Aerial survey of red deer following a pest-control operation on Molesworth Station in 2017

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Aerial survey of red deer following a pest control operation on Molesworth Station in 2017

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This report has been commissioned by the Marlborough Branch of the New Zealand Deerstalkers Association. The field research was conducted by this association, with input on survey design, data analysis and report preparation from ecologists at Manaaki Whenua - Landcare Research, Cameron Speedy Director of Wildlife Management Associates Ltd, Turangi and Kaylyn Pinney.

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Dr James Ross	Associate Professor Dr Adrian Paterson

Executive Summary

Introduction

In October 2017, Operation Solutions for Primary Industry (OSPRI) conducted an aerial 1080 baiting operation targeting possums over 59,594 ha (595.94 km^2) of Molesworth Station. An aerial helicopter-based survey of red deer (live and dead) was conducted soon after by the Marlborough Branch of the New Zealand Deerstalkers Association. Advice on survey design was provided by New Zealand ecologists employed at Manaaki Whenua - Landcare Research and Cameron Speedy Director of Wildlife Management Associates Ltd, Turangi.

Objectives

To estimate the percentage by-kill of red deer and density/km^2 of live deer remaining following an aerial 1080 baiting operation for possum control on Molesworth Station in the spring.

Methods

- In the initial survey design, 20 flight transects, each 1 km in length and at least 1.5 km apart were delineated inside the operational area, excluding a 2 km internal buffer around the boundary. In practice, strict adherence to this design proved impractical in the steep, mountainous terrain. This precluded the use of distance and/or sighting efficiency methods for estimating actual densities, so the survey aim was modified to compare the number of live and dead deer observed in areas considered by observers to be the best deer habitat. Estimates of dead deer density were made by placing 50 large brown paper bags throughout the search area (298.2 km^2 being the total area minus a buffer zone and repellent-treated areas) to imitate deer carcasses using the proportion of bags found during the survey to convert the number of actual carcasses found to an estimate of overall carcass density.
- A helicopter carried four observers, (two per side, left and right, including the pilot) and one recorder, to GPS-mark and record the pilot's observations. Each observer independently counted and GPS-marked, all live or dead deer and

paper bags on their side of the helicopter and recorded their estimated distances from the flight path.

- Deer carcasses recorded were only considered individual if they were GPS marked further than 200 m from one another or within 200m when observed by the same person or observed by different sides if there was discrepancy between distance from the flight transect recorded of 100 m or more or in the number of carcasses observed, or if the observers were both back seat observers.
- The actual survey covered a 74.5 km^2 observational area (being 150m either side of the flight path x the length of flight path searched), which was 25% of the total search area (298.2 km^2), during 2.5 hours of flight time.
- Tissue samples from 21 dead deer were collected and submitted for 1080 residue analysis by the Manaaki Whenua - Landcare Research Toxicology Laboratory.
- Simple mark recapture analysis was then conducted where the ratio m/M (number of bags observed/number of bags deployed) was applied to the number of individual dead deer observed (n) for both the observed area and the total area. Estimates of the number of dead deer within the operational area were calculated based on two assumptions; firstly, that the observational area was representative of the total search area, where the density of dead deer within the observational area was applied to the total control area; and, secondly, the flight path was considered independent of paper bag placement, where the total search area was treated as the sampling unit.

<u>Results</u>

- A total of 117 dead deer sightings, representing 92 individual deer, were recorded. Sixty-six of these were estimated to be within the observational area (i.e. within 150 m either side of the helicopter). The average distance of dead deer observed was 52 m from the flight path.

- Observers sighted 20% of the total paper bags in the search area, with an average observation distance of 138 m. Bags were observed as far as 300 m from the flight path; however, when only the observational area was considered, the rate of detection of the paper bags increased to 30%.
- Based on the number of bags observed, the estimated density of dead deer using simple mark-recapture within the observational area was 2.95 dead deer/km^2 and, over the total search area, it was 1.54 dead deer/km^2.
- Live deer were observed on four occasions during the survey, but only two sightings were within the search area; these were observed on different days and within 900 m of each other.
- All 21 carcasses tested positive for 1080 residues in their tissue samples ranging from 0.19 - 4.89 mg/kg (Appendix 4). Dead deer were observed in varying states of decomposition.

<u>Conclusions</u>

- The number of deer carcasses observed and the presence of 1080 residue in all deer tested, indicated that the 1080 operation killed a substantial proportion of the deer population. While the actual percentage by-kill cannot be directly quantified from the data collected, the ratio of 2:92 for live/dead deer, suggests the by-kill was substantially higher than the 30% by-kill expected by OSPRI.
- The results from this survey suggest the residual deer population is low. This is further supported by follow-up survey (Morriss, Yockney et al. 2019), which suggests this possum control operation will significantly impact on hunting opportunities in the operational area for several years.
- It is assumed that there is a degree of bias in the current survey's estimated dead deer density, the degree and direction of this bias is unknown. Therefore, the actual number of deer killed over the entire operational area may be higher or lower than reported here.
- While OSPRI did apply deer repellent to a 20 km^2 area in this operation, the mitigating effect was not quantified due to the small size of the area treated.

Recommendations

- The NZDA should actively seek the use of deer repellent for all vector control or pest management operations where hunting would be significantly negatively impacted without its use.
- Ongoing deer population and hunter use monitoring should be developed to provide a cost-effective way to identify areas where this would be the case and quantify the success of any mitigation techniques applied in operations for these areas. For example, a reliable system which records hunter returns would provide data on hunter usage and success, both before and after vector control operations.
- Previously reported deer by-kill estimates may be used to indicate possible deer by-kill in comparable habitats but should not be used to base decisions on for the application of mitigation, rather, the significance of the resource at risk as identified above.
- Areas where deer repellent will be advocated for should be clearly defined and presented to vector control agencies to allow for accurate budgeting before operational plans are publicised.
- The development and field testing of deer repellents which are less expensive, but as effective at repelling deer should be encouraged to reduce the cost of mitigation.
- The funding, or development, of a professional team, including pilots experienced in research-based flying would greatly improve any future aerial surveys conducted by NZDA.

Introduction

In October 2017, Operation Solutions for Primary Industry (OSPRI) conducted an aerial application of 1080 cereal pellets (0.15% w/w) for possum control over 59,594 ha (595.94 km^2) of Molesworth Station. The aerial application is part of a nine-year possum control plan with the goal of TB freedom in livestock by 2020, and in possums (*Trichosurus vulpecula*) by 2027 (OSPRI 2017). The plan includes three areas selected for control across Molesworth Station, with three aerially-broadcast 1080 applications to occur in each area on a three-yearly cycle. The Marlborough Branch of the NZDA was concerned that the OSPRI vector control operations planned for Molesworth Station would result in a high non-target by-kill of the resident deer population. Such a reduction would significantly impact the future of recreational hunting in this area. As such, an aerial helicopter-based survey of (*Cervus elaphus*) red deer (live and dead) was conducted by the Marlborough Branch of the NZDA with financial contributions from multiple not for profit organisations (see acknowledgements), three weeks after the toxic applications. Advice on survey design was provided by New Zealand ecologists, both independent and those employed at Manaaki Whenua - Landcare Research.

Background

Molesworth Station

Molesworth Station is located Inland of the Kaikoura Mountain range in the Marlborough District, South Island. It totals 180,787 ha (1,807.87 km^2) (42°S, 173°E), and is currently managed by Pāmu Farms of New Zealand (formerly Landcorp Farming Limited) as a working cattle station. On 1 July 2005, the administration of Molesworth Station became jointly managed by Pāmu Farms of New Zealand and the Department of Conservation, who are responsible for coordinating public access for recreation while working alongside the current farming practices. Molesworth Station is a recreational reserve and hunting is a popular recreational activity on the station with 170 applications, representing 465 hunters, for the limited 100 hunter party permits in the roar of 2016. During the non-roar period of 2016 there were 216 applications for permits, representing 446 hunters (Provided by Wairau / Renwick Office, Department of Conservation). Hunting may provide some benefit to farming by reducing the densities of game animals present on Molesworth Station, thereby reducing feed resource competition with farmed cattle and possible spill back risks of *Mycobacterium bovis,* the cause of bovine tuberculosis (TB) (Nugent, Gortazar et al. 2015).

Molesworth Station is part of the last large farmed area in New Zealand impacted by endemic TB infection in wildlife. The sheer scale and terrain of this high-country station provides many challenges for TB eradication and vector control, with elevations of between 500 – 2100 m. Valley floors and low slopes are generally open with short tussock (*Agrostis caprillaris*) and introduced grasses, mid-altitude slopes and gullies are typically thick with shrubby vegetation and dominated by either rose briar (*Rosa rubiginosa*) or native matagouri (*Discaria toumatou*), while higher altitudes support tall tussock (*Chionochloa pallens*), spaniard grasses (*Aciphylla spp.*) and mountain flax (*Phormium cookianum*), interspersed by large areas of uninhabitable steep shingle scree (Glen, Byrom et al. 2012). To cope with some of the challenges presented by this landscape, OSPRI (formerly known as the Animal Health Board [AHB]) commissioned extensive research throughout the 2000s on Molesworth Station into TB-vector control, TB eradication methods and cost reduction techniques. Briefly, surveys conducted between 2004 and 2007 identified possums and pigs (*Sus scrofa*) as the main hosts of TB on Molesworth Station (Byrom, Nugent et al. 2008, Nugent and Whitford 2008). TB infection was found to be largely confined to the south-eastern third of the station, where the highest density of possum population was also recorded. When Byrom, Nugent et al. (2008) compared TB prevalence with the control of possums, pigs and ferrets (*Mustela putorius furo)* independently, possum control alone was found to provide the greatest reduction in TB. They concluded that the control of possums was paramount to reducing TB levels in Molesworth Station wildlife. In 2008, an aerial poisoning operation was conducted in the south-eastern section of Molesworth Station using 1080 cereal baits (0.15% w/w) sown at 1.0–2.5 kg of bait/ha without pre-feeding and using a selective coverage approach (Byrom, Nugent et al. 2008, Yockney and Nugent 2008). The operation was jointly funded by OSPRI and Landcorp and was structured as an operational test of the cost effectiveness of different aerial poisoning strategies. First, only areas predicted to have at least a moderate relative abundance of possums were treated, and they compared two levels of coverage: low coverage (high risk and low cost) and high coverage (low risk and high cost), with two sowing strategies, broadcast and cluster sowing. Cluster sowing reduced sowing rates by 60% to just 1 kg/ha in the poisoned areas. The high coverage strategy was more successful than a low coverage strategy, although all residual possum counts were well within the post-control performance standard (i.e. < 2% RTCI) (Yockney and Nugent 2008). In addition, there was no evidence of a markedly poorer kill when using a 60% lower sowing rate and cluster sowing dispersal. The use of pre-feeding, along with high coverage cluster sowing, produced better results than any of the other no pre-feed treatments. A follow up survey on the possum recovery rate two years post-control found the annual exponential rate of increase over the two years was well above the reproductive capacity of possums (Nugent, Yockney et al. 2011). It was suggested that this apparent high rate of population growth may have resulted from an over estimation of the post-control possum reduction due to poor detection rates, or an overestimation of possum recovery due to increased detectability resulting from the relationship between the reduced possum density and possum home range expansion, or a combination of the two. Nugent, Yockney et al. (2011) concluded that, while the 2008 1080 baiting operation initially appeared to have successfully reduced possum numbers, the rapid possum recovery suggested that the low coverage technique may have been sub-optimal and that it should not be implemented again. However, they did recommend continuing the use of cluster sowing using high coverage of cereal as a possible technique to reduce costs in future operations.

Other studies investigating the use of cluster and strip sowing have also found these techniques to be effective in reducing possums and other pest species, while substantially reducing both costs and toxin use with recommendations for further investigation (Nugent, Morriss et al. 2012, Nugent, Warburton et al. 2012, Nugent and Morriss 2013, Morgan, Warburton et al. 2015). A study by Nugent and Morriss (2013) reported as little as 0.33 kg/ha pre-feeding and just 0.17 kg/ha of toxic bait at a 150 m flight path spacing and a 30-day pre-feeding to toxin application interval substantially reduced previously unmanaged possum populations, with post control chew card indices recording a zero count. Strip sowing or cluster sowing without the use of deer repellent may increase the by-kill of red deer. A survey by Nugent, Morriss et al. (2012) reported some weak indications of a possible increased deer by-kill using strip sowing in comparison the broadcast methods. However, they also reported that Epro Ltd deer repellent was highly effective in reducing deer by-kill for both strip sowing and broadcast sowing.

Between 2011 and 2016 Molesworth Station entered a 50/50 partnership arrangement with OSPRI to undertake vector control on the Station. With the subsequent adoption, in 2016, of the National Pest Management Plan to eradicate TB from NZ by 2055, the Station was split into three large blocks and a rolling pest management programme implemented to achieve full coverage over three years. Despite the extensive previous research contracted by OSPRI to investigate methods of cost reduction in possum control techniques, the broadcast method was selected for the 2017 possum control operation. This is largely due to industry reluctance to use high coverage cluster sowing or strip sowing due to the financial risk of failure to meet targets. The consistent success of strip or cluster sowing techniques has not yet been confirmed due to the limited number of operations conducted which utilise best practise of these techniques.

Incidental by-kill of red deer

While deer are considered spill over hosts for TB, active management of wild deer is not considered essential for local TB eradication in New Zealand (Nugent, Gortazar et al. 2015). Deer densities on Molesworth Station in the early 2000s were assumed by Nugent and Whitford (2008) to be of the order of 1 deer/km^2 or lower, based on deer sightings during goat culls (60 observations over 4.5 hours flight time) and during pig hunting trials, in 2006, as well as anecdotal evidence of a low annual deer harvest that year. If deer harvest rates were lower than recruitment rates and remained so, then the density of deer could have increased in the years since those estimates were made. However, there have been no annual harvest data retrieval or estimates carried out.

The use of aerially-dispersed 1080 baits in mammalian pest control operations can result in a significant by-kill of wild deer (Nugent and Yockney 2004, Speedy 2005, Eason, Miller et al. 2011, Nugent, Morriss et al. 2012, McBrearty 2015). Prior to the 2017 possum control operation on Molesworth Station, OSPRI indicated an expected 30% deer by-kill to result from the operation although reasoning behind this expected by-kill was not provided. One OSPRI-commissioned survey conducted by Nugent, Morriss et al. (2012) to investigate deer deaths, reported a 'one-third' by-kill, in the Hauhungaroa Ranges. Though presumably the expected by-kill was not based on this operation as the two operations are not comparable, differing in landscape, vegetative cover and season, with the Hauhungaroa operation being conducted in the Winter and the Molesworth operation being conducted in the Spring. A recent study (Malham, Elliot et al. 2019) did not detect any effect from aerial 1080 baiting on deer sighting rates in South Westland. However, in contrast to Molesworth Station, the South Westland study sites were in densely-forested areas. Dense undergrowth may limit the number of baits a deer could find and consume before starting to feel discomfort, causing sublethal poisoning rather than mortality. The acute oral toxicity (LD_{50} mg/kg) of 1080 for deer is 0.5 mg/kg. Therefore, a 120 kg deer needs to consume at least six 6g baits to have a 50% chance of dying. Deer mortality following aerial 1080 operations is known to vary considerably ranging from near zero to 93%, and with no apparent consistent pattern in the number of deer deaths, based on bait type, sowing rate or toxic loading, suggesting that other external factors may be important (Nugent, Fraser et al. 2001). Due to variation in the observed by-kill in previous studies, the open landscape of Molesworth Station and the potential for significant impacts on hunting in the event of a high by-kill, the Marlborough Branch of the New Zealand Deerstalkers Association (NZDA) requested that OSPRI use deer repellent to reduce the risk this operation posed to deer. Significant deer by-kill following 1080 operations is now largely avoidable since the development of a deer repellent by Epro Ltd (Speedy 2005), currently used for all Recreational Hunting Areas (RHA's). Following initial screening of the repellent by Epro Ltd, OSPRI funded further development and field testing. The bait coating, which remains palatable to possums and rodents, significantly reduces the non-target deer by-kill (Morriss and Nugent 2008, Nugent, Morriss et al. 2012). Due to the expense of applying deer repellent to the total area, at more than $2 per ha, $120,000 over 60,000 ha or double if applied to both the toxic baits and prefeed, OSPRI agreed to fund the use of deer repellent for a 2,000 ha (20 km^2) area, around 3% of the total operational area for only the toxic application in the 2017 Molesworth operation. The Marlborough Branch NZDA selected an area with high available feed for wintering deer and most favourable landscape aspect for spring grass growth for application of repellent.

The current survey

In consideration of the above, this survey aimed to identify whether the by-kill of deer following the control operation on Molesworth Station was greater than the 30% estimate, quantify the percentage by-kill of deer, estimate the remaining population of deer and give recommendations to the NZDA about techniques for minimising non-target impacts following future 1080 operations on Molesworth Station.

Objectives

- To estimate the percentage by-kill of red deer and to estimate the density of live deer remaining following an aerial 1080 baiting operation for possum control on Molesworth Station in the spring of 2017.

Methods

Survey Area

The survey area included the planned 2017 vector control operational area on Molesworth Station, as outlined by OSPRI (640.91 km^2), minus the 20 km^2 where Epro deer repellent (EDR) was to be used (Appendix 1). This included a 2 km buffer zone inside the operational perimeter to minimise any edge effects, such as overestimation of by-kill percentages due to deer movement into the drop zone from the adjacent habitat (Appendix 2). This left a survey (search) area of 298.2 km2.

In October 2017, OSPRI pre-fed 59,594 ha (595.94 km^2) of Molesworth Station with 6 g non-toxic RS5 baits without EDR at a sowing rate of 1 kg/ha. This was followed 16 days later by a toxic application of 6 g RS5 cereal 1080 (0.15%) baits sown at 2 kg/ha without EDR over 57,625 ha (576.25 km^2) and with EDR for the remaining 1969 ha. Only 21 mm of rain fell between the toxic bait drop and the carcass survey (Fire Emergency New Zealand rainfall data Molesworth MLX).

Survey design

The final survey design comprised a helicopter-based count of the number of deer carcasses and live deer observed during a single flight over parts of the poisoned area. This differed from the original survey design, which had aimed to use systematic search of flight transects and a double-count method to obtain unbiased density estimates (Griffin, Lubow et al. 2013, Lubow and Ranson 2016) but, for the reasons noted, below, this could not be implemented as planned.

The initial plan involved flying 20 transects 10 km in length and spaced 1.5 km apart that were created using Arc GIS (version 10.5.1). In areas that were not large enough to fit an entire 10 km transect line, the transect was to be split into several parts which, when flown, would be counted as a single transect. This would allow the counts from the individual transects to be compared, giving an estimate of deer density variances throughout the search area. Transects were to be flown on two occasions, once in the morning and once in the evening, once heading SW and once heading NE, to assess the repeatability of the counts for individual transects. Flight times were primarily aimed at detecting remaining live deer. The transect direction was selected to follow most valleys lengthwise to minimise flight difficulties due to the large fluctuations in elevation and attempt to reduce the possibility of motion sickness in the observers. A double count method was to be applied with two independent pairs of observers, one either side of the helicopter, with the observers in pairs also working independently (Griffin, Lubow et al. 2013). The sightability between observers and observer pairs was to be calculated with the application of bias correction modelling to give more accurate estimates of actual deer densities (Lubow and Ranson 2016).

Due to concerns over several factors, which could result in difficulties in conducting the preferred method, a further technique for determining the detection rate of dead deer was also applied simultaneously. This involved using ‘fake deer carcasses’, or large brown paper bags as visual proxies for deer carcasses, a method used in some previous assessments of 1080-caused deer by-kill (Morriss and Nugent 2008, McBrearty 2015). We assumed that the observers would be more likely to detect deer that were within 150 m of the flight path. Therefore, an observational area 150 m wide was added to each side of the planned transect lines using ArcGIS. Within this 300 m wide observational area of all 20 transects, 50 random locations were selected no closer than 1 km apart using the ArcGIS random sampling tool. At each of these 50 locations deer-sized brown paper bags (395x125x890 mm 2 ply Kleensaks, Shardlows, Christchurch) were deployed in the nearest position that a dead deer could realistically lie. The bags were deployed the week before the aerial survey. The pilot used during the deployment of the paper bags was different from the pilot used to conduct the search. The paper bags were filled with vegetation to simulate the bulk of a deer carcass. The percentage of paper bags observed during the survey were to be used to estimate the detection probability of observing a deer carcass if it were present. This detection probability was to be applied to the number of carcasses observed to estimate the overall proportion of dead deer.

On the morning of the first day of the search the cloud sat low over the mountains and did not lift until midday. The period available to do this survey was restricted by the helicopter's availability, volunteer availability and financial limitations. It was determined that assessing the proportion of deer carcasses along the transects was more important than assessing the density of the remaining live deer. Therefore, the flight time for the first search changed from morning to midday. During the first three transects undertaken it was discovered that the pilot was unable to follow the transect lines created and his attempts to do so resulted in motion sickness in the observers. As such, the mountainous terrain made the survey design impractical and so the survey method was altered. The transects were largely abandoned, instead, the most practicable flight paths were followed, favouring areas most likely to be used by deer, as determined by the observers (Appendix 3). The area surveyed was, therefore, no longer a systematic search over the entire area nor was it a random sample of the search area. As the transects were not followed strictly the pilot was unable to repeat the survey from the opposite direction and so this preferred method was unable to be implemented.

Observations were made over three periods, midday, evening and morning. The helicopter carried a team of four observers (two per side, left and right, including the pilot) and one recorder, to GPS-mark and record the pilot's observations. Each observer independently counted and recorded the GPS locations for all live or dead deer visible on their side of the helicopter. The observers were asked to estimate the lateral distance of the carcass from the helicopter's flight path. As the distance of observation was to be defined by eye for each observer, substantial errors of accuracy in the lateral estimations were expected, increasing with distance from the flight path. It was expected that 0 m would have the highest accuracy, being directly below the helicopter, and estimations greater than 150 m would have substantial errors and would, therefore be recorded as being greater than 150 m. The numbers of deer carcasses observed were considered as a total, excluding those sightings considered likely to be the same deer. Dead deer sightings were to be investigated as potential double ups if the GPS locations marked were within 200 m of one another. Prior to the survey, the potential overlap GPS points may be the same point were identified by the observers GPS-marking a predetermined stationary land mark as the helicopter passed over. It was considered that sightings within 200 m when observed by the same person were different carcasses, but those observed by both observers on the same side were the same carcass. Carcasses within 200 m recorded by observers on different helicopter sides were to be considered as different carcasses if there was a discrepancy between distance from the flight transect recorded of 100 m or more or in the number of carcasses observed, or if the observers were both back seat observers.

<u>Data analysis</u>

The observation of pre-placed filled brown paper bags was used as a proxy for estimating the probability of detecting deer carcasses, and therefore how many deer may have been missed by the searchers. Estimates for recapture probabilities (i.e.

the proportion of sacks rediscovered) were determined using the following formula (Davidson and Armstrong 2002).

$\check{N}_i = n_i / p_i$

Where n_i = number of individuals caught on occasion i

And p_i = recapture probability for occasion i

An approximate 95% confidence interval for each population estimate is given by: $\check{N} \pm 2\,se$

Where $se(\check{N}) = n(se[p]) / p^2$

Estimates of potential overall by-kill of deer as a result of the control operation were extrapolated from the collected data using two scenarios, each with an overarching assumption. First, the density of dead deer within the observation area (150m either side of the flight path) where carcass visibility was best, was representative of the total search area. For this, the deer carcasses per km^2 of observation area were calculated, where the ratio m/M (number of bags observed/number of bags) applied to the number of individual deer carcasses seen within the observation area. To identify paper bags that were within 150 m either side of the flight path, the distance between paper bags GPS positions and the flight path was measured post survey using Arc GIS. Second, the entire search area was considered as the sampling unit and that the flight was independent of paper bag placement. For this, the deer carcasses per km^2 over the entire search area were calculated, where the ratio m/M applied to the number of individual deer carcasses observed. Confidence intervals were similarly extrapolated from the error margins determined using the above formula.

Cause of death

To confirm that the dead deer observed had, been killed by 1080, 21 carcasses were sampled from within the search area to confirm the presence of the toxin. The tissue samples collected were bagged individually, labelled and then frozen as soon as possible before being sent to the Manaaki Whenua - Landcare Research Toxicology Laboratory, Lincoln, for 1080 residue analysis using Toxicology Laboratory Method TLM 005 (with a method detection limit of 0.001 mg/kg).

Results

Observational area

The flight time of the actual search within the search area totalled 2.5 hours, and the total combined flight path length was 248 km. Assuming a 300 m observational swath, the observational area covered 74.5 Km^2, 25% of the total search block area (i.e. the area >2 km from the planned poisoned area boundary was 298.2 km^2; Appendix 3).

Observations of live deer

Live deer were observed on four occasions during the survey, but only two of these sightings were within the search area. One was within 1 km and the other was within 400 m of the southern border of the search block. The two sightings were within 900 m of one another, and both were sighted by the same observer in the back of the helicopter, one in the evening flight and the other in the morning flight. It is unknown if the two sightings were of the same or different deer. Two sightings were observed during the ferry time between base camp and the search area within the 2 km buffer zone. The midday flight was considered a sub-optimal time for observing live deer, although one deer outside the search area was observed during the midday flight, the other was observed during the morning flight and they were more than 11 km apart.

Observations of dead deer

A total of 117 dead deer sightings were recorded, representing 92 individual carcasses. Twenty five of the 92 individual deer were sighted by both pairs of observers (on the same helicopter side) and determined as a double count.

Of these 92 individual carcasses, 66 (72%) were within the 74.5 km^2 observational area (i.e., recorded as being within 150 m of the flight path), and the density of the carcasses observed was 0.89/km^2. The average distance of dead deer observed was 52 m from the flight path.

Estimation of carcass density

Of the 50 paper bags deployed as imitation deer carcasses, GIS analysis showed that the flight paths came within 150 m of 20 (40%) of them and within 300 m of 31 (62%) of them. No bags were seen beyond 300 m from the flight path, with the average distance to flight path of the observed bags being 138 m.

Observers detected six (30%) of the 20 bags within 150 m of a flight path, observational area (Table 2). Applying that detection percentage to the density of observed carcasses (0.89/km^2) provided a carcass density of 2.95/km^2 within the 74.5 km^2 observational area (Table 1).

In total, 10 bags were observed (20% of the total of 50). If the flight paths actually flown were assumed to be independent of the locations at which the bags were deployed, applying the 20% detection of all bags to the total of 92 carcasses recorded provides a lower estimate of 1.54 carcasses/km^2 for the total 298 km^2 study area (Table 1).

Table 1 Estimated density of dead deer within the search block and total operational area on Molesworth Station following the 2017 OSPRI vector control operation using simple mark-recapture analysis when the observation area is considered representative of the operational zone or when the flight path is considered independent of control placement.

	Detection area (km^2)	Dead deer observed	Deer observed / km^2	Paper bags %	Density of dead deer (km^2)	SE	95% CI	Total dead deer est. in search block 298.2 km^2	Total dead deer est. in operational zone 576.25 km^2
Observation area	74.5	66	0.89	30%	2.95	2.06	4.12	880±614	1700 ±1187
Search area	298.2	92	0.31	20%	1.54	1.2	2.5	459±358	887±692

Causes of death

All the 21 carcasses tested had traces of 1080 residue in their tissue samples (Appendix 4), indicating a high likelihood that all deer observed had been killed by 1080. Dead deer were observed in varying states of decomposition, from bloated to only bones and skin remaining. While some were found in water, which slowed the rate of decay, others were in a similar state in the open.

Figure 1 Four of the 21 dead deer sampled, as an example of the varying states of decay observed, K Pinney.

Conclusions

The number of deer carcasses observed in this search, and the presence of 1080 residue in all of the 21 deer tested, indicates that the 1080 operation killed a substantial number of deer. While the percentage by-kill cannot be directly quantified from the data collected, the ratio of two live deer to 92 dead deer observed suggests by-kill was high. A subsequent OSPRI-commissioned aerial survey of live deer by Manaaki Whenua - Landcare Research in an adjacent block on Molesworth Station recorded a sighting rate of 1.7-deer/km^2 (Morriss et al 2018). If the density of deer in the operational area was similar to that of the adjacent area surveyed by Manaaki Whenua - Landcare Research, then the similarity between this and the estimated by-kill density from the current survey also suggests that the deer by-kill was high. This is further supported by a follow-up survey comparing deer abundance and rates of increase in poisoned and un-poisoned areas on Molesworth station, which confirmed relative deer abundance was much lower in poisoned areas than non-poisoned (88% lower in 2018 and 83% in 2019) (Morriss, Yockney et al. 2019). While the authors found the increase in deer numbers from 2018 to 2019 was not statistically significant, when typical annual increases of red deer were assumed, they concluded that recovery could take 6-7 years, depending on immigration rates and hunting pressure. This suggests this possum control operation will significantly impact hunting opportunities in the operational area for several years.

The number of deer killed estimated in this survey was calculated based on assumptions which are known to not be the case. Firstly, the flight path in this survey covered what observers estimated as deer-preferred habitat that, so long as the observer's estimations were accurate, this would result in the estimate of carcass density being biased high. Secondly, it was assumed that the flight path was independent of paper bag placement. While the pilot was not aware of the position of paperbags, the flight path chosen largely followed closely to transects which fell in areas considered best deer habitat by observers. If the flight path was actually independent of paperbag placement the detection rate of paperbags would be expected to have been lower than what is reported here due to the scale of the search area and the minimal number of paperbags placed. This would bias the dead deer density low. While it can be assumed that there is a degree of bias in the current survey's estimated dead deer density, the degree and direction of this bias is unknown.

An overestimation in individual dead deer would make the bias for carcass density high, although the probability of possible overestimation to any significant degree in this study is considered unlikely for the following reasons. Carcass density will be biased high if the sightability of dead deer is much higher than for the live deer. This seems unlikely on Molesworth Station given the lack of forest cover. Large expanses of low scrub and tussock could easily conceal carcasses, less so, live standing deer. Dead deer, GPS-marked within 200 m of one another by observers on opposite sides of the helicopter were considered different deer, which could result an overestimation of the number of individual dead deer observed (resulting in the % kill figure being biased high). However, it was noted that the back observers have a much narrower field of view than the front observers, making double counting by back observers unlikely and the few sightings by the front observers that were recorded close enough to raise questions had discrepancies in carcass number and distance from flight path. In addition, no paper bags were double counted by observers on opposite sides of the helicopter.

Alternatively, the 2 km buffer applied to the internal periphery of the operational area which reduces the effect that deer movement could have had on the estimated carcass and live deer density for this survey but may also result in this survey significantly under estimating the total number of deer killed. In a study comparing ranging behaviours of TB hosts on Molesworth Station, the average home range size of 13 red deer when monitored for 14 months was 37.8 km^2 (3780 ha), with a weekly range estimated to be approximately 11 km^2 or 1100 ha (Yockney, Nugent et al. 2013). Potentially, many deer have home ranges partially encompassing operational area, which were not present at the time of the operation, but, may have entered in the weeks following while bait was still likely to be toxic due to low rain fall. As such, the density of deer killed within the operational area is potentially higher than the pre-operation density of live deer. Consequently, the operation may have also significantly impacted on deer density in areas adjacent to the operational area. The amount of time the bait was present on the ground and remained toxic following the operation is unknown, although whole baits were observed at the time of paper bag placement, 10 days after the poison operation, with no significant rainfall occurring before the survey was undertaken. Deer movement into the operational area may also explain some of the variation in the level of carcass decomposition observed although, in many cases, the reason for variation is more likely due to the location of death, being in or out of water, and level of sun exposure due to terrain aspect.

The density of carcasses may also be biased low if the detection probability determined using paper bags was significantly higher than reality or biased high if the opposite is true. Paper bags did appear to be much more visible from a distance than carcasses, with an average distance to the flight path of bags being 138 m for 13 observations, compared to only 52 m for 117 observations of dead deer. However, the detection rate of paperbags was so low that the standard error about the estimations of deer density crossed zero. While the low detection rate may indicate that the number of carcasses not observed was high, alternatively it could suggest that the paperbag controls may not have been indicative of the sightablility of dead deer. The preferred systematic search double count method would have provided more accurate estimates of dead deer densities. However, the method could not be implemented in this survey due to the restricted time frames for volunteer participants, finances and pilot competencies.

The large home range of deer on Molesworth could have led to an overestimation of live deer although, in this survey, the exclusion of these sightings would have resulted in a zero count. With only a singular pass over the search area there is no basis to conduct statistical analysis of live deer observed. It is equally likely the survey underestimated live deer, observing live ungulates can be challenging as they actively avoid observation, although this is more often the case in areas that have been subject to intensive helicopter hunting (Forsyth and Clarke 2005). While the detection probability of back-seat helicopter observers seeing dead deer is typically much lower than those of front-seat observers (Griffin, Lubow et al. 2013), they do have greater potential to spot live deer, as deer will often flee after the helicopter has passed over. This was the case in the current study, with three of the four deer observed overall being sighted by a backseat observer only. The altered method was sub-optimal for detecting live deer with only one morning search, one evening search and one midday search. Morning and evening are considered the best times of day for observing live deer; however, on some occasions very few deer may be observed despite moderate deer densities. Typically, the total sightings are likely to represent only a small percentage of the actual population, with the probability of detecting ungulates from a helicopter decreasing with increasing concealing vegetation (e.g. Pollock & Kendall 1987; Rice et al. 2009; Griffin et al. 2013). The open landscape of the Molesworth would limit the available cover for a live deer to hide. The probability of sighting an ungulate from a helicopter, conditional on it being present, increases with the number of ungulates in a group (e.g. Pollock & Kendall 1987; Rice et al. 2009; Griffin et al. 2013). In the current survey, only single deer were observed, also suggesting the remaining population is low. A low residual deer population is in agreement with the follow-up survey by Morriss, Yockney et al. (2019) with as few as 0.2 deer sightings / km^2 in the 117.6 km of poisoned area surveyed in 2018.

The high by-kill observed in this survey contrasts with the results of the recent study by Malham, Elliot et al. (2019). While differences in vegetative cover may be a factor affecting by-kill, it is important to note that the South Westland study did not measure mortality, rather, changes in deer observations. The operational areas in their survey were small, with site boundary diameters spanning less than 5 km. The home range of red deer in South Westland was not considered in this study but could easily be large enough that deer in the adjacent habitat began repopulating the operational areas within weeks of the operation, particularly if the deer density in the surrounding areas was high. The follow up survey on Molesworth by Morriss, Yockney et al. (2019) noted a three-fold increase in hinds and fawns in the poisoned areas surveyed, some of which could not be a result of breeding alone, and that hind dispersal relative to the nearest un-poisoned area suggested some immigration. However, the scale of Molesworth means that without substantial immigration, coupled with low hunting pressure, it will likely take several years to recover. If deer repellent is not used in the future operations planned for the remainder of Molesworth station, then substantial immigration seems unlikely. In addition, this operation is to be repeated twice more within the next six years further preventing red deer recovery in this area. Therefore, small scale operations conducted in densely forested areas with moderate or high deer density may not impact on the hunting of red deer. However, large scale operations in open landscape may impact hunting of red deer for several years, further extended by consecutive operations over the same or adjacent areas.

Recommendations

The NZDA should actively seek the use of deer repellent for all vector control or pest management operations where hunting would be significantly negatively impacted without its use. Ongoing deer population and hunter use monitoring should be developed to provide a cost-effective way to identify areas where this would be the case and quantify the success of any mitigation techniques applied in operations for these areas. For example, a reliable system which records hunter returns would provide data on hunter usage and success, both before and after vector control operations.

Areas where deer repellent will be advocated for in the future should be clearly defined and presented to vector/pest control agencies to allow for accurate budgeting and appropriate planning of operations. Previously reported deer by-kill estimates may be used to indicate possible deer by-kill in comparable habitats only but should not be used to base decisions on for the application of mitigation, rather, the resource at risk determined as per above paragraph.

The increased cost of using deer repellent will undoubtably influence decisions around its application in future vector control operations. The development and field testing of deer repellents which are less expensive, but as effective at repelling deer should be encouraged to reduce the cost of mitigation. Alternatively, other bait dispersal methods, which significantly reduce costs while still being effective in vector control, should be considered to offset higher costs of using deer repellent. These alternative methods should only be used in conjunction with deer repellent to prevent any possible increased risks they may pose to deer.

The funding or development of a professional team, whose focus is to identify herds needing research, monitoring or surveying, with the experience and skills to direct or undertake such intensive tasks, would be of significant value to the NZDA and the hunting community. The planning, preparation and undertaking of surveys such as this require significant effort, time and resources, beyond that which is appropriate to expect of volunteers. When considering aerial surveys in the future, only pilots who have experience in research-based flying should by employed.

Acknowledgements

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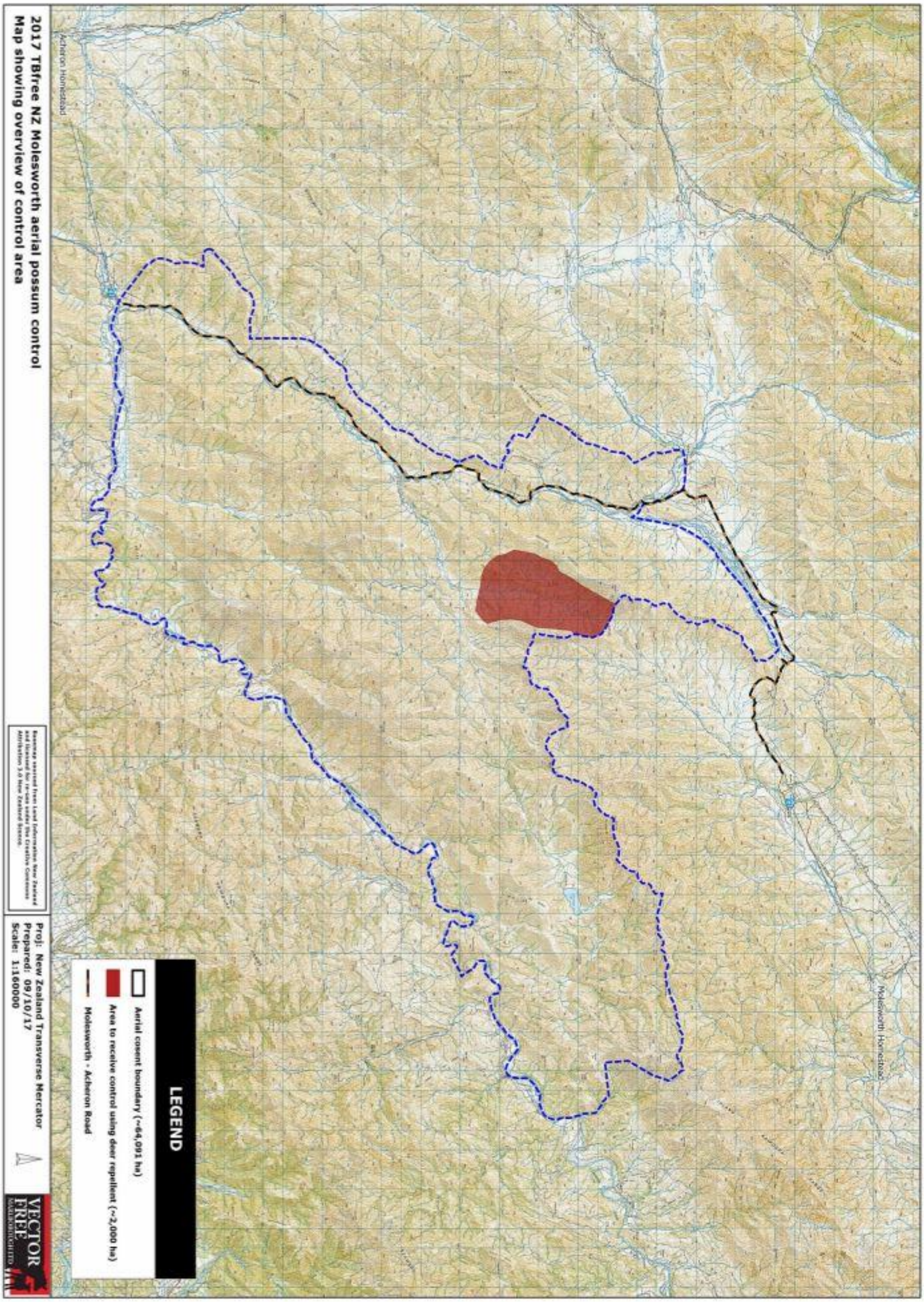
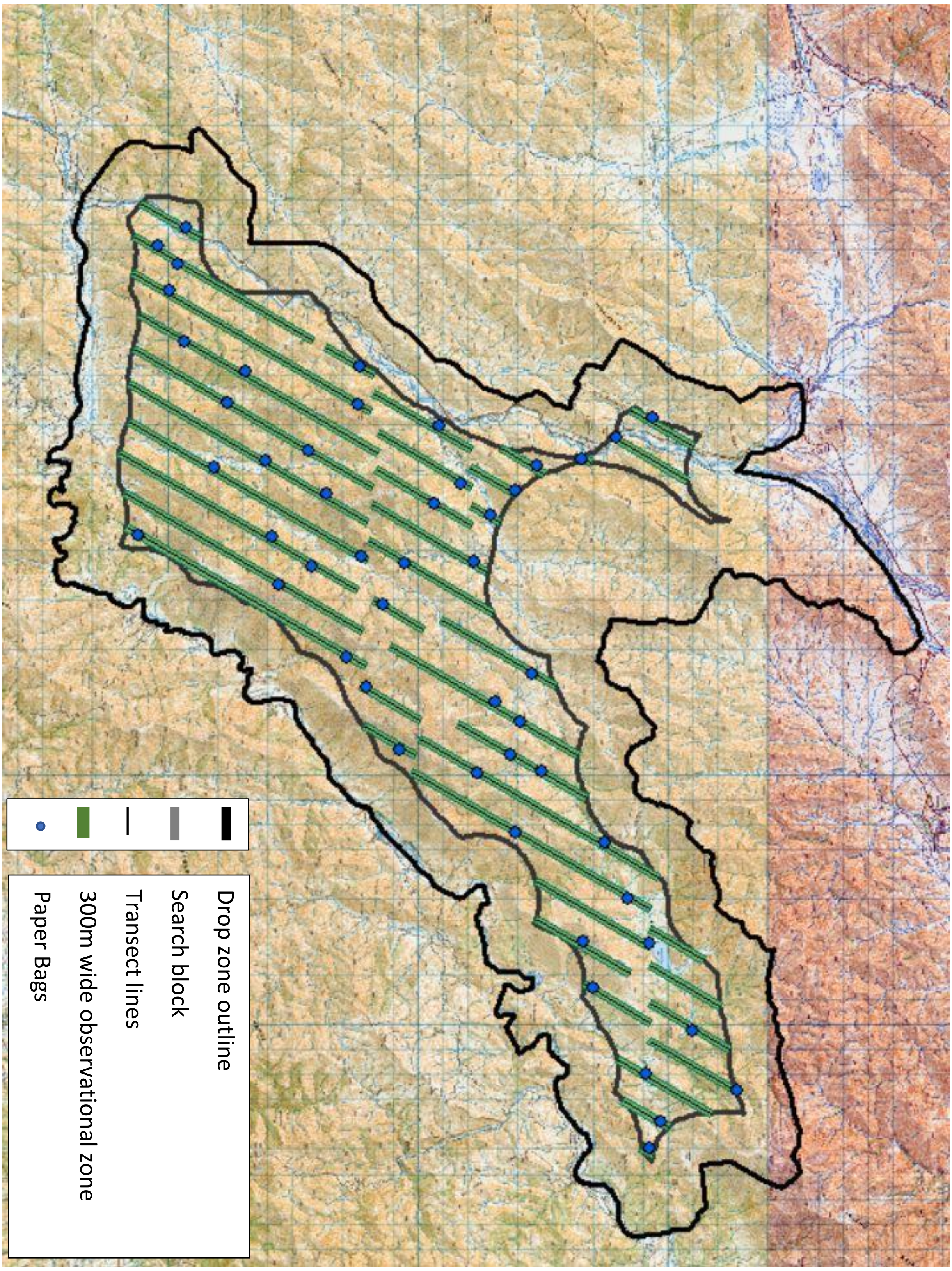
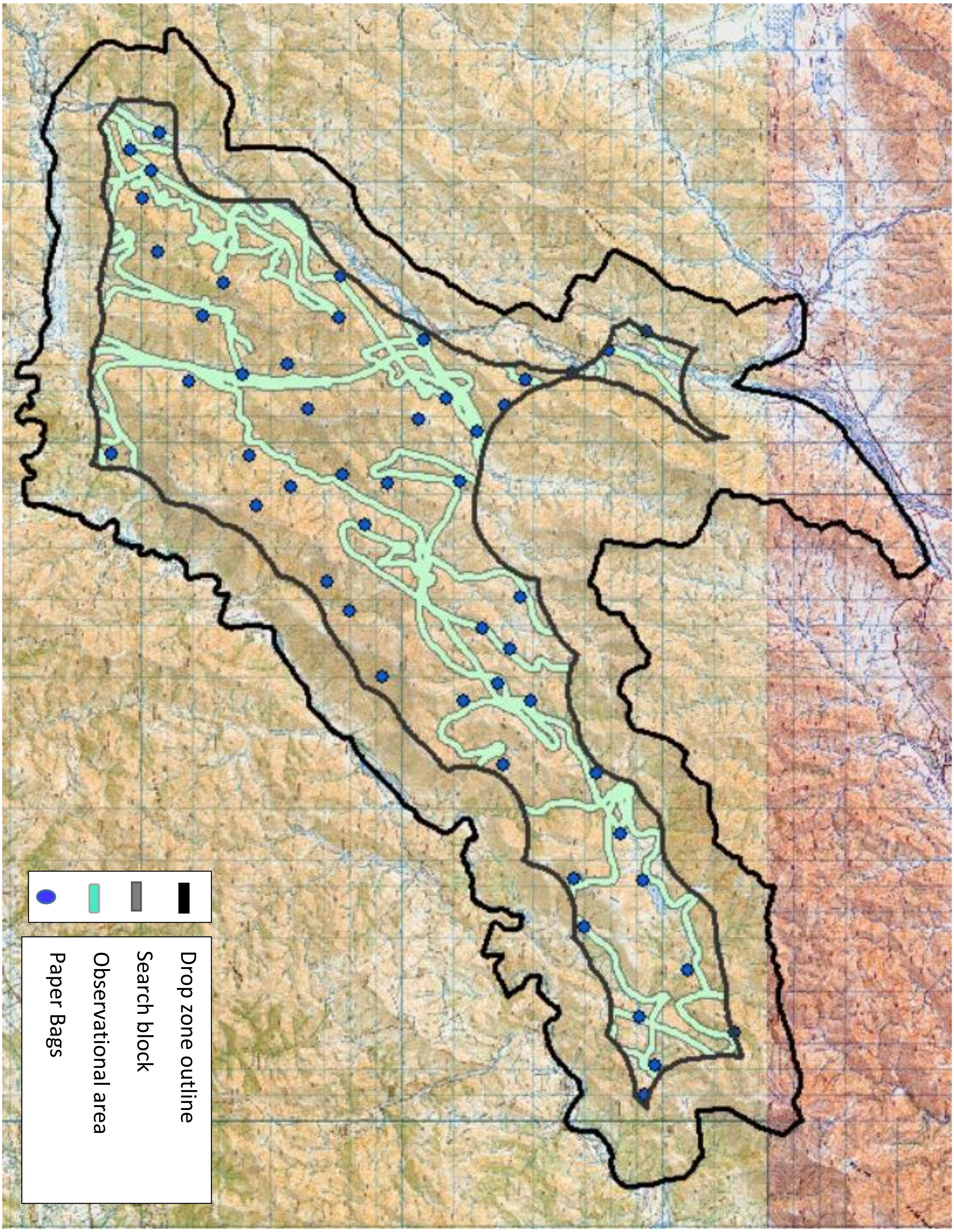
Appendix 1. Planned operational area supplied by TB free NZ



Appendix 2 Search block area within the drop zone displaying transect lines intended for the search and paper bag placement



Appendix 3. Search block area within drop zone displaying the actual observational zone and paper bag placements



Appendix 4. Results of 1080 residue analysis on 21 randomly sampled deer

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Landcare Research

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Toxicology Laboratory Analysis Report

Report No: T6697

CLIENT:

CLIENT REFERENCE No.:

Telephone No:

SAMPLES: Twenty one deer muscle samples
REQUIREMENT: Examine for brodifacoum
RECEIVED: 24 November 2017

Sample/s were received for analysis. The details were entered into the laboratory sample system and the sample/s given a reference number. The sample details and results are as follows:

No. samples: 21

LabNo.	Description	Fluoroacetate, µg/g
21400	Muscle tissue, MW06	0.34
21401	Muscle tissue, MW11	0.55
21402	Muscle tissue, MW19	0.19
21403	Muscle tissue, MW20	0.64
21404	Muscle tissue, MW21	0.69
21405	Muscle tissue, MW01	0.76
21406	Muscle tissue, MW07	0.33
21407	Muscle tissue, MW09	0.40
21408	Muscle tissue, MW14	0.81
21409	Muscle tissue, MW15	0.42
21410	Muscle tissue, MW18	0.64
21411	Muscle tissue, MW02	0.23
21412	Muscle tissue, MW03	0.63
21413	Muscle tissue, MW04	0.32
21414	Muscle tissue, MW05	1.32
21415	Muscle tissue, MW08	0.37
21416	Muscle tissue, MW12	0.36
21417	Muscle tissue, MW13	0.61
21418	Muscle tissue, MW16	1.20
21419	Muscle tissue, MW17	0.44
21420	Muscle tissue, MW22	4.89