Eradication of red deer from Secretary Island, New Zealand: changing tactics to achieve success

N. Macdonald[1], G. Nugent[2], K-A. Edge[3] and J.P. Parkes[4]

[1]Department of Conservation, PO Box 743, Invercargill 9840 <nmacdonald@doc.govt.nz>. [2]Landcare Research, PO Box 69040, Lincoln 7640, NZ. [3]Edge-Effect, 48 Bligh St., Te Anau, NZ. [4]Kurahaupo Consulting, 2 Ashdale Lane, Christchurch, NZ.

Abstract Red deer (*Cervus elaphus*) established on 8,140 ha Secretary Island after swimming from the mainland in the early 1960s. Attempts to remove them began in the 1970s and after several starts and stops they were eradicated in late 2014. Since late 2006, 688 deer have been removed. Ground hunters killed 365 deer in 1,827 hunter-days, 320 deer were shot from helicopters in 211 flying-hours, two deer were trapped and one was known to have been killed by a fisherman. The campaign since 2006 was planned in three phases – an initial population reduction, a mop-up phase and a surveillance and rapid response to any new immigration phase. An initial reduction of 80% of the population, between 530 and 550 in 2006, was planned and achieved in the first two years. The removal of surviving deer was planned to take a further four years but despite 114 being shot and probably less than 14 deer remaining in 2013 eradication was not achieved using the methods that succeeded in the initial phase. The change in tactics in 2014 that allowed for eradication was to (a) ground survey the island and use camera traps to locate areas with deer, (b) identify individual deer from faecal DNA to estimate numbers, know when they were shot or still alive, and to estimate potential new immigration from the mainland – which was low, and (c) move from individual hunters seeking any deer within a widespread population, when about 10% of hunter-deer encounters led to a kill, to re-train hunters as teams using GPS/radio systems and integrate them with aerial hunting to seek individual deer at known locations, when 100% of encounters led to a kill. The change of tactics that led to eradication success required about half the costs, i.e. $25,000 to $10,500 per deer direct operational costs, expected if no change had been made.

Keywords: aerial hunting, catch-per-unit-effort, density, faecal DNA profiles, ground hunting, operational costs, World Heritage Area

INTRODUCTION

There are few published examples of successful deer eradication campaigns in the world. This is mostly because deer are generally valued as resources rather than as pests but, in New Zealand, red deer are an introduced species so there is interest in completely removing deer from some places in order to protect the native biota (Parkes & Murphy, 2003). Here we document a prolonged but ultimately successful campaign to remove deer from a large island in south-western New Zealand.

Secretary Island covers 8,140 ha and rises to 1,196 m a.s.l. at 45°14' S 166°55' E in Fiordland National Park, part of Te Wahi Pounamu South-west New Zealand World Heritage Area (Fig. 1). Red deer (*Cervus elaphus*) swam to Secretary Island from the mainland in the early 1960s (Mark & Baylis, 1975; Crouchley, et al., 2007) across a sea gap of at least 630 m. A population established and their impact on the pristine native forests was severe and rapid (Mark & Baylis, 1975; Mark, et al., 1991) so in the 1970s, New Zealand Forest Service attempted, unsuccessfully, to remove the deer (Tustin, 1977). However, in the early 2000s, the New Zealand Department of Conservation (DOC) initiated a new campaign (Brown, 2005; Crouchley, et al., 2007) that began in earnest in late 2006. This second eradication attempt was itself reassessed by DOC once the population had been reduced to very low numbers (estimated at 14 individuals) in 2012/13, resulting in changes in strategy and operational tactics that eventually led to successful eradication of the deer. In this paper, we briefly reiterate the results presented in early reports and in the second Island Invasives conference for the first eradication attempt, and update the results from the initial reduction phase (Crouchley, et al., 2011; Edge, et al., 2011). We then focus on the new data to report on the change in strategy and tactics to remove the last few deer from the island and compare the predictions of a catch-per-unit-effort (CPUE) model produced in 2012 (Nugent & Arienti-Latham, 2012) with the actual outcomes of the deer control during the final phase of the project.

MAIN FINDINGS

First eradication attempt: 1970–1989

Ground and aerial hunting began in the early 1970s and although 250 deer were reported as killed by the New Zealand Forest Service between 1970 and 1985 (Brown, 2005) the population, in the presence of abundant food (Mark & Baylis, 1975), continued to increase. Tustin (1977) guessed about 200 deer were present in 1975. A poisoning technique (1080 gel smeared on the leaves of deer-preferred plants; see Parkes, 1983) was trialled from 1975 to1987 (when 10% of the island was poisoned) but informal track and pellet counts suggested efficacy was moderate at best (Brown, 2005). The abundance of preferred food species and a perception that the difficult terrain on Secretary Island restricted ground access (later disproved when hunters covered the whole island to survey for surviving deer) were likely reasons this trial did not lead to eradication of the deer. In contrast, in an area on Stewart Island, where white-tailed deer (*Odocoileus virgineanus*) had removed most palatable food plants and accessibility to people was not difficult, the 1080-gel technique removed close to 100% of the population of deer in the treated area (Nugent, 1990). The best control methods depend on context, showing that successful precedent does not supply a recipe for new projects.

By the early 1980s it was concluded that neither hunting nor the 1080-gel method could remove all deer, so the policy shifted in 1985 to one of sustained control to low residual densities (Sanson & von Tunzelman, 1985). By 1989, official deer control on the island was halted because of budget constraints and the expectation that reinvasion would always compromise the project (W. Chisholm, 1989, unpubl. DOC Invercargill file ANI 4/6). Deer were still shot on Secretary Island by commercial venison recovery helicopter operators. However, the goals of restoring the island's ecosystems by controlling deer and stoats were

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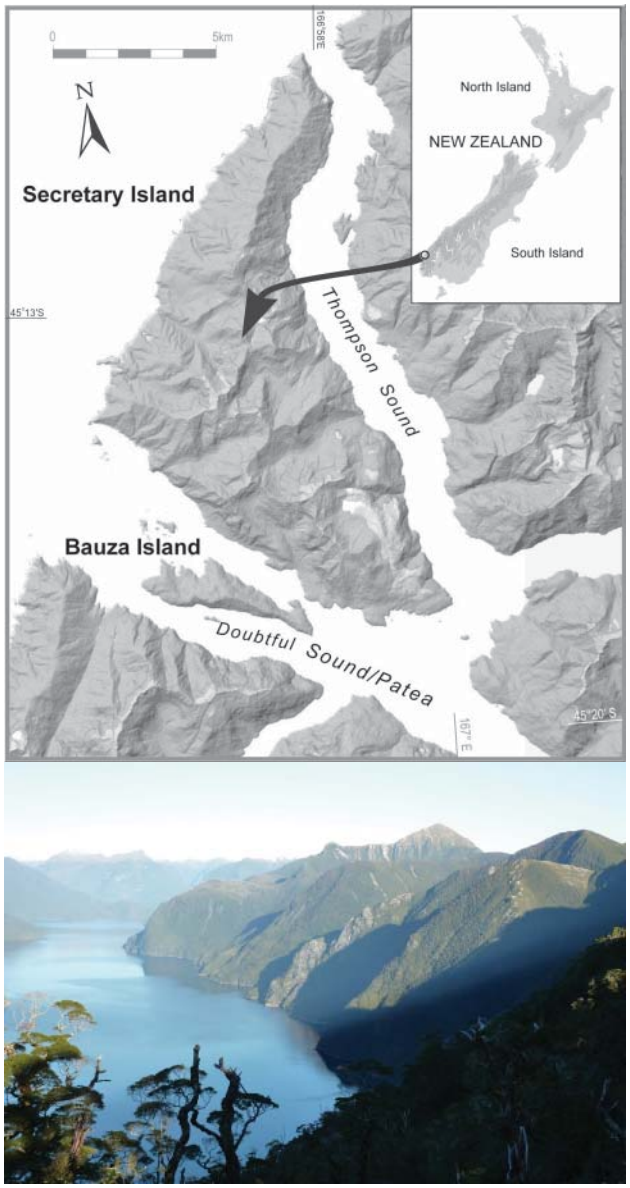

Fig. 1 Secretary Island, Fiordland National Park, New Zealand (photo L. Wilson).

not forgotten (Munn, 2001) and in the early 2000s a new eradication project was proposed (Brown, 2005) with a formal operational plan developed in 2007 (Crouchley, et al., 2007).

Second eradication attempt: November 2006–April 2013

A new decision to attempt eradication of red deer (and also stoats (*Mustela erminea*)) from Secretary Island and nearby Resolution Island (21,000 ha) was proposed in 2004 and a budget of NZ$7.1 million was allocated (Edge, et al., 2011). This second attempt adopted a more strategic approach, aiming to reduce the population by 80% within two years, then remove survivors within four years, and subsequently detect and remove any new immigrants in perpetuity (Crouchley, et al., 2011). It was expected that the initial knockdown would rely on two main methods (ground hunting with indicator dogs and helicopter shooting) but that a variety of 'niche' control methods (17 capture pens, fences, the use of telemetered deer) would probably be required during the 'mop-up' phase (Crouchley, et al., 2011). The ground hunting involved hunters (and their dogs) operating individually from nine huts across the island, so each hunter covered different areas in each hunting period (usually about nine days) with hunters often swapping areas between hunting periods (see Crouchley, et al. (2011) for a detailed description of the hunting and other methods). Aerial and ground hunting began in November 2006.

The 'rapid knockdown' aim was effectively met as 84% of the total deer killed were shot within three years (by the end of 2009). We estimated that hunters operating individually killed only about 10% of deer they 'encountered', i.e. seen, heard or known to be in the area being hunted from fresh sign. There was little motivation to persist with hunting a particular deer that escaped when there were plenty of other deer in the area being hunted. However, the aim to eradicate the population by the end of 2012 was not met as deer were still present. In retrospect, 98% of the final tally had been killed by then, but not the 100% required for eradication.

Final push: January 2014–August 2014

Failure to eradicate by 2012 (Fig. 2) led to a hiatus in activity while the strategy and tactics being used for the 'mop-up' phase were reconsidered. The surviving deer were extremely wary and could detect and escape hunters (with dogs) operating as individuals and were avoiding the open grasslands where they would be most vulnerable to aerial shooting. The Department of Conservation had no novel control tools to add to the mix it had already used so decided that they had to apply ground and aerial hunting in a different way to counter these learnt avoidance behaviours of the deer. A decision was made to shift from individual hunting to team hunting informed by all available information. To some extent this was informed by the experience of the new project manager (the senior author) who with a private company (Prohunt Ltd, now Native Range Ltd) had recently achieved eradication of feral pigs (*Sus scrofa*) from Santa Cruz Island (Parkes, et al., 2010). Technological advances available in the final phases of the Secretary Island project included the use of hand-held GPS and radios that allowed immediate contact and location details to be shared between hunters, high definition remote trail cameras, and the ability to identify individual deer from DNA in faecal pellets.

The first step, in February 2013, under the revised strategy, was to use hunters with indicator dogs to search the whole island from ridge tops to the sea along transects about 200 m apart for sign of deer. Analysis of the DNA in the mucus layer of fresh (i.e. moist with unbroken exterior estimated to be only a few day's old) faecal pellets (see Ramón-Laca, et al., 2014 for details of the methods; such

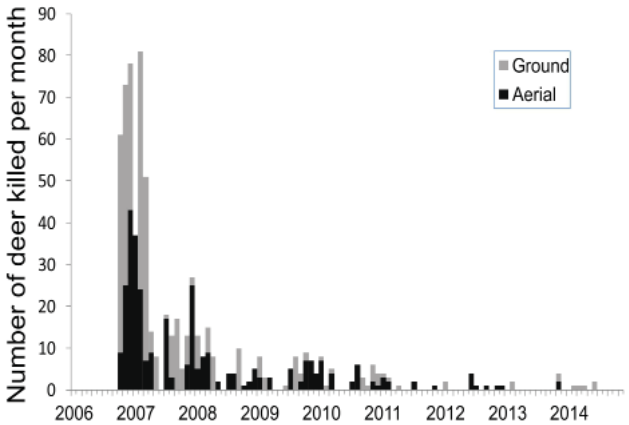

Fig. 2 Monthly kills of red deer on Secretary Island between the start of the second eradication campaign in late 2006 and the last deer killed in August 2014.

analyses currently cost about NZ$90 per sample depending on sample size) found during this survey allowed individual deer to be identified and the area in which they lived to be located. The whole-island sign survey suggested that possibly 14 deer remained at the end of April 2013 (Macdonald, 2013). The second step, in late 2013, was to select and train the hunters in the skills (and attitudes) required for a team hunting and targeting individual deer. The logic of this change in hunting method depended on (a) identifying from ground surveys for sign roughly where a targeted survivor was living, (b) using a helicopter to place a team of hunters at key exit points around that location, (c) then deploying the best hunter-and-dog teams in the suspected range of the deer to attempt to find and kill it, (d) and, where that failed and the deer also avoided the perimeter hunters, to then use the dog to track the deer and the helicopter to either relocate the perimeter ambushers or to shoot the deer if it became visible.

As hunting under a new strategy proceeded and the DNA taken from shot animals was compared with DNA found in an ongoing collection of faecal pellets it was estimated that only eight deer remained by the end of 2013. Deployment of 13 trail cameras at key sites around the island combined with ongoing DNA sampling did not identify any new 'unknown' deer at this stage of the mop-up. All deer shot after the island-wide survey in 2013/14 were (apart from two fawns shot with their mothers) identified with the DNA faecal pellet database, and all but one had an image captured by a trail camera.

Nine deer were shot in in 2014 under the new strategy. Seven were adults (3F, 4M) and two were fawns. Three deer were shot by ground hunters, two from helicopters, and four from helicopters after the deer had been flushed out of the forest by ground hunters and their dogs. The last known animals were shot during August 2014 – a pregnant female which was flushed out of the forest by hunters and their dogs and shot from a helicopter, and an adult male shot by the ground hunters.

Initial population size

The careful collection of hunting statistics – numbers of deer killed, their age and sex and hunting effort – allows us to construct models of the population size and structure at any point during the project since 2006. The ages of 78 females shot on the island in 2006/07 and classed as adults by the hunters were determined from tooth cementum layers (Fraser & Sweetapple, 1993). All other animals were aged into three classes (young of the year, yearling, and older) by the hunters in the field. The population size in 2006 can be estimated using a form of the 'minimum number known to be alive' (MNA) analysis of McCullough, et al. (1990). Simply, the age of each animal shot was used to determine if it was alive in 2006 and the pre-fawning MNA population size in December 2006 (fawns are assumed all born at this time of year) is all animals shot after December 2006 that had been born before December 2006, plus all deer killed in 2007 other than fawns born in December 2006, plus all deer shot in 2008 other than fawns born in 2008 and sub-adults born in 2007, and so on. After 2009 an unknown number of deer in the oldest age class may have been born after 2006. To subtract these from our estimate of the initial population we used the age-class distribution of the 78 deer accurately aged and assumed the proportions remained the same across the post-2009 deer that were killed. Given 84% of the estimate of initial population size accumulates in the first three years, the potential errors in using this age distribution for older deer born after 2006 are minor. We assumed all deer were accurately aged, particularly when allocated an age class in the field, there was no immigration from the mainland and hunting by the official hunters was the major cause of mortality.

Between November 2006 and August 2014, a total of 688 deer were killed, of which at least between 530 and 550 would have been alive at the start of the eradication project in late 2006: an MNA 2006 density of 6.7 deer/km^2. The actual number was probably slightly higher as our estimate is based on known deaths and does not include animals that may have been wounded and died, died naturally, or were shot by other hunters and not reported.

Costs

Assuming direct operational costs of NZ$950 per flying-hour and $330 per hunter-day (the hunters were contracted for set periods but paid whether they actually hunted on a particular day or not) and using a population reconstruction model with a starting population size of 530 animals and an annual recruitment rate of 24%, the cost per deer shot increased rapidly as deer density declined for both aerial and ground hunting methods (Fig. 3). The cumulative 2006–2014 direct operational costs totalled $732,830 plus unknown management overheads that are likely to be roughly similar across years as they are less related to hunting effort.

We fitted a negative power function to the cost per deer versus density data from 2006 to 2012 (Fig. 3). Extrapolation from that curve suggested that expenditure of > $200,000 in direct costs would be required to remove the estimated residual population of eight deer within one year if there were no change in tactics. However, with the change in tactics in 2014, the actual direct costs were only about $84,000, indicating that the change in tactics was not only successful but much more cost-efficient. This of course ignores the significant factor of good luck (or bad luck from the deer's point of view) at the end of such

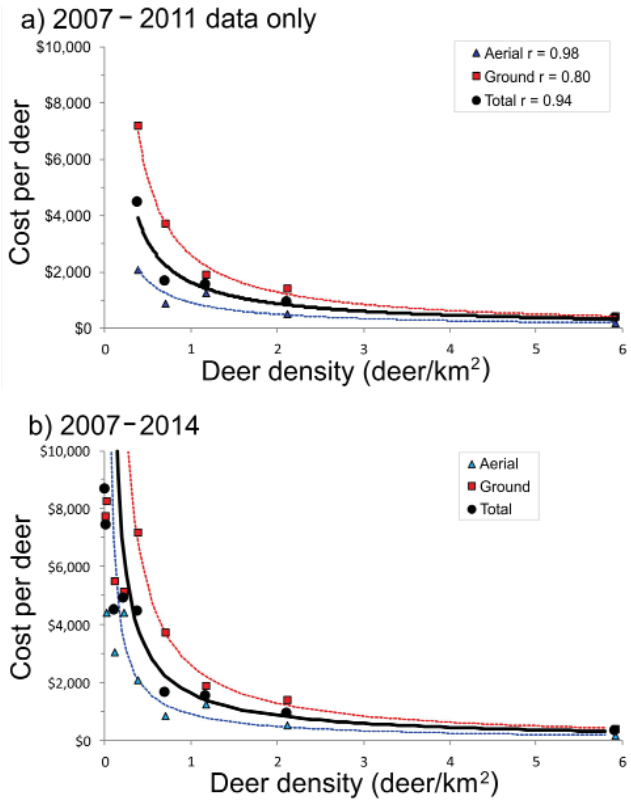

Fig. 3 Direct costs (hunter-days and flying hours) per deer killed with decreasing density, for aerial hunting, ground hunting and overall, for (a) the data from the first five years, and (b) for the whole campaign. The power curves in (b) are extrapolations from the 2007–2011 data and show that costs in the final stages (after adoption of new tactics) were lower than predicted from the initial data.

eradication projects, e.g. see the last pig from Santa Cruz Island which was shot incidentally to another task (Parkes, et al., 2010).

DISCUSSION

Eradication projects that rely on a succession of control events to eventually remove the population have one advantage over single-event projects, such as aerial baiting for rodents, in that information on progress and problems accrues as data are collected from each event. This allows managers to change tactics as the population is reduced and especially when surviving animals are less accessible or have learnt to avoid the control methods deployed at the start of the project. Previous successful and efficient eradication projects of this type have developed some practices (e.g. Ramsey, et al., 2009; Parkes, et al., 2010) that were, in part, used in the Secretary Island project.

The first success factor in such projects is that they reduce the population to very low densities as quickly as possible using control techniques that maximize the probability that every animal is killed at first encounter and thus minimize the possibility that surviving animals learn to avoid all control methods. It might be argued that live trapping in capture pens or 1080-gel on natural bait poisoning does not make surviving deer more wary, at least to subsequent hunting if not to the danger of traps, and should be used first. However, trapping is capital and labour intensive, unlikely to achieve rapid reduction in deer populations, while the earlier attempts at natural bait poisoning in Secretary Island were thought to be unsuccessful in achieving a large reduction. This left aerial and ground-based hunting as the only practical tools to achieve the initial population reduction, but which inevitably do not kill all deer at first encounter and so leave wary survivors. It is unknown whether the same successful initial reduction could have been achieved, and without creating wary survivors, by starting with the approach (team hunting with the additional improved GPS/radio and DNA technologies, and closer integration between ground and aerial hunting) deployed in the mop-up phase after 2013.

Many of the estimates of the number of deer left at various points across the campaign were essentially informed guesses. However, three tools were used to improve confidence in estimates of the number and identity of deer surviving on the island – a model based on catch per unit effort data, camera traps and the use of DNA from faecal pellets and aged and sexed shot individuals to determine presence of un-shot deer (pellets present for an individual not yet shot) and familial relationships (younger animal shot but not yet its parents) and potentially whether the DNA is from a resident survivor or an immigrant from the South Island.

The DNA from the deer shot during the campaign suggested they were all closely related (Crouchley, et al., 2011). This precluded trying to use the DNA in young animals (which were easier to shoot than adults) as a marker to see if their parents are eventually shot (e.g. see Nugent, et al., 2005). However, this is good news as the island deer had few of the rarer alleles present on the mainland. This suggests that the initial immigration in the 1960s had not been repeated, probably because deer populations throughout Fiordland were greatly reduced by commercial aerial hunting after that time (Nugent, et al., 1987). Therefore, the extirpation of the resident population on Secretary Island might indeed be eradication sensu stricto – still, a precautionary approach of surveillance and rapid response to any new incursions is intended.

Some general observations to ensure surviving deer did not escape are:

(a) to deploy hunters at optimal times/weather rather than on a set schedule,

(b) to know the general areas on the island where the surviving deer are living by extensive ground searches and use of camera traps,

(c) to know which individual deer have escaped the hunters by comparing DNA in faeces with DNA in animals shot and,

(d) to change the mindset of the hunters from 'control' to 'eradication', i.e. from acting as individuals, however skilled, each hunting any deer in their hunting block, to team hunters with appropriate technologies to act as a team and target individual deer.

The success on Secretary Island, and other smaller islands in Fiordland National Park, provides some templates for the proposed projects against red deer on similar islands. Eradication of red deer has been attempted on Resolution Island (21,000 ha), which is also in Fiordland National Park (Edge, et al., 2011). This project has not succeeded and is currently being reviewed (N. Macdonald, pers. comm.). The Government of Argentina is also considering whether to attempt to eradicate red deer and feral goats (*Capra hircus*) from Isla los Estados (Staten) Island (53,400 ha) in Tierra del Fuego – another remote, mountainous island dominated by southern beech forests (A. Schiavini, pers. comm.). New technologies to locate cryptic deer are also becoming available with improvements in infrared systems (FLIR) currently being deployed against black-tailed deer (*Odocoileus hemionus*) that have survived an eradication attempt on 1,637 ha Ramsay Island in British Columbia (N. Macdonald, unpubl. data).

The general strategy used on Secretary Island, of an initial rapid reduction in the deer population followed by removal of survivors, succeeded in its aim of eradication. However, in retrospect there is always going to be a difficult decision for managers when deciding when to deploy different control tactics across such a campaign. An ideal approach would be to begin with control methods that do not teach surviving animals to avoid later control, and then to apply control methods in a way that minimises the chance of animals escaping each encounter. On Secretary Island, and potentially for other deer eradication projects, we suggest that the team hunting system and coordination between ground and aerial hunting may have been better applied from the start of the 2006 hunting campaign rather than towards the end of the eradication.

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REFERENCES

Brown, D. (2005). *Secretary Island Deer Eradication Scoping Document*. Invercargill: Department of Conservation.

Crouchley, D., Brown, D., Edge, K-A. and McMurtrie, P. (2007). *Secretary Island Operational Plan: Deer Eradication*. Te Anau: Department of Conservation.

Crouchley, D., Nugent, G. and Edge, K-A. (2011). 'Removal of red deer (*Cervus elaphus*) from Anchor and Secretary Islands, Fiordland, New Zealand'. In: C.R. Veitch; M.N. Clout and D.R. Towns (eds.). *Island invasives: eradication and management*, pp. 422–425. Occassional Paper SSC no. 42. Gland, Switzerland: IUCN and Auckland, New Zealand: CBB.

Edge, K-A., Crouchley, D., McMurtrie, P., Willans, M.J. and Byrom, A. (2011). 'Eradicating stoats (*Mustela erminea*) and red deer (*Cervus elaphus*) off islands in Fiordland'. In: C.R. Veitch; M.N. Clout and D.R. Towns (eds.) *Island invasives: eradication and management*, pp. 166–171. Occassional Paper SSC no. 42. Gland, Switzerland: IUCN and Auckland, New Zealand: CBB.

Fraser, K.W. and Sweetapple, P.J. (1993). *Assessing the Age and Condition of Deer from Jawbones*. Christchurch, New Zealand: Landcare Research.

McCullough, D.R., Pine, D.S., Whitmore, D.L., Mansfield, T.M. and Decker, R.H. (1990). 'Sex linked harvest strategy for big game management with a test case on black-tailed deer'. *Wildlife Monographs* 11: 1–41.

Macdonald, N. (2013). *Removal of Red Deer from Secretary Island, Fiordland National Park 2013–2014*. Invercargill: Department of Conservation. DOCDM-1294828.

Mark, A.F. and Baylis, G.T.S. (1975). 'Impact of deer on Secretary Island, Fiordland, New Zealand'. *Proceedings of the New Zealand Ecological Society* 22: 19–24.

Mark, A.F., Baylis, G.T.S. and Dickinson, K.J.M. (1991). 'Monitoring the impact of deer on vegetation condition of Secretary Island, Fiordland National Park, New Zealand: A clear case for deer control and ecological restoration'. *Journal of the Royal Society of New Zealand* 21: 43–54.

Munn, A. (2001). *Secretary Island. A Consideration of the Ecological Values of the Island and the Potential for Restoration*. Invercargill: Department of Conservation.

Nugent, G.; Parkes, J.P. and Tustin, K.G. (1987). 'Changes in the density and distribution of red deer and wapiti in northern Fiordland'. *New Zealand Journal of Ecology* 10: 11–21.

Nugent, G. (1990). *A White-tailed Deer Poisoning Trial on Stewart Island*. Christchurch, New Zealand: Forest Research Institute Contract Report FEW 90/4.

Nugent, G.; Whitford, J. and McEwan, M. (2005). 'DNA-based Mark-recapture of Wild Deer: Using Fawns to Capture their Mothers'. In: J. Parkes, M. Statham and G. Edwards (eds.) *Proceedings of the 13th Australasian Vertebrate Pest Conference*, pp. 91–95. Lincoln, New Zealand: Landcare Research.

Nugent, G. and Arienti-Latham, C. (2012). *Simple Models of the Secretary Island Deer Eradication Programme*. Lincoln, New Zealand: Landcare Research Contract Report LC1057.

Parkes, J.P. (1983). 'Control of feral goats by poisoning with compound 1080 on natural vegetation baits and by shooting'. *New Zealand Journal of Forestry Science* 13: 266–274.

Parkes, J.P.; Ramsey, D.S.L.; Macdonald, N.; Walker, K.; McKnight, S.; Cohen, B.S. and Morrison, S.A. (2010). 'Rapid eradication of feral pigs (*Sus scrofa*) from Santa Cruz Island, California'. *Biological Conservation* 143: 634–641.

Parkes, J. and Murphy, E. (2003). 'Management of introduced mammals in New Zealand'. *New Zealand Journal of Zoology* 30: 335–359.

Ramón-Laca, A.; Gleeson, D.; Yockney, I.; Perry, M.; Nugent, G. and Forsyth, D.M. (2014). 'Reliable discrimination of 10 ungulate species using high resolution melting analysis of faecal DNA'. *PLOS ONE* 9(3): e92043.

Ramsey, D.S.L.; Parkes, J.P. and Morrison, S.A. (2009). 'Quantifying eradication success: The removal of feral pigs from Santa Cruz Island, California'. *Conservation Biology* 23: 449–459.

Sanson, L.V. and von Tunzelman, J.R. (1985). *Wild Animal Control Plan for Secretary Island, Fiordland National Park*. Invercargill: New Zealand Forest Service.

Tustin, K.G. (1977). 'Secretary Island – a problem in deer control'. *What's New in Forest Research* No. 50. Rotorua, New Zealand: Forest Research Institute.