
9	Okarito	2011	After	1	2
10	Okarito	2011	After	1	1
11	Okarito	2011	After	1	1
12	Okarito	2011	After	1	1
13	Okarito	2011	After	1	1
14	Okarito	2011	After	1	2
15	Okarito	2011	After	1	2
16	Okarito	2011	After	1	3
17	Okarito	2011	After	1	2
18	Okarito	2012	After	0	2
19	Okarito	2012	After	0	4
20	Okarito	2012	After	0	2
21	Okarito	2012	After	0	2
22	Okarito	2012	After	0	2
23	Okarito	2013	After	0	2
24	Okarito	2013	After	0	2
25	FoxParinga	2010	Before	0	1
26	FoxParinga	2010	Before	0	1
27	FoxParinga	2010	Before	0	2
28	FoxParinga	2011	After	1	2
29	FoxParinga	2011	After	1	3
30	FoxParinga	2011	After	1	1
31	FoxParinga	2013	After	0	2

Models of fledgling production containing the 1080 effect (coded as the Site x Time interaction) ranked lowly (Table 7) and Likelihood Ratio Tests comparing the two models with the effect against the two nested models without it gave p=0.5793 and p=0.5244, respectively.

The Constant model ranked top and the Time (Before/After 1080) model was competitive (Table 7). Under the Time model, fledgling production was higher after the 1080 drop. This model is somewhat confounded with the 1080 effect because very few nests fledged at Fox-Paringa during the 'After' period (Table 6).

Table 7: Model ranking and AICc model weights for competing models of factors affecting the number of fledglings produced at successful nests.

	No. parameters	Delta AICc	Model weight
Constant	1	0	0.3803
Time	2	0.9698	0.2342
Site	2	2.206	0.1262
Mast	2	2.224	0.1251
Site + Time	3	3.391	0.0698
Mast + Site + Time	4	5.034	0.0307
Site x Time	4	5.733	0.02164
Mast + Site x Time	5	7.49	0.00899
Season	6	9.988	0.002579
Site + Season	7	13.34	0.0004824

The mean fledgling count was 1.81. The mode was two fledglings (0.58%), followed by one (32%), three (6%) and four (3%).

Overall kea productivity

According to our results, aerial 1080 and stoat irruptions influence kea productivity via effects on nest survival. For the purpose of estimating the 1080 effect on productivity, we used model averaging to generate three estimates of nest survival, respectively, for 1) untreated low-stoat years, 2) untreated high-stoat years and 3) years following 1080 (Table 8).

We then calculate three annual productivity rates using the three nest survival rates whilst maintaining constant nest initiation rates and fledgling counts. The resultant productivity rates are 0.45, 0.07, and 0.76 female fledglings per adult female per year for the three year types, respectively (Table 8).

Table 8: Productivity estimates for three categories of predator conditions. The 'Treated' category includes nests from Okarito over three years after the aerial 1080.

Conditions	Nest.init	Nest.surv	n.Chicks	Productivity
Untreated low stoats	0.58	0.431	1.81	0.45
Untreated high stoats	0.58	0.067	1.81	0.07
Treated	0.58	0.722	1.81	0.76

Kea productivity during the three breeding seasons after the rimu mast can thus be estimated as the sum of the three applicable productivity rates. For untreated Fox-Paringa, this is $0.45 + 0.07 + 0.07 = 0.59$ fledglings per adult female. For 1080-treated Okarito it was $0.76 + 0.76 + 0.76 = 2.28$ fledglings per adult female.

The aerial 1080 operation, therefore, provided a 3.9 -fold boost ($2.28/0.59= 3.9$) to the productivity of keas over three years.

Discussion

Effect of 1080 operation on kea productivity

Our study leaves little doubt that the aerial 1080 at Okarito in spring 2011 caused a substantial increase in kea productivity, via a large increase in nest survival. Our nest survival result is consistent with previous studies of other large New Zealand birds, the kaka, kokako, kereru and whio, for which nest survival increased from very low levels without predator control to moderate or high levels with it (Innes et al. 1999, 2004, Moorhouse et al. 2003, Whitehead et al. 2008).

We attribute the effect to the successful control of mammalian nest predators, as indicated by the footprint tracking index for rodents and mustelids and the residual trap catch index for possums. The same conclusions were reached for the other large New Zealand birds mentioned above (Innes et al. 1999, 2004, Moorhouse et al. 2003, Whitehead et al. 2008). This conclusion is consistent with Innes [@-Innes2010] that bird populations in unmanaged New Zealand forests are primarily limited by predation rather than food.

The relative importance of controlling stoats versus possums in our results cannot be distinguished here due to their concurrent (i.e.,confounded) control. However, a high importance of stoats as nest predators is highlighted by the large drop in kea nest survival at our untreated site when stoats rose to peak levels. Hence, we attribute a large part of the 1080 effect to the successful control of stoats via secondary poisoning. Rats appear to be relatively unimportant predators of kea nests - nest survival remained moderate at Fox-Paringa while rat tracking rates were very high. This result is consistent with previous studies of the kaka [Beggs and Wilson (1991);Wilson1998;Moorhouse2003;Powlesland2003] and the whio (Whitehead et al. 2008), but rats were also found to be important predators of kokako and kereru nests (Innes and Barker 1999, Innes et al. 2004). This may simply be a function of the size of the birds, or perhaps due to habitat differences as the kokako and kereru studies occurred in North Island podocarp-broadleaf forests.

Experimental studies of large forest birds in which aerial 1080 was the sole predator control tool are surprisingly rare given the predominance of 1080-only regimes. Thus, this paper represents a major contribution to our understanding of benefits from aerial 1080 use.

From aerial 1080-only, the kaka showed improved nest survival for one season (Greene et al. 2004) but stoats reinvaded quickly such that no benefits were evident a year later. Repopulation of the Okarito 1080 area by stoats was much slower than this in our study and thus keas enjoyed a prolonged period of boosted nest survival. The third season of high kea nest survival after the 1080 was surprising to us, given that the mustelid FTI had returned to moderate-high levels. However, the rat FTI was also elevated at this time, perhaps providing an easier food source for the stoats (Murphy et al. 1998).

Another 1080-kaka study detected no benefit due to poor timing of the operation with respect to kaka's trait of breeding only in mast seasons (Powlesland et al. 2003). Our finding that kea breeding effort was consistent among years suggests that timing with respect to mast may not be an issue in terms of coinciding with kea breeding effort.

Experimental design

The main shortcomings of our study were a lack of replication, non-random assignment of the 1080 treatment among blocks and non-blind observers. An attempt was made to replicate the study in an upland beech forest in Kahurangi National Park, but the physical difficulties associated with working in the mountains prevented the collection of a dataset sufficient for a BACI analysis. A beech forest replicate is unlikely to occur in the future, but measurement of kea productivity has occurred at three beech forested National Parks for which predator density can be crudely indexed according to masting and predator control. The results from beech forests will be presented, and compared to this rimu forest study, elsewhere. Non-random assignment of treatment was an artefact of utilizing a predator control operation implemented for other reasons, namely the protection of forest values and management of disease-vector populations at a priority site. Having 'blind' observers is not really possible under these conditions, as 1080 baiting operations are very obvious events.

Methodological considerations

Estimating kea productivity as a product of three components has pros and cons. Our estimate of nest initiation rates, for example, is bound to be an under-estimate as some nests will have failed between searches. This will have been compensated for, in general, by the over-estimation of nest survival rates due to non-inclusion of these early failed nests. However, if nest survival becomes very high after 1080, as we observed, then the benefits of aerial 1080 will be greater if nest initiation rates are in fact higher than we estimated. Modellers and managers should consider this when attempting to balance the non-target costs of 1080 with benefits to productivity.

Stoat control with 1080

Stoats die when 1080 is used because they eat poisoned animals such as rodents and possums (Murphy et al. 1999, Alterio 2000). We did not specifically seek to identify the primary transmission agents at Okarito, but we suspect that ship rats were the main transmittor of toxin to stoats due to their importance in stoat diet when available. Ship rats were widespread and moderately abundant at the time of baiting, with presence on 18/21 footprint tracking transects and an average of 3/10 tunnels tracked per transect. We caution against extrapolating our stoat kill result to different contexts until further study is undertaken on the effect of variation in vector/transmission-agent composition on stoat kills. For example, very low rodent abundance occurred at Okarito for several years before 2011 and also at Fox-Paringa after the post-mast crash, in what appears to be a fashion very similar to that observed over the masting cycle in upland beech forests (King and Moller 1997). Whether aerial 1080 during these inter mast rodent lows delivers benefits to kea remains a question in need of an answer.

The aerial 1080 appears to have altered the medium-term ship rat carrying capacity of Okarito forest. While a high peak in tracking rates was averted (cf. Fox-Paringa, Figure 2), the dramatic post-peak crash at Fox-Paringa did not occur at Okarito. Instead, after taking 12 months to recover from zero to moderate after the 1080, Okarito rat tracking rates remained at moderate levels. This has important implications for management; 1) A repeat 1080 operation after three years would probably result in a repeat high stoat kill and thus another three years of improved kea productivity, 2) Failure to deliver a repeat 1080 operation will probably result in the negation of any benefits that may have accrued to rat-sensitive species such as bush robin and yellow-crowned kakariki in the area. We recommend, therefore, that when aerial 1080 is used in rimu forests it is done on the basis of a medium-term plan to re-bait every three years on average, with flexibility to move operations forward or back depending on when masts occur, provided that analysis incorporating non-target risk estimates indicates a strong likelihood if a net benefit to kea populations.

Conclusions

1) Aerial 1080 can provide a significant boost to kea productivity for three years.
2) Kea productivity is very low during uncontrolled stoat irruptions in rimu forest.
3) Aerial 1080 over a large scale in a mast year can prevent a stoat irruption occurring in the following year.
4) Aerial 1080 in lowland rimu forests alters the dynamics of the small mammal community.

Recommendations

4) Repeat operations be implemented to ensure that benefits of 1080 are sustained and unintended consequences are avoided.
5) The applicability of our results to beech forest habitats is investigated.
6) The effect of rodent abundance on the degree of stoat control requires is investigated.

Acknowledgements

This research was funded by the Department of Conservation and the Animal Health Board (now TbFreeNZ, OSPRI NZ). We also thank those who contributed to collection of field data: Dan Palmer, Vanessa Smith, Kirsty Moran, Paul van Klink. We thank the staff of the Franz-Josef *Waiau* and Fox Glacier *Weheka* offices of the Department of Conservation for their support with the field programme. We thank Susan Timmins, Jeff Flavell, Allan Ross, Nic Hancox, Penny Fairweather and Paul Livingstone for managerial support and input throughout the project. Thanks also to Christine Hunter and Graeme Elliott for statistical advice and valuable comments on draft manuscripts.

References

Alterio, N. 2000. Controlling small mammal predators using sodium monofluroacetate (1080) in bait stations along forestry roads in a new zealand beech forest. New Zealand Journal of Ecology 24:3–9.

Beggs, J., and P. Wilson. 1991. The kaka nestor meridionalis, a new zealand parrot endangered by introduced wasps and mammals. Biological Conservation 56:23–38.

Coleman, J. D., K. W. Fraser, and G. Nugent. 2007. Costs and benefits of pre-feeding for possum control. New Zealand Journal of Zoology 34:185–193.

Dinsmore, S., G. White, and L. Fritz. 2002. Advanced techniques for modeling avian nest survival. Ecology 8:3476–3488.

Gillies, C., and D. Williams. 2013. DOC tracking tunnel guide v 2.5.2: Using tracking tunnels to monitor rodents and mustelids.

Greene, T., R. Powlesland, P. Dilks, and L. Moran. 2004. Research summary and options for conservation of kaka (nestor meridionalis). DOC Science Internal Series 178.

Hegg, D., D. I. MacKenzie, and I. Jamieson. 2013. Use of bayesian population viability analysis to assess multiple management decisions in the recovery programme for the endangered takahe porphyrio hochstetteri. Oryx 47:144–152.

Innes, J., and G. Barker. 1999. Ecological consequences of toxin use for mammalian pest control in new zealand - an overview. New Zealand Journal of Ecology 23:111–127.

Innes, J., R. Hay, I. Flux, P. Bradfield, H. Speed, and P. Jansen. 1999. Successful recovery of north island kokako (callaeas cinerea wilsoni) populations, by adaptive management. Biological Conservation 87:201–214.

Innes, J., D. Kelly, J. M. Overton, and C. A. Gillies. 2010. Predation and other factors currently limiting new zealand forest birds. New Zealand Journal of Ecology 34:86–114.

Innes, J., G. Nugent, K. Prime, and E. B. Spurr. 2004. Responses of kukupa (hemiphaga novaeseelandiae) and other birds to mammal pest control at motatau, northland. New Zealand Journal of Ecology 28:73–81.

Karl, B., and M. N. Clout. 1987. An improved radio transmitter harness with a weak link to prevent snagging. Journal of Field Ornithology 58:73–77.

King, C. M., and R. Edgar. 1977. Techinques for trapping and tracking stoats (mustela erminea); a review, and a new system. New Zealand Journal of Zoology 4:193–212.

Laake, J. 2013. RMark: An r interface for analysis of capture-recapture data with MARK. AFSC Processed Report 2013-01, Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. SErv., 7600 Sand Point Way, NE, Seattle WA 98115. P.25.

Livingstone, P. 1994. The use of 1080 in new zealand. The Royal Society of New Zealand Miscellaneous Series Proceedings of the Science Workshop on 1080:1–9.

Mayfield, H. 1961. Nesting success calculated from exposure. Wilson Bulletin 73:255–261.

Moorhouse, R., T. Greene, P. Dilks, R. Powlesland, L. Moran, G. Taylor, A. Jones, J. Knegtmans, D. Wills, M. Pryde, I. Fraser, A. August, and C. August. 2003. Control of introduced mammalian predators improves kaka nestor meridionalis breeding success: Reversing the decline of a threatened new zealand parrot. Biological Conservation 110:33–44.

Morgan, D. R., J. D. Coleman, and P. Sweetapple. 2000. Effectiveness of aerial baiting of possums in different seasons and different forest types. Science for Conservation 152.

Murphy, E., B. Clapperton, P. Bradfield, and H. Speed. 1998. Effects of rat-poisoning operations on abundance and diet of mustelids in new zealand forests. New Zealand Journal of Zoology 25:315–328.

Murphy, E., L. Robbins, J. Young, and J. Dowding. 1999. Secondary poisoning of stoats after an aerial 1080 poison operation in pureora forest, new zealand. New Zealand Journal of Ecology 23:175–182.

NPCA. 2011. Possum population monitoring using the trap-catch method.

Nugent, G., B. Warburton, C. Thomson, P. Sweetapple, and W. Ruscoe. 2011. Effect of prefeeding, sowing rate and sowing pattern on efficacy of aerial 1080 poisoning of small-mammal pests in new zealand. Wildlife Research 38:249–259.

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

Powlesland, R., D. Wills, A. August, and C. August. 2003. Effects of a 1080 operation on kaka and kereru survival and nesting success, whirinaki forest park. New Zealand Journal of Ecology 27:125–137.

Robertson, H., R. Colbourne, P. Graham, P. J. Milller, and R. Pierce. 2011. Experimental management of brown kiwi apteryx mantelli in central northland, new zealand. Bird Conservation International.

Robertson, H., J. Dowding, G. Elliott, R. Hitchmough, C. Miskelly, C. O'Donnell, R. Powlesland, P. Sagar, R. Scofield, and G. Taylor. 2012. Conservation status of new zealand birds. Department of Conservation, Wellington.

Rotella, J. 2009. Nest survival models. *in* E. C. &. G. White, editor. Program MARK. analysis of data from marked individuals. "a gentle introduction". 3rd editions.

Veltman, C., and I. M. Westbrooke. 2011. Forest bird mortality and baiting practises in new zealand aerial 1080 operations from 1986 to 2009. New Zealand Journal of Ecology 35:21–29.

White, G., and K. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46:120–139.

Whitehead, A., K.-A. Edge, A. Smart, G. Hill, and M. Willans. 2008. Large scale predator control improves the productivity of a rare new zealand riverine duck. Biological Conservation 141:2784–2794.

Wilson, P., B. Karl, R. Toft, J. Beggs, and R. Taylor. 1998. The role of introduced predators and competitors in the decline of kaka (nestor meridionalis) populations in new zealand. Biological Conservation 83:175–185.

Yee, T. 2010. The VGAM package for categorical data analysis. Journal of Statistical Software 32:1–34.

W. F. Benfield

THE THIRD WAVE

Poisoning the Land

Tross Publishing

WELLINGTON

NEW ZEALAND

greatest threat to the bat after habitat loss. Former forestry workers have claimed that many dead bats are often found along bush margins after 1080 operations.

A case study of the kea would be an interesting example of what is going on in the forest and the official response to it.

Kea belong to a group of birds, such as paradise ducks and pukeko, that had prospered with the coming of European agriculture. Cheeky and very intelligent, they were soon fossicking round the newly established high country stations in the South Island looking for opportunities. They soon found them in the form of sheep and, although some have claimed it a myth that kea attack sheep, they have been photographed lodging themselves on the back of healthy animals and digging into the live flesh to reach the fat round the kidneys. (12) This was not appreciated at all by the run-holders and it was not long before there was a bounty on kea; it was two shillings and sixpence a beak when I was a lad, and eight to ten beaks would cover a boy's weekly wage in 1956. The bounty was not lifted until 1971 but in the years before that it is estimated that the bounty was paid out on about 150,000 birds, (13) but that would not have included the many more kea that run holders would have shot, trapped or poisoned and never submitted a claim for, being just being glad to be rid of the "feathered wolf". Despite that, kea were still common; we used stay at a fishing hut on the shores of Lake Pearson and soon after we arrived a couple of curious kea would always show up to check out the possibilities. At that time, with the bounty in place and no protection on the kea, the bounty "harvest" alone would have amounted to at least 1,500, possibly 2,000 birds a year, plus what others the farmers shot and left. Despite that, at the time it was thought that their numbers were on the increase.

Kea were not finally totally protected until 1985 but since then their population has gone into a dramatic decline. So, what happened to the kea? Why the huge decline? Though DoC has claimed predation by possum and stoats, I think that herbivore possum is a joke while stoats are a possibility, though the kea is a large, well armed, powerful bird and a predator itself to boot, so only its chicks would be at risk. But there were stoats (and cats) around when the kea population was on the increase.(14) I don't think that is the cause of their decline. In 2009, some kea corpses found near Mt Cook were analysed and found to contain lead. DoC immediately blamed lead headed nails on tramping club huts. DoC even claimed that kea found lead sweet.(15) But again, there were lead headed nails around when kea were not declining. It is possible a new source of lead could be responsible, viz. DoC's animal control operations against chamois and tahr. They use shotguns from helicopters for search and destroy operations, the animals are shot from above and so any lead shot will be right over the kidneys, the area of the body that kea target.

Still, a kea or two succumbing to lead poisoning is not thousands because a population which was increasing despite the culling of around 1,500 to 2,000 birds a year means there is now a massive loss going on somewhere. I think Spurr put his finger on it in his "A theoretical assessment of the ability of bird species to recover from an imposed reduction in numbers, with particular reference to 1080 poisoning." (16) The kea is in the group at high risk of extinction from the use of 1080! Plus its range is subject to two methods of poisoning, either by 1080 bait stations for wasps, or aerial 1080 for all other species. As there was no monitoring of kea populations during wasp control operations we do not know what impact they have had. All you can be sure of is that a bait station would be no great challenge to a kea, and it was around the time of wasp control operations that kea decline was becoming apparent. Just how vulnerable kea are to the latter is demonstrated by a single poison drop in the Franz Josef area of the West Coast. In this case, 17 kea had been fitted with radio tags and a short time later (Feb 2008) an aerial 1080 operation was carried out "targeting possum". It also killed 7 of the radio tagged kea, or 41% of that population. Apply that level of loss across the whole population and the reason for kea decline becomes clear. Continue for a few more poisoning cycles and kea may well be extinct; no slow breeding population can sustain those losses. Not to be put off, DoC are now investigating a "kea repellent" to put on their baits, so that they can continue poisoning. What will repel a curious bird, that finds anything from rotting meat, to yogurt, windscreen wipers, fruit and vegetables fascinating?

Although the Japanese whaling activities may be cruel and unnecessary, they are unlikely to drive the whales to extinction. DoC activities are just as cruel and a good case can be made that they are also unnecessary but DoC and the AHB are, unlike the Japanese in the Southern Ocean, likely to drive rare and endangered wildlife to extinction.