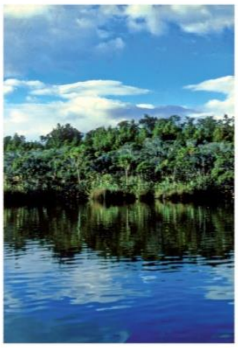

Eliminating TB from Molesworth Station:

II. Persistence of TB on Molesworth Station two years after aerial 1080 baiting

Animal Health Board

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Landcare Research
Manaaki Whenua

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Graham Nugent, Ivor Yockney, Jackie Whitford

Landcare Research

Prepared for:

Animal Health Board

PO Box 3412
Wellington

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Landcare Research, Gerald Street, PO Box 40, Lincoln 7640, New Zealand, Ph +64 3 321 9999, Fax +64 3 321 9998, www.landcareresearch.co.nz

Reviewed by:	*Approved for release by:*
Andrew Gormley Scientist Landcare Research	Andrea Byrom Science Team Leader Wildlife Ecology & Epidemiology

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Contents

Summary

Project and Client

- Landcare Research, Lincoln, was contracted by the Animal Health Board to determine the relative effectiveness of experimental aerial 1080 baiting strategies conducted in 2008 in reducing possum abundance and TB levels in wildlife on Molesworth Station, Marlborough. This report documents changes in the relative abundance of possums and TB prevalence in both wild resident and purpose-bred sentinel pigs in 2009–2011.

Objectives

- To determine whether reduced coverage or lower baiting rates are more effective than current approaches for reducing TB levels in wildlife on Molesworth Station, by:
    - Determining trends in relative densities of possums and other species (using Chewcard and WaxTags® indices) by annual monitoring in late 2009 and 2010.
    - Determining trends in TB levels in resident and sentinel pigs and cattle from late 2009 to mid-2011 in the 1080 baited areas and an unbaited area.

Methods

- In late 2008, experimental aerial 1080 poisoning treatments comprising four main combinations of two levels of landscape coverage and two sowing methods (broadcast vs cluster) were applied to 17 800 ha on Molesworth Station.
- The Residual Trap Catch Index (RTCI) method was used to assess possum abundance immediately after control. In late 2008, 2009 and 2010 pest abundance was assessed by using chewcards and WaxTags® (CC, WT, and WTCC indices).
- The effects of the 1080 operation on TB levels in wildlife were assessed from (1) surveys of resident pigs in poisoned and unpoisoned blocks in Autumn 2009, 2010, and 2011; (2) the release and recovery of 54 purpose-bred TB-free sentinel pigs of which 30 were fitted with GPS collars to obtain information on home range size and movement patterns; and (3) TB levels in cattle overwintered in the poisoned area.
- Additional data from related studies were collected on home range size and movement patterns of possums, and the efficacy of cluster-sown aerial-1080 baiting with ultra-low sowing rates in this habitat.

Results

- In baited areas, all indices of possum abundance (CCI, WTI, or WTCCI) decreased post-control to 6.2–7.9% of pre-control levels. One year post-control the transformed indices had increased to 24.4–27.7% of pre-control levels, and 2 years post-control to 44.7–55.4% of pre-control levels. The annual exponential rates of increase over the two years (0.97–1.08, n = 560 sites) were well beyond the reproductive capacity of possums. For the 107 sites located >75 m from where toxic bait was sown, the indices decreased by 84–91% immediately after

poisoning, and the subsequent annual rates of increase (0.70–0.75) were only marginally lower than those recorded inside the poisoned areas. The high rates of increase within the baited areas were not related to baiting coverage, with no indication of possum immigration from unbaited areas to baited areas.

- In pigs born before the 1080 operation, TB prevalence was high (71% overall), and higher in the poisoned than the unpoisoned area. That pattern was reversed after poisoning and, in relative terms, the apparent annual incidence (AAI) for the poisoned areas fell to one-quarter that of the unpoisoned area. However, pigs still became infected in the poisoned area in 2010/11, including one born in November 2010, suggesting a recent infection source. For pigs born in 2009, TB prevalence was significantly lower in the low-coverage areas (24%) than the high coverage area (67%), but for those born in 2010 the prevalences were statistically similar (20% and 29% respectively). The AAI for pigs released into the poisoned area was 0.31, compared with 1.34 in the unpoisoned area, again indicating a lower force of infection in the poisoned areas. For cattle overwintered in the baited area after 2008, we estimated an approximate annual incidence of 0.006 for both Winter 2009 and Winter 2010.
- The average home range size for 16 sentinel pigs (males and females) fitted with GPS collars was 506 ha (range 103–1948 ha). For 25 GPS-collared possums the mean home range size was 23.1 ± 6.1 ha (range 6.4–65.2 ha). Experimental aerial 1080 baiting in adjacent blocks on the Clarence Reserve in 2011 achieved a 94% possum kill using prefed cluster sowing at 0.25 kg/ha with 100-m flight path spacing, and 76% with unprefed cluster sowing at 0.05 kg/ha, with a 500-m flight path spacing.

Conclusions

- Although the 2008 aerial 1080 baiting operation successfully reduced possum numbers to <2% RTCI, the subsequent rapid increase in all of the indices to 45–55% of pre-control levels in the ensuing 2 years following control creates a high risk that any break in the TB cycle may be short-lived.
- Overall the poison operation reduced TB levels in pigs in the poisoned area by about 80% within 2 years. However, the detection of TB in pigs in all four blocks indicates that the source of TB remains widespread. This is further supported by the detection of TB in the ‘first calver’ herd of which half are overwintered in the poisoned area.
- One implication of the (inferred) continued widespread infection in possums after 2008, despite all blocks having RTCIs < 2% immediately after poisoning, is that the behaviour of possums on Molesworth is somehow much more conducive to TB transmission than is usual. If so, then the low-coverage strategy aimed at reducing aerial baiting costs may have been inappropriate. Eradication of TB from possums is likely to require either much more intensive or complete (with respect to coverage) possum control than was applied in 2008. Alternatively, 2008 operations would need to have been repeated several times at short – intervals (2–4 years).
- This study has demonstrated that on-site rearing of TB-free sentinel pigs for release to the wild is feasible. Combined use of residents and released sentinel pigs appears to be a cost-effective approach to TB surveillance in this area.
- Research elsewhere suggests high possum kills can be obtained using prefed cluster baiting to deliver small amounts (<250 g/ha) of toxic bait, with the large home ranges of possums

documented in this study indicating that flights paths of up to 200 m would still put all possums at risk even with cluster baiting and certainly with broadcast baiting.

Recommendations

- That the low-coverage strategy suggested as a way of reducing aerial baiting costs not be used in future, as it appears possible that TB could persist in some part of the area that is excluded from coverage (given that it has persisted for at least 2 years at the reduced possum densities of all four baited blocks).
- That further TB surveillance is conducted using resident pigs, in 2012 and/or 2013, to determine whether TB levels in wildlife remain at (or decline from) current reduced levels, or have begun to increase as a result of the possum population recovery. The outcome would provide guidance on the frequency of possum control (by aerial 1080 baiting) needed to eradicate TB from this area.
- That AHB and Landcorp consider reapplying aerial baiting of this area (and other high risk parts of Molesworth Station) as soon as is feasible within the funding resources available. Based on other studies, we suggest that the AHB's specification for cluster baiting (including aligned prefeeding) should enable the area to re-baited at a similar or less cost than the 2008 operation in which 1080 bait was applied at 2.5 kg/ha without prefeeding. Alternatively, prefed aerial broadcasting with large (12-g) baits and a wide (200–250 m) flight path spacing could be used.

1 Introduction

Landcare Research, Lincoln, was contracted by the Animal Health Board (AHB) to determine the relative cost-effectiveness and efficacy of two new tactics (reduced coverage and reduced sowing rates) in aerial 1080 poisoning of possums in reducing possum abundance and the incidence of bovine tuberculosis (TB) in wildlife (as assessed by the levels in released and resident wild pigs) on the eastern parts of Molesworth Station, Marlborough. Previous reports have documented the immediate reductions in possum abundance achieved by the late-2008 poisoning operation. This report documents the rate of recovery of the possum population over the 2 years post-control (late 2008 – late 2010), and the effect of reduced possum abundance on TB prevalence in both resident and sentinel pigs and in cattle.

2 Background

Molesworth Station (180,000-ha) and adjacent areas comprise a vast mountainous landscape that forms the last large farmed area in New Zealand in which possums and other vectors of bovine tuberculosis (TB) are not yet fully under intensive control. Historically the area was considered too large and contained too few cattle to warrant its inclusion in the second phase of the National Pest Management Strategy for TB (NPMS), but better-than-projected progress toward national NPMS goals has allowed some vector control to be initiated in parts of this area. However, the immense size of the area and the low density of farmed livestock it carries inevitably make the cost of vector control very high, both in terms of the total amount of funding required and especially in terms of the cost per livestock unit. Consequently, reducing the high costs associated with pest control is a major priority, and recent research has shown that two alternative bait application strategies may help significantly reduce costs.

First, possum densities are naturally low in parts of the area (Byrom et al. 2008), presumably because the unforested semi-arid landscape is sub-optimal habitat for possums, the main vector of TB. Further, there is a gradient in possum density across Molesworth Station, with highest densities in the central-south-eastern part, which is where TB is also most prevalent in wildlife and livestock (Nugent & Whitford 2007; Byrom et al. 2008). Research has suggested that foci of TB infection in possums occurred (and were likely to persist) only in small isolated patches of more favourable habitat that held above-average densities of possums (Nugent & Whitford 2007). An analysis of the biophysical correlates of an index of possum abundance, the Trap Catch Index (TCI; NPCA 2008a), was used to map the predicted relative abundance of possums across Molesworth Station. The first new tactic was therefore to impose possum control in only the most ‘possumy’ parts of the landscape, and we applied this tactic of partial landscape coverage at two levels. Under a safer (but more expensive) ‘high coverage’ treatment, control was applied to all habitat in which the predicted possum abundance exceeded a low threshold (5%TCI), while under a more risky but lower cost ‘low coverage’ treatment, only habitat in which the predicted possum abundance exceeded 10%TCI was controlled.

The second tactic for reducing costs was to reduce the cost of aerial 1080 (sodium monofluoroacetate) poisoning, the primary tool used for large-scale possum control in this and other remote areas. The most recent previous aerial poisoning operations on Molesworth Station had broadcast 1080-laden bait (without any non-toxic prefeeding) at a sowing rate of 2.5 kg/ha, but 2007 trials indicated that sowing rates could be reduced, without loss of efficacy, by sowing bait in clusters (Nugent et al. 2008). We therefore compared the effect of reducing the sowing rate by 60%, to just 1.0 kg/ha.

A large poisoning operation covering the south-easternmost 28 500 ha of Molesworth Station was undertaken in Spring 2008. It was the first aerial 1080 operation targeted at possum-Tb in this part of the station, and effectively completed the implementation of intial possum control over the parts of the station thought to contain Tb possums. Previous operations to the north and west in the early 2000s had contributed to a rapid decline in TB in cattle and (in those areas) pigs (Byrom et al. 2008; Nugent et al. 2011). The 2008 operation was structured to enable us to apply four different combinations of coverage and sowing rate (Figure 1). The initial reductions in possum density have been reported previously (Yockney & Nugent 2008; Nugent et al. 2009). The actual overall reduction in possum abundance (to an average post-control RTCI of 0.9%) is likely to have exceeded 90%, with no evidence of any consistent difference in efficacy between the broadcast- and cluster-baiting techniques.

Over the subsequent two years the recovery of the possum population was monitored using interference devices, and we assessed the impact of the reduction in possum abundance on TB levels in wildlife by monitoring TB levels in both resident and deliberately released sentinel pigs. This report documents those findings, and combines them with AHB data on the trends in TB levels in cattle, and with findings from other research, to assess the likely relative cost effectiveness of each combination of sowing rate and spatial coverage in reducing TB levels in wildlife. It also summarises data on pig movements and home range size that were collected while tracking the released sentinel pigs.

The report also includes some relevant ancillary data collected in a parallel Ministry of Science and Innovation (MSI)-funded programme (C09X0803 Sustaining TB freedom) aimed at investigating the relative efficacy of lethal control and vaccination of possums in an area adjacent to Molesworth Station. Specifically, we briefly summarise the outcome of two experimental aerial 1080 poisoning protocols in which low (0.25 kg/ha) and very low (0.05 kg/ha) sowing rates of 1080 bait were used, and some GPS-tracking data for possums showing larger-than-usual home range sizes in habitats similar to those on Molesworth Station.

3 Objectives

- To determine whether reduced coverage or lower baiting rates are more effective than current approaches for reducing TB levels in wildlife on Molesworth Station, by:
    - Determining trends in relative densities of possums and other species (using Chewcard and WaxTags® indices) by annual monitoring in late 2009 and 2010.
    - Determining trends in TB levels in resident and sentinel pigs and cattle from late 2009 to mid-2011, in the 1080 baited areas and an unbaited area.

4 Methods

4.1 Design

Four different aerial 1080 bating treatments were imposed. These comprised an unreplicated 2×2 factorial design with two levels of landscape coverage and two sowing rates.

- Block 1 (low-coverage broadcast): Low coverage of the landscape (through targeting of only those areas predicted to have a TCI > 10%), with 2.5 kg/ha of 1080 cereal bait broadcast in the areas actually poisoned
- Block 2 (high-coverage cluster): High coverage of the landscape (through targeting of those areas predicted to have a TCI > 5%), with 1.0 kg/ha of 1080 cereal bait sown in clusters in the areas actually poisoned
- Block 3 (high-coverage broadcast): High coverage of the landscape (through targeting of those areas predicted to have a TCI > 5%), with 2.5 kg/ha of 1080 bait broadcast in the areas actually poisoned
- Block 4 (low-coverage cluster): Low coverage of the landscape (through targeting of only those areas predicted to have a TCI > 10%), with 1.0 kg/ha 1080 cereal bait sown in clusters of in the areas actually poisoned

Treatement were allocated to blocks, at the behest of the Station Manager, according to the TB-risk to cattle; (i.e.; the high coverage treatments were applied in Blocks 2 & 3, the main grazing area). The 'high-coverage broadcast' treatment (Block 3) was the approach most similar to the most recent previous aerial poisoning operations targeting possums on Molesworth Station. Like those previous operations, prefeeding was not used in the four blocks above because this almost doubles the cost. Also, previous non-prefed operations on Molesworth had successfully (and quickly) reduced cattle-reactor rates (J. Ward, pers. comm.) and the incidence of TB in pigs (Byrom et al. 2008).

4.2 Study areas and poison operation

The study blocks (Figure 1) were delineated in consultation with Molesworth Station staff. The area to be poisoned within each block was then defined by using the spatial model developed by Byrom et al. (2008) to identify and exclude areas with a predicted pre-control Trap Catch Index (TCI) below the designated coverage targets specified in Section 4.1. As it is not practical to aerially sow bait into (or leave out) small areas of up to 50 ha, the boundaries of respective treatment areas were smoothed to facilitate aerial sowing. Smoothing involved including within the area to be treated any small area that had a lower predicted possum density than was required for inclusion. In addition, the resource consent for the operation imposed a 150-m exclusion zone alongside the Clarence River. This exclusion zone was not controlled.

The non-treatment Clarence Reserve (37,000 ha) is located adjacent to, and southeast of trial blocks 5, 1, 3 and 4 but is divided from Molesworth by the Clarence River, a significant geographical barrier for wildlife immigration between sites.

Cinnamon-masked green-dyed RS5 cereal bait with a nominal mean weight of 8 g (Animal Control Products, Wanganui) was applied, without prefeeding, along flight paths spaced 130 m apart. Poison bait was sown on 29–30 October 2008. Two Squirrel helicopters were used with either a 500-kg bait-capacity bucket or 700-kg bucket. The reloading site was at the Molesworth homestead, about 25 km from the centre of the poisoned area.

An additional small block (Block 5, Figure 1) was also poisoned at the same time, using the high-coverage cluster approach but (unlike the four main blocks) with prefeed applied beforehand. We recorded 100% reduction in interference in that block (Nugent et al. 2009), but possum recovery there was not monitored so it is not included in this report. The total area poisoned was 17 800 ha.

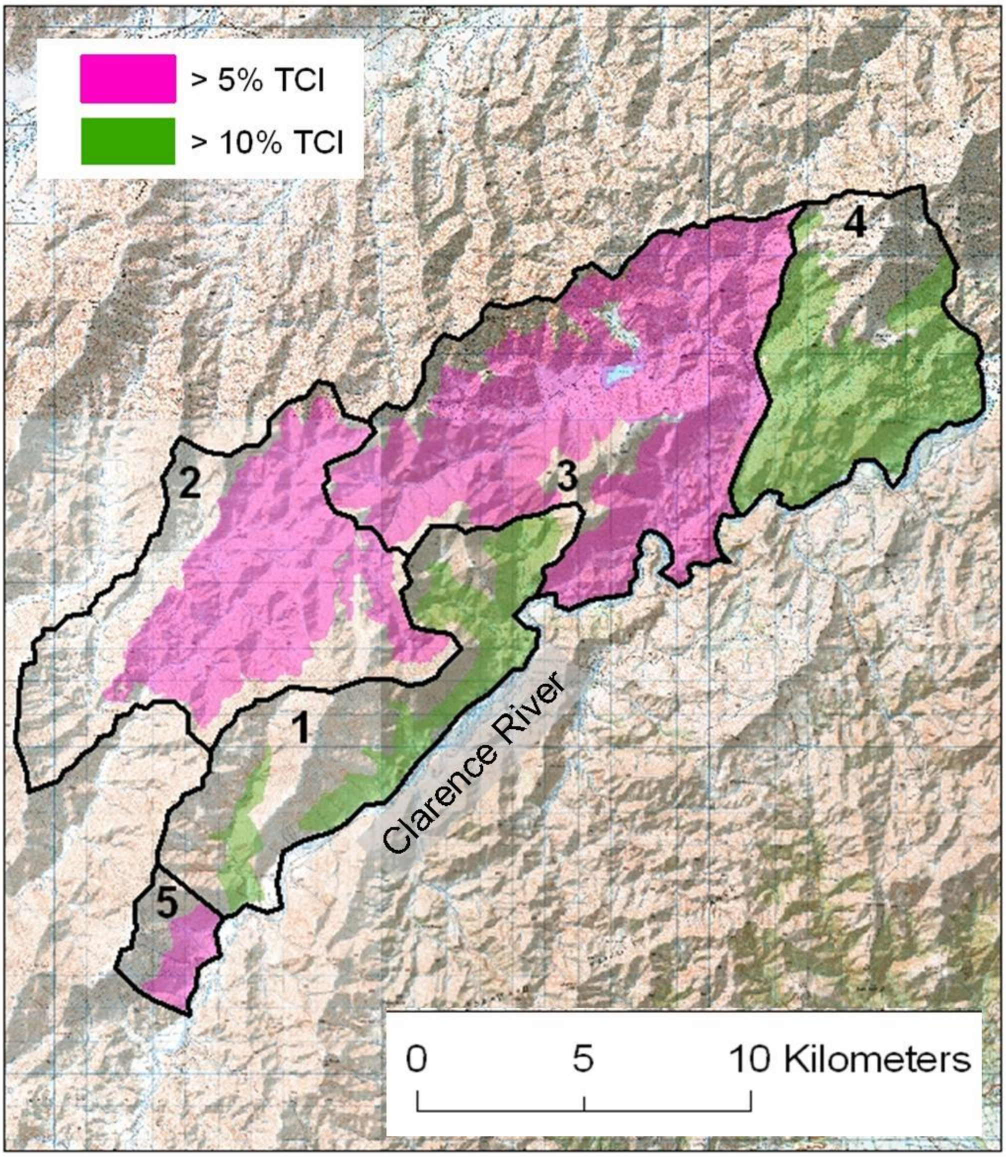

Figure 1 Study area showing five blocks on Molesworth Station, where one of the various aerial poisoning treatments was applied to the shaded area in each block. In Blocks 2, 3, and 5, all of the habitat in the shaded treatment area was predicted to have a pre-control possum Trap-Catch Index (TCI) > 5%, whereas in Blocks 1 and 4, only habitat with a predicted TCI > 10% was included. The non-treatment Clarence Reserve is the area to the south and east of the Clarence River.

4.3 Trends in the abundance of possums (and other species)

To determine the relative effect (from late 2008 to late 2010) of the different treatments on possum abundance (and incidentally on that of other species), we used the rate at which each species left bite marks on two different 'interference' devices: chewcards and WaxTags®. Chewcardss are plastic corflute cards baited to attract animals (Sweetapple & Nugent 2011), whereas WaxTags® are functionally similar but unpalatable devices that animals bite out of curiosity (NPCA 2008b).

In each block, 1-km-long transects were established. These began at random accessible start points near main watercourses and were directed upslope toward the nearest boundary of the area to be poisoned. Some, but not all, transects extended outside the area to be poisoned, by up to 300 m. Every 50 m along each transect, one chewcard and one WaxTag® were pegged to the ground using a metal peg, with the waxtag 10 m away from the chewcard. The location of each device was recorded and mapped. Chewcards were baited as recommended by Sweetapple and Nugent (2008). Interference (bite marks) according to species was classified in the field, but those field classifications were later checked in the laboratory, using a microscope where necessary.

Devices were first deployed on 18–24 September 2008 (pre-control), checked and replaced between 7 and 9 November 2008 (about one week after control), and then checked and removed between 18 and 28 November 2008. As this was the first time that aerial cluster sowing had been used operationally, there was concern that possums might not find bait for some time after poisoning. To check whether any card chewed in the post-control survey might have been bitten by possums subsequently poisoned, the bitten cards found during the 18–28 November check were replaced, and checked and removed on 18 December.

The long time-interval between first deployment and the immediate post-control check was caused by the poison operation being postponed. The resulting difference in the length of time between checks means that any reduction in interference rates is likely to be overestimated. However, we assumed that this bias will have been the same for all blocks, and therefore that the reductions reported provide a valid *relative* index of the differences in true reduction between blocks.

In 2009, devices were deployed on 18 and 19 November and checked and removed on 29 November. In 2010, devices were deployed on 16 and 17 November and checked and removed on 27 November. The same transects were used in each of the three (2008, 2009, 2010) post-control surveys, in order to eliminate variation due to transect location from analyses of the trend through time in the three post-control surveys.

For subsequent analyses, cards were classified as being either inside the poisoned area (i.e. <75 m from a helicopter flight path) or outside (the remainder). Devices not found during the checking phase of surveys were excluded. The percentage of sites on each line at which bite marks indicated a species was present were used to calculate a Chewcard Index (CCI), a WaxTag Index (WTI), and a combined index (WTCCI). The latter is the percent of sites with *either* chewcard or waxtag interference. The indices recorded immediately after control were used as an index of pre-control abundance, while those recorded 3 weeks after control were used as indices of the post-control abundance. Because percent indices of animal abundance usually exhibit a curvilinear relationship with absolute density (becoming saturated at high index levels), we endeavoured to increase linearity a least somewhat by applying a Poisson transformation to the indices the data (Caughley 1977).

For comparing trends in animal activity through time within the poisoned area (i.e. for the bulk of the sites), each of the three indices was calculated separately for each line, and the line mean estimated for each survey unit and year. On most lines there were few or no sites outside the poisoned area, so indices were calculated from the pool of sites for the whole block rather than for each line.

Using the combined WaxTag and ChewCard Index (WTCCI), a linear- mixed effects model (Pinheiro et al. 2011) package 'nmle' in the R statistical computing environment v2.13.1 (R Development Core Team 2011) was used to compare the annual exponential rates of increase recorded for each transect between the low coverage and high coverage blocks. Block differences were treated as a random effect and coverage as a fixed effect.

4.4 Effect of 1080 poisoning on TB levels in wildlife and cattle

To assess the effect of the reduction in possum numbers on TB levels in wildlife we surveyed wild resident pigs, released and recovered purpose-bred TB-free sentinel pigs, and obtained and collated herd testing data for cattle grazed in the poisoned area on Molesworth Station. Similar data were also collected from an adjacent unpoisoned or 'non- treatment' area to the south-east (Clarence Reserve), which served as an experimental control.

4.4.1 TB levels in resident pigs

To determine the effect of the 1080 poisoning on TB levels in resident pigs we conducted necropsy surveys of pigs in the four poisoned areas and on the adjacent unpoisoned Clarence Reserve. Historic data on TB prevalence in pigs for these areas were available from previous research (Byrom et al. 2008; Nugent & Whitford 2007; Nugent et al. in press). In total, data from 220 pigs were available from these 'baseline' surveys spanning 1999–2008.

Between September 2009 and May 2011, as part of this study, we obtained data for a further 296 resident pigs. Most were obtained from 21 aerial hunting forays (predominantly on Molesworth Station) but a further 126 were obtained by ground hunting (mostly on the Clarence Reserve) during the same period.

Wild pigs were obtained for necropsy using two different aeral shooting techniques (Figure 2):

1. Shooting of resident pigs – where hunting was conducted at productive times of the year when pigs were highly visible (predominantly late autumn and winter)
2. Judas shooting – where sentinel animals were radio-tracked and their associates shot. This was usually conducted when shooting of resident pigs became less productive (on a ratio of flight time to kill)or while recovering sentinel animals. See Yockney & Nugent (2006) and Knowles (1994) for more detailed explanations of this technique.

Figure 2 Aerial shooting on Molesworth Station.

Some pigs were necropsied whole, occasionally where killed but more usually at one of several field processing sites in the study area. For most pigs, however, only the head was inspected, either at one of the field processing sites or in a purpose-designed necropsy facility at Landcare Research, Lincoln. Previous research has shown little loss of diagnostic sensitivity from restricting inspection to the head, because it is the predominant site of infection in pigs (Nugent et al. in press). All necropsied pigs were assigned a unique ID number.

Necropsies were conducted by experienced staff, using sterile techniques. For all pigs, inspection of the head involved removal and thin slicing (1–3 mm) of the submaxillary, parotid, retropharyngeal and atlantal lymph nodes and the oropharyngeal tonsils. The jaw was also removed for ageing, using the methods described by Clarke et al. (1992). The kill date and age at death were used to assign pigs to latest-likely-birth-year cohort, and to assess whether they were likely to have been born before or after poisoning in late 2008.

For the whole-body necropsies each pig was weighed, tagged, measured (body length), and key tissues were inspected in the thoracic cavity (visual inspection of the pleura and lungs, and thin slicing of the bronchial, apical and mediastinal lymph nodes), the abdominal cavity (thin slicing of the liver and kidney, and of the hepatic, renal, and ileocaecal and ileojejunal lymph nodes associated with the intestines, as well as the internal subiliac lymph nodes) and the body (thin slicing of the inguinal, popliteal, precural and prescapular lymph nodes). The submaxillary lymph nodes of all pigs, including those with no visible lesions (NVL), were submitted to AgResearch, Wallaceville, for mycobacterial culture.

4.4.2 TB levels in released sentinel pigs

Because feral pigs range widely (see 5.3) it was not possible to be certain that any resident pig found to be infected had actually acquired infection within the study block in which it was shot. We therefore aimed to complement the resident pig data with data from deliberately released (and later recovered) sentinel pigs fitted with GPS and/or VHF radio-collars that enable us to more definitively identify the area they occupied during the time they were in the wild and potentially exposed to TB infection.

The sentined pigs used were raised from wild-type breeding stock held in a 1-ha pig enclosure on Muzzle Station, on the edge of the Clarence Reserve. During November 2008, wild pigs were captured alive in the Marlborough Sounds (outside a TB-infected area) and pregnancy-scanned.

Those pigs that appeared to be pregnant were lightly anaethestised and transported via vehicle or light plane directly to the enclosure on Muzzle Station. Seven sows and a boar captured locally using a trained live-capture dog were added in February 2009. The capture methods, construction of the pens, and husbandry were the same as those documented in previous studies (Byrom et al. 2008), except that we constructed enclosed yards and a work bench to faciltate capture, sedation and surgery of pigs to be released with implanted transmitters (see below). All animal manipulations were covered under Landcare Research Animal Ethics Approval 08/07/03.

All released sentinels were surgically implanted with a single VHF transmitter (Sirtrack, Havelock North) to enable radio tracking and eventual recovery of released pigs. In addition, 30 pigs were fitted with either a GPS collar or GPS implant unit. Implantation procedures are described in Appendix 1. During implantation, pigs were also injected in the ear with 0.1ml of tuberculin.

Three days later these pigs were remustered in the pen, and resedated with Zoletil (1 ml per 40 kg). GPS collars were fitted to some at this time, the TB test was read, and the VHF transmitter was checked. Pigs were then placed in a flat-floored steel-sided transport crate capable of holding up to six pigs. A helicopter was then used to transport them to predetermined release sites chosen to be well within each treatment block, and as far as possible to be close to good pig habitat.

After release, we attempted to re-locate each pig on several occasions using the lack-of-motion ('mortality') sensing capabilities of the radio-transmitters to check if the pig was dead or if the collar had fallen off. For more detail on telemetry procedures see Appendix 1.

Sentinel pigs that remained alive were eventually shot and recovered using a helicopter, and their kill location recorded. The pigs recovered were necropsied whole and inspected for TB as for resident pigs above. The timing of recovery varied depending on our perception of the risk that pigs might be killed by private hunters and the data lost. Although hunting pressure was restricted by land managers at both sites throughout the duration of the study, some recreational pig hunting did occur, with a substantial number of sentinel deaths on Molesworth Station (20) but few on the Clarence Reserve site (3).

In total, 82 sentinels were bred, TB-tested (all negative), fitted with GPS devices and/or VHF transmiters, and released either into one of the four treatment blocks on Molesworth (n = 64) or the non-treatment area (n = 18) between May 2009 and July 2010. Of these, 54 were successfully recovered. Of the remander, 5 could not be re-located, and 23 were found to be dead but considered too rotten to necropsy.

The recovery rate of approximately 64% of sentinels released, while disappointing, is not entirely unexpected. The average age of a pig on Molesworth is approximately 20 months (Byrom et al. 2008), suggesting a high natural mortality rate in this environment coupled with occasional hunting pressure by recreational hunters with dogs. This would suggest that a balance needs to be found between length of exposure for sentinel animals and the risk of mortality during this time.

The mortality rate of sentinels was nearly twice as high on Molesworth 31% (n = 20 of 64 released) as on the Clarence Reserve 16% (n = 3 of 18 released), suggesting either higher natural mortality or hunting pressure on Molesworth.

4.4.3 TB levels in cattle

We obtained an overall summary of cattle testing data for Molesworth Station from the AHB (S. Loeffler pers. comm.), and also some more detailed data for the 'first calver' group of cattle, some of which are overwintered in the treatment blocks above. This herd starts as approximately 1200 heifers, which are grazed from April to December with the steers in the Acheron. In January of each year the heifers are separated at Tarndale and are tuberculin-skin and blood-tested then. Approximately 500 of these animals are 'culls' and taken out to Hanmer; the remaining approximately 700 heifers are moved to the Awatere Valley to run with the bull around the Molesworth homestead. In May the heifers are pregnancy-tested, after which the herd is split, with approximately 350 heifers being mustered out to Lake McRae for the winter, while the remaining heifers from this herd graze around the Molesworth homestead for the winter. In October the Lake McRae heifers are mustered out of the block, joined back with the homestead heifers, and then skin- and blood-tested. This herd is then sent to the Alma area and as 3-year-olds referred to as the 'Tarndale Herd' and are never grazed in the Lake McRae block again.

4.4.4 Analysis

The sentinel and resident pigs were classed as infected (or not) based, ultimately, on the results of mycobacterial culture, and TB prevalence for each was calcuated from the percentage infected, with 95% confidence intervals calculated after Collet (1991). For each resident pig, an age (in months) was assigned based on the dentition, up to a maximum of 42 months when the full dentition is attained. Birth year was estimated by subtracting the age from the kill date.

We used apparent annual incidence rates (AAI: estimated number of new infections per year of pig exposure; Thrusfield (1995) to quantify and compare the rates at which resident and sentinel pigs became infected. For resident pigs, we assumed that piglets did not become infected until after 2 months of age, and for each pig, calculated the exposure time (in months) as the age in months minus 2 months for uninfected pigs, and as half that number for infected pigs. The AAI was then calculated for each sample group as the number of infections per year to total exposure (see Nugent et al. 2011a). In areas where the annual incidence is high, the AAI is strongly biased low for older pigs, because the majority of them are likely to have become infected well before they reached half their age at death. For sentinels, the exposure period was the time between release and recovery.

4.5 Ancillary data

4.5.1 Pig movements and home range size

The radio-tracking and GPS data were used not only to identify which block (or blocks) each sentinel pig had occupied during the time it was in the wild, but also to assess how much of each block they 'surveyed' during that time.

Of the 30 pigs fitted with GPS devices, 14 failed to produce enough useful data, for a variety of reasons. The most common reasons were that the collar slipped off the pig at an early stage, failure of the GPS implant, or that the collar ran out of battery power well before its predicted lifespan. Two collars were never recovered, due to lack of a trackable signal, most probably due to the aerials being chewed by other pigs, which is a common occurrence.

Data downloaded from the GPS devices recovered were used to map the areas used by the sentinels during their time in the wild, and to estimate home range size. Home range size was caluclated using 'Home Range Tools (v1.1) add-on' in ArcGIS (v9.3; Environmental Services Research Incorporated, Redlands, CA) (Rodgers et al. 2005). We used the reference method (Seaman et al. 1999) with a 95%

kernel home range using the adaptive kernel method (K95; e.g. Worton 1989; Kie et al. 2002), and using a raster cell size of 12 m.

4.5.2 Possum movements and home range size in late spring

The low-coverage tactic being investigated in this project was based on the assumption that resident possums occupied stable home ranges that were small in relation to the size of the treatment areas. In an observational study designed in part to test that assumption, we radio-collared 30 possums on Muzzle Station in 2009, in similar habitat about 6–10 km downstream from the eastern boudary of Molesworth Station.

Possums were captured and fitted with GPS/VHF collars that allowed for up to six fixes per night. Captured possums were released at the point of capture (presumably within their normal home range) and not recovered until some 6 months later. We obtained sufficient GPS data for the October–December period (i.e. spanning the timing of the annual possum surveys undertaken in this project) from 25 possums. Home ranges were assessed as for pigs above.

4.5.3 Low cost aerial poisoning

Insight into the cost of controlling possums in Molesworth-like landscapes was provided by an MSI-funded aerial 1080 baiting operation conducted in January 2011 for research purposes in four 1000-ha blocks on the Clarence Reserve. In two of the blocks, we aimed to achieve a high kill (>90%) using 75% less toxic 1080 bait than used in the 2008 Molesworth operation (i.e. 0.25 kg/ha cf. 1.00 kg/ha) but *with* prefeeding. In the other two blocks, we specifically aimed to achieve a moderate kill (~75%) using 95% less toxic 1080 bait than used in the 2008 Molesworth operation (i.e. 0.05 kg/ha cf. 1.00 kg/ha) *without* prefeeding.

The 'high kill' treatment comprised application of prefeed (non-toxic unlured, undyed 2-g cereal RS5 baits applied at 0.50 kg/ha on 13 January 2011, with a slow-speed spinner used to broadcast bait over a 40–50-m swath centred on flight paths spaced 100 m apart. Toxic cinnamon-lured green-dyed 6–8-g RS5 cereal 1080 (0.15% concentration) pellets were then sown in clusters along the same flight paths on 25 January 2011, at a rate of 0.25 kg/ha. Bait clusters were spaced 50 m apart, with ~20 baits per cluster. This protocol produced near total kills of possums, rats and mice in mixed beech forest at Maruia in winter 2010 (Nugent & Morriss 2010).

The 'low kill' treatment did not include prefeeding, and comprised application (also on 25 January 2011) of toxic cinnamon-lured green-dyed 6–8-g RS5 cereal 1080 (0.15% concentration) pellets in clusters along the flight paths spaced 500 m apart at a rate of 0.05 kg/ha. Bait clusters were spaced as above.

Possum kill was assessed directly from the mortality of radio-collared possums. Possums were captured by leg-hold trapping in each of the four blocks in December 2010, and each possum fitted with a mortality-sensing VHF radio collar (Sirtrack, Havelock North).

5 Results

5.1 Trends in pest abundance

5.1.1 Possums

All of the indices of possum abundance decreased to low levels immediately after poisoning, but then increased rapidly over the following two years (Figure 3). Overall, for the 560 monitoring sites within the four poisoned blocks combined, the transformed indices declined to 6.2–7.9% of pre-control levels, depending on the index (CCI, WTI, or WTCCI). One year later, the transformed indices had increased to 24.4–27.7% of the pre-control levels, and 2 years later to 44.7–55.4%.

Again depending on the index, the annual exponential rate of increase was 1.41–1.47 in 2008–09, and 0.54–0.90 in 2009–10 (see Figure 4). These very high rates of increase appear to be well beyond the reproductive capacity of possums, as the intrinsic (or maximum) rate of increase (r_m) is considered to be in the 0.35–0.45 range (Nugent et al. 2010). The results therefore indicate either errors in the data, some change in the relationship between the indices and possum density, high immigration rates, or some combination of these.

We did identify some anomalies in the data. Specifically, and for chewcards in particular, zero CCI indices were recorded on three transects in Block 2 before control, yet by 2010 the indices for these lines were moderate or high (CCI range 19–38%). That indicates that either possums were (for unknown reasons) well below carrying capacity at those sites even before control, or there are some technical problems with the index recorded on those transects. However, excluding these three transects had only a small effect on the estimated overall rate of increase.

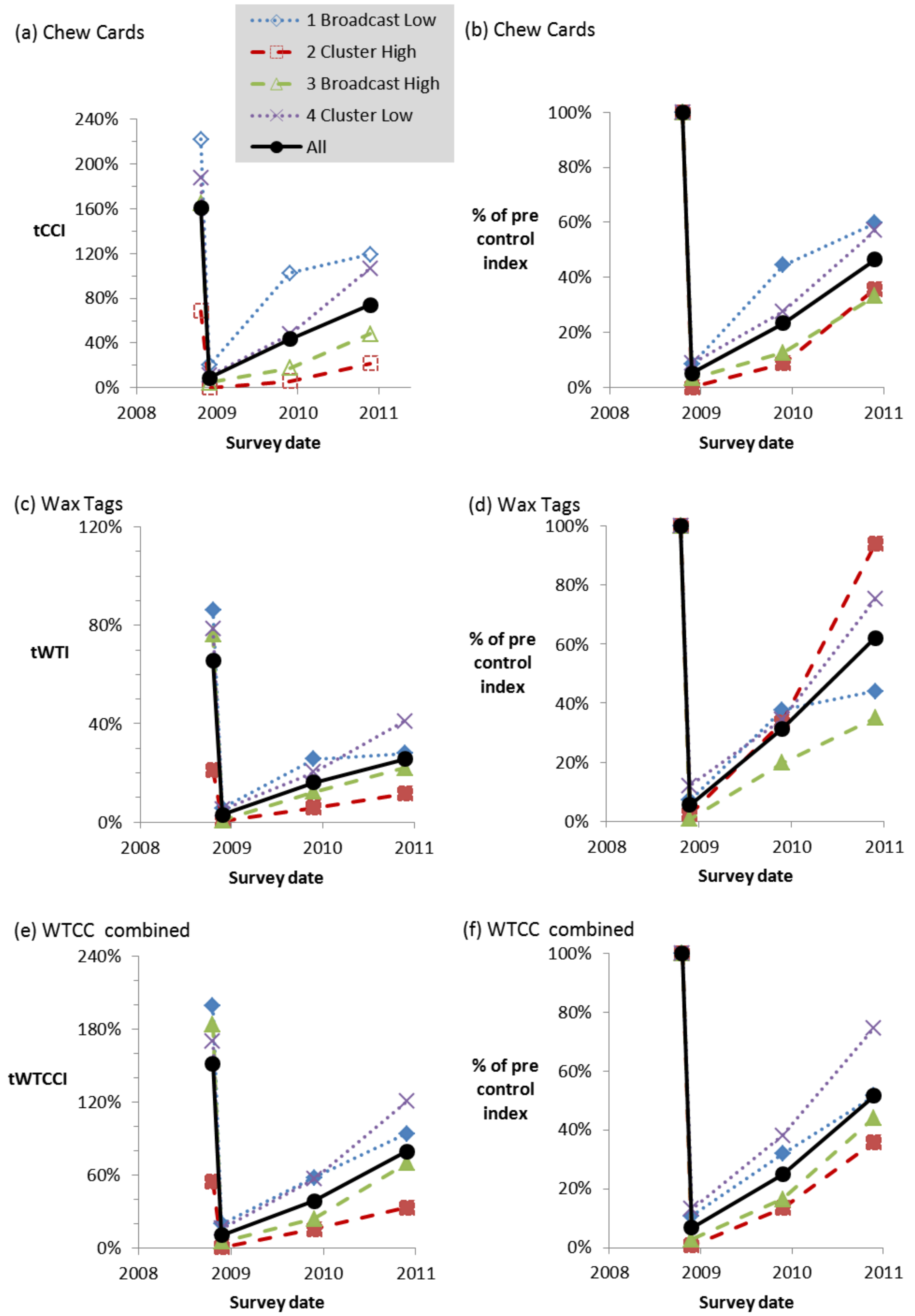

Figure 3 Changes in three indices of possum abundance over 2 years in response to aerial 1080 baiting in late 2008, for four blocks on Molesworth Station and overall. The leftmost graphs (a,c,e) are the Poisson-transformed indices actually recorded, while in the rightmost graphs (b,d,f) the post-control indices are all expressed as a percentatge of the pre control indices for the particular area. Only monitoring sites <75 m from the 1080-baited area are included, and data from three anomalous transects in Block 2 are excluded. The legend labels show block number, sowing method (broadcast or cluster), and coverage (high or low).

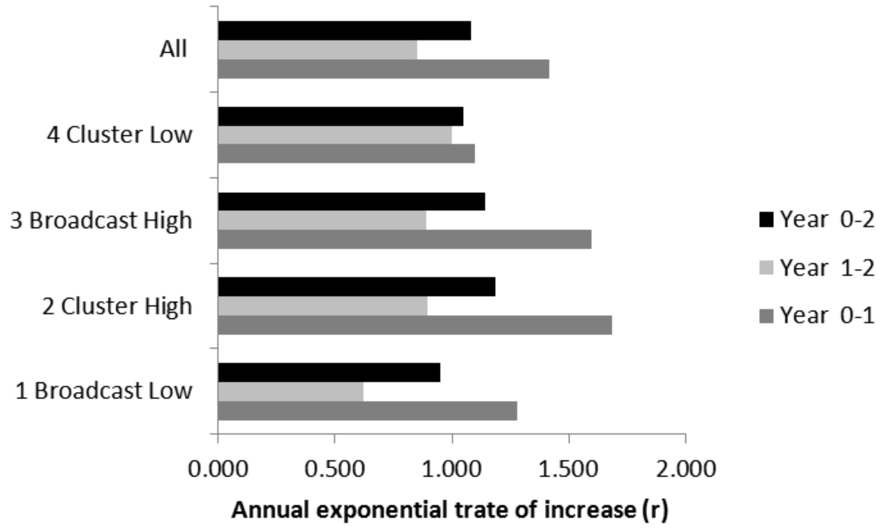

Figure 4 Annual exponential rates of increase in the combined WTCCI, for each block on Molesworth Station and overall, for the first year after control (Year 0–1), the second year after control (Year 1–2), and for the 2-year period after control (Year 0–2). The legend labels show block number, sowing method (broadcast or cluster), and coverage (high or low).

There were 107 sites located >75 m from where bait was sown. The indices recorded at these sites decreased by 84–91% immediately after poisoning, and the subsequent annual rates of increase over the 2-year post-poison period were also high, although somewhat lower than those recorded inside the poisoned areas (0.70–0.75 for the 107 sites outside the baited areas compared with 0.97–1.08 for the 560 sites within baited areas). There was therefore no evidence that the rate increase in the adjacent unbaited zone was being slowed by emigration of possums from there into the baited areas.

Comparison between the four blocks indicated higher post-control indices in the low-coverage blocks than in the high-coverage blocks (Figure 3 a,c,e). Expressed as a percentage of pre-control indices, however, there did not initally appear to be any consistent pattern with coverage, but when the three anomalous transects with zero pre-control CCIs (see above) were excluded, outcomes were consistent with there being a slightly slower recovery in the high-coverage blocks (Figure 3 b,d,f). As there was no signficant difference between blocks in the annual exponential rate recorded over the 2 years after baiting (t_2 = 0.15, P = 0.90), the difference in the extent of recovery toward pre-control possum abundance reflected differences in the numbers left after control (see Yockney & Nugent 2008; Nugent et al. 2009).

Incidental data were obtained for several other species. The number of rabbits detected on the 665 sites monitored each year varied from 14 (2.1%) before control, 9 (1.4%) immediately after, 5 (0.8%) in 2009, and 19 (2.9%) in 2010, providing no evidence of any major effect of poisoning on rabbit numbers. Likewise, there were no apparent effects on ferrets with 6 (0.9%) ferret detections recorded in all surveys except 2009, when there were none. However, the number of hedgehog detections declined from 10 (1.5%) before control to 1 (0.2%) immediately afterward, 7 (1.1%) in 2009, and 12 (1.8%) in 2010.

For mice, we originally reported high detection rates, but are now uncertain as to whether some of the large number of detections recorded in 2008 were caused by another species. Specifically, interference on chewcards was often assigned to mice where the peanut bait had been removed from the corflute channels to a depth of 3–5 mm (as is typical of mouse interference) but there were no obvious bite marks. We now suspect some of that interference may have been caused by invertebrates (possibly grasshoppers or weta), and so do not make any attempt to assess trends in mouse numbers.

5.2 Effect of 1080 poisoning on TB levels in wildlife and cattle

5.2.1 TB levels in resident pigs

Previous 'baseline' surveys indicated very high TB prevalence in pigs in both the poisoned blocks on Molesworth Station and the unpoisoned Clarence Reserve study area (Table 1). The AAIs for the earliest birth-year cohorts appear low, but this is an artefact of the age bias in estimating AAI – the earliest chorts are made up of older animals born before the surveys were begun. Comparison across the three birth-year cohorts suggests TB levels were consistently higher on Molesworth than on the Clarence Reserve, perhaps almost twice as high, during 2002–2007.

In this study, 295 resident pigs were necropsied, and 168 (56.9 (51.1 – 62.7 95% CL)) were confirmed by culture as infected. There was no evidence of a difference between males (60.4% infected, n = 139) and females (52.9% infected, n = 136) (Fisher's Exact Test; P = 0.14).

For the pigs born at least one year before aerial poisoning, the prevalence of TB and the AAI were higher for the Molesworth area than for the Clarence Reserve, as in the baseline surveys. However, in subsequent cohorts, TB prevalence declined steadily on Molesworth, and, in relative terms, the AAI fell to one-quarter of that on the Clarence Reserve (Table 1). Despite that decline, however, pigs were still becoming infected in 2011, as one of nine young pigs born in or after November 2010 was infected when they were killed in Autumn 2011.

Excluding pigs born before the 2008 poisoning, and comparing prevalence between poisoned blocks, there was a near-significant difference between blocks for both pigs born in 2009 (mean age at death 14.2 months, Fishers's Exact Test, P = 0.058) and those born in 2010–11 (mean age at death 8.6 months, Fishers's Exact Test, P = 0.096), with the lowest prevalence in both years being in Block 1, immediately adjacent to the unpoisoned areas on the south-east bank of the Clarence River.

Pooling animals in relation to coverage, TB prevalence was significantly lower in the low- coverage areas (Blocks 1 & 4, prevalence = 24%) than in the high-coverage area (Block 3, prevalence = 67%), Fishers's Exact Test, P = 0.028) for pigs born in 2009, but not signficantly so for those born after that (Blocks 1 & 4, prevalence = 20%; Block 3, prevalence = 29%, Fishers's Exact Test, P = 0.557).

Table 1 Sample size, mean age, prevalence of culture-confirmed TB, and apparent annual incidence (AAI) for resident pigs surveyed prioir to and during this study, for the parts of Molesworth station aerially 1080 poisoned in 2008 this project and an adjacent unpoiosned area to the south-east (part of the Clarence Reserve). The Relative AAI expresses the AAI for Molesworth Station samples as a proportion of the equivalent AAI for the Clarence Reserve. Pigs were assigned to likely birth years on the basis of the kill date and their age when killed. The baseline surveys were conducted as part of several 'precursor' projects

Birth-year cohorts	Clarence Reserve (CR) (unpoisoned)				Molesworth Station (MS) (poisoned 2008)				Relative Apparent Annual Incidence (MS/CR)
	N pigs	Mean age (months)	Prevalence (%TB ± 95% CI)	Apparent Annual Incidence	*N* pigs	Mean age (months)	Prevalence (%TB ± 95% CI)	Apparent Annual Incidence	
Baseline surveys									
1999–2002	39	20.5	64.1 (47.2–78.8)	0.45	30	34.5	90.0 (75.3 – 97.9)	0.53	1.18
2003–2004	27	9.3	40.7 (22.4–61.2)	0.61	64	18.2	92.2 (87.2 – 97.4)	1.13	1.84
2005–2007	20	12.8	50.0 (27.2 – 72.8)	0.65	40	7.8	80.0 (64.4 – 91.0)	2.88	4.42
All	**86**	**14.6**	**53.5 (42.2 – 64.3)**	**0.52**	**134**	**16.4**	**88.1 (81.3 -93.0)**	**1.02**	**2.00**
This study									
2007 or before	25	29.1	72.0 (50.6 – 87.9)	0.43	30	24.7	90.0 (73.5 – 97.9)	0.65	1.53
2008	38	20.6	76.3 (59.8 – 88.6)	0.79	22	17.8	54.5 (31.2 – 75.6)	0.54	0.69
2009	39	12.8	61.5 (44.6 – 76.6)	1.05	53	14.2	50.9 (36.8 – 64.9)	0.68	0.65
2010 or 2011	19	7.3	63.2 (38.4 – 83.7)	2.17	63	8.6	25.4 (15.3 – 37.9)	0.54	0.25
ALL	**121**	**16.8**	**68.6 (59.5 – 76.7)**	**0.77**	**168**	**13.6**	**48.8% (41.1-56.6)**	**0.62**	**0.80**

Table 2 Sample size, mean age, prevalence of culture-confirmed TB, and apparent annual incidence (AAI) for the 2009 and 2010–11 birth-year cohorts of resident pigs in three of the Molesworth blocks poisoned in late 2008. No pigs in these cohorts were killed in Block 2, simply because the pig population in that block is very low

	N pigs	Mean age (months)	Prevalence (%TB ± 95% CI)	Apparent Annual Incidence
2009 cohort				
1 Low coverage	8	13.9	25.0 (3.2 – 65.1)	0.30
3 High coverage	27	14.3	66.7 (46.0 – 83.5)	1.02
4 Low coverage	18	14.1	38.9 (17.3 – 64.3)	0.47
2010/11 cohort				
1 Low coverage	10	8.3	0.0 (0.0 – 25.9)	0.00
3 High coverage	38	8.8	28.9 (16.9 – 49.3)	0.63
4 Low coverage	15	8.5	33.3 (11.8 – 61.6)	0.72

5.2.2 TB levels in released sentinel pigs

Of the 54 sentinel pigs successfully recovered and necropsied from both treatment and non-treatment sites, 14 (26 (15.4 – 39.9)%) were confirmed infected (culture positive). There was no difference between males (23.1% infected, $n = 26$) and females (28.6% infected, $n = 28$) (Fisher's Exact Test; $P = 0.76$, df = 1).

The released pigs almost all stayed close to where they were released, with the average distance between release locations and where they were killed being just 1.73 ± 0.59 (95% CL) km (range 0.03–14.93 km; only one pig moved more than 6 km). Only two moved out of the blocks into which they had been released; one of these became infected. In this instance the pig's disease status was allocated to the block into which it moved, subsequently spent most its time in and was also eventually recovered from.

The AAI for pigs released onto the unpoisoned Clarence Reserve was moderately high (1.34; Table 3), and intermediate between that recorded for the 2009 and 2010–11 cohorts of resident pigs killed there (Table 1). Comparison of the AAI for 2010–11 cohorts of residents (2.17) and the 2010 releasees (0.61) suggests that the latter figure may be biased low by sampling error reflecting the short duration of exposure for the releasees.

On Molesworth Station the AAI incidence was, overall, 78% lower than on the Clarence Reserve (AA1 = 0.31 and 1.34 respectively; Table 3). There was no evidence of any major decline in AAI on Molesworth Station between 2009 and 2010 (Table 3). For both years combined, AAI was lowest in Block 1 (0.20), slightly higher in Block 2 (0.26) and Block 3 (0.32), and highest in Block 4 (0.28). In 2010–11, infected sentinels were recorded in all four blocks.

Table 3 Number of released sentinel pigs for each of the four treatment and non-treatment blocks and the number of pig/days of exposure in each block

	N pigs	Mean exposure (months)	Prevalence (%TB ± 95% CI)	Apparent Annual Incidence
Clarence Reserve (unpoisoned)				
2009 releasees	4	7.1	100.0 (47.3 – 100.0)	3.36
2010 releasees	9	4.8	22.2 (2.8 – 60.0)	0.61
All Clarence	**13**	**5.5**	**46.2 (19.2 – 74.9)**	**1.34**
Molesworth Station (poisoned)				
2009 releasees				
1 Low coverage	5	7.2	0.0 (0.0 – 45.1)	0.00
2 High coverage	1	11.9	0.0 (0.0 – 95.5)	0.00
3 High overage	8	7.5	25.0 (3.2 – 65.1)	0.46
4 Low coverage	7	7.6	28.6 (3.7 – 71.0)	0.54
All 2009	21	7.7	19.0 (5.5 – 41.9)	0.33
2010 releasees				
1 Low coverage	4	6.7	25.0 (0.6 – 80.6)	0.51
2 High coverage	4	10.0	25.0 (0.6 – 80.6)	0.35
3 High overage	7	9.2	14.3 (0.4 – 57.9)	0.20
4 Low coverage	5	11.1	20.0 (0.5 – 71.6)	0.24
All 2010	20	9.4	20.0 (5.7 – 43.7)	0.28
All Molesworth	**41**	**8.5**	**19.5 (8.8 – 34.9)**	**0.31**

5.2.3 TB levels in cattle

In the mid-2000s, large numbers of TB-lesioned cattle were recorded on Molesworth Station. For the period 2002/03 to 2005/06, a total of 29 694 cattle were tested, and 421 lesioned cattle were detected (Nugent & Whitford 2007). The number of lesioned reactors has declined from a peak of 50 in 2002/03, to very low levels by 2009/10 (Figure 5). Clearly, this decline largely preceded the 2008 poisoning operation, and is presumed to reflect both high efficacy (in reducing TB) of the programme of aerial 1080 baiting progressively rolled out across the station since 2002, and the increased level of herd TB testing throughout this period.

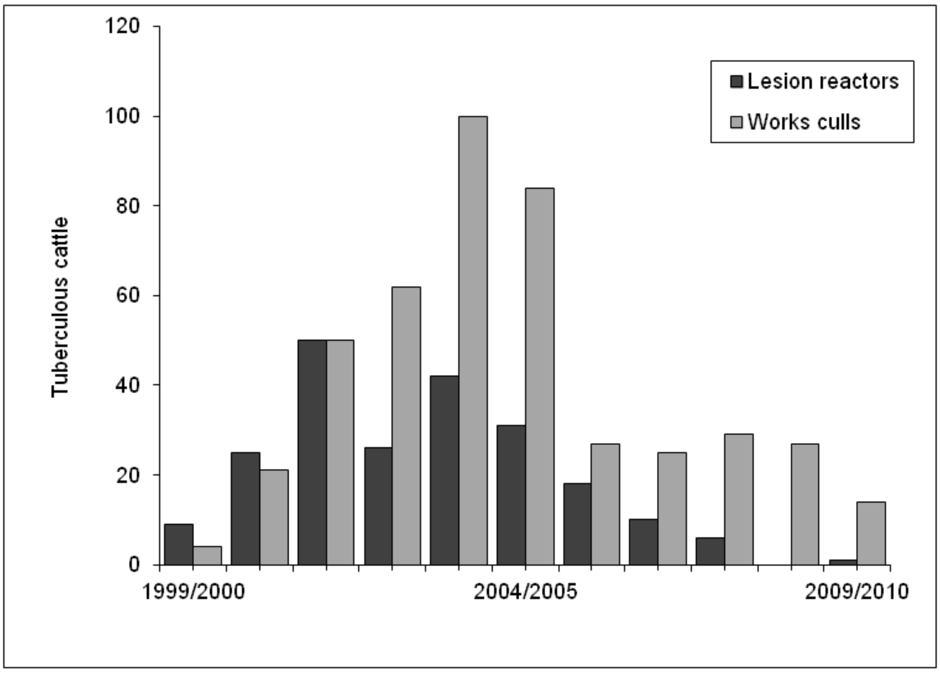

Figure 5 Number of TB-lesioned reactors and culls from Molesworth Station by year.

The specific area poisoned in 2008 is used for overwintering replacement heifers. In December 2009 a parallel blood test was completed on 787 cattle mustered from overwintering within the treatment blocks and an adjacent area, with two blood-test-positive animals recorded (January 2010). One of these had visible lesions (and positive culture) at slaughter in March 2010. Assuming ~350 of the mob were overwintered for about 5–6 months within the poisoned area near Lake McRae, and that the observed infection was acquired there, this outcome suggests an AAI of the order of 0.006.

For the 2010–11 year, 715 first calvers, including c. 350 mustered from overwintering within the treatment blocks, were tested, with 4 testing positive to the parallel blood tests in January 2011. Diagnosis at slaughter and later TB culture was confirmed for only one of these animals, with the other three showing no visible lesions at slaughter; this suggests an AAI for Winter 2011 of the order of 0.006.

In contrast, as part of an investigation of the efficacy of vaccination in protecting cattle from natural infection, an annual incidence of 0.06–0.07 has been recorded in unvaccinated cattle grazing in the same parts of the Clarence Reserve from which we obtained the 'non-treatment' pigs for this study (unpublished September 2011 report for Milestone 14b, AHB Project R-10711 Efficacy of BCG vaccination in protecting cattle against possum TB).

5.3 Pig movements and home range size

Most sentinel pigs were seen associating with resident pigs on at least one occasion during their time in the wild, so we infer that the movement patterns and home-range-size data of sentinels are likely to match those of resident pigs.

A total of 16 sentinel pigs (8 male, 8 female) fitted with GPS devices were successfully recovered with enough data to conduct home-range analysis (a total of 642 days' coverage for female pigs and

770 days' coverage for male pigs) (Figures 6 and 7). The average area of home range for both sexes combined was 506 ha (range 103–1948 ha). The two largest home ranges recorded were from pigs released into the largely open habitat within the Dillon catchment (Block 2), where very few resident pigs reside. Although we recorded a slightly smaller mean home range size for females than for males (452 ha and 560 ha respectively), the difference is not statistically significant (t_{14} = 0.42, P = 0.68).

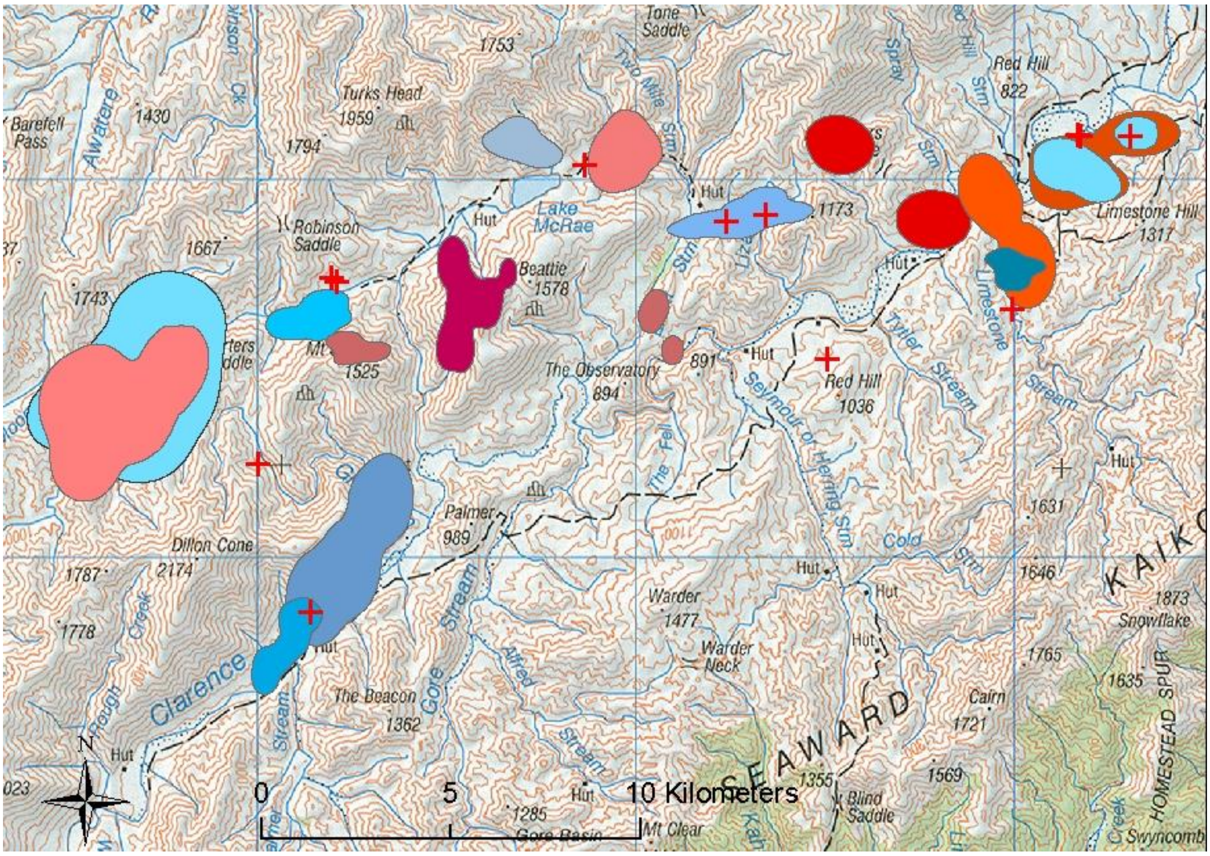

Figure 6 Location, shape, and size of the 95% kernel home ranges calculated from GPS-units recovered from 16 pigs released into posioned areas on Molesworth Station and non-treatment areas of the Clarence Reserve in 2009 or 2010. Red crosses indicate locations of TB-positive sentinel pigs.

5.4 Possum movement and home range size

For the 25 possums monitored between October and December 2009, mean home range size was 23.1 ± 6.1 ha (range 6.4 – 65.2 ha). The home ranges of males were more variable but on average larger (28.1 ± 8.2 ha, range 6.4 – 65.2 ha) than for females (15.0 ± 5.9 ha, range 6.6 – 33.4 ha). The difference is significant (t_{23} = 2.31, P = 0.02).

We also calculated the distance between successive locations, which are likely to have usually been about 2–3 hours apart as the collars were set up to seek six fixes per night. These averaged 122 ± 24 m (range 81–199, n = 11) for females, and 171 ± 35 m (range 71–301, n = 14) for males. This difference between the sexes is not significant (t_{23} = 1.25, P = 0.224).

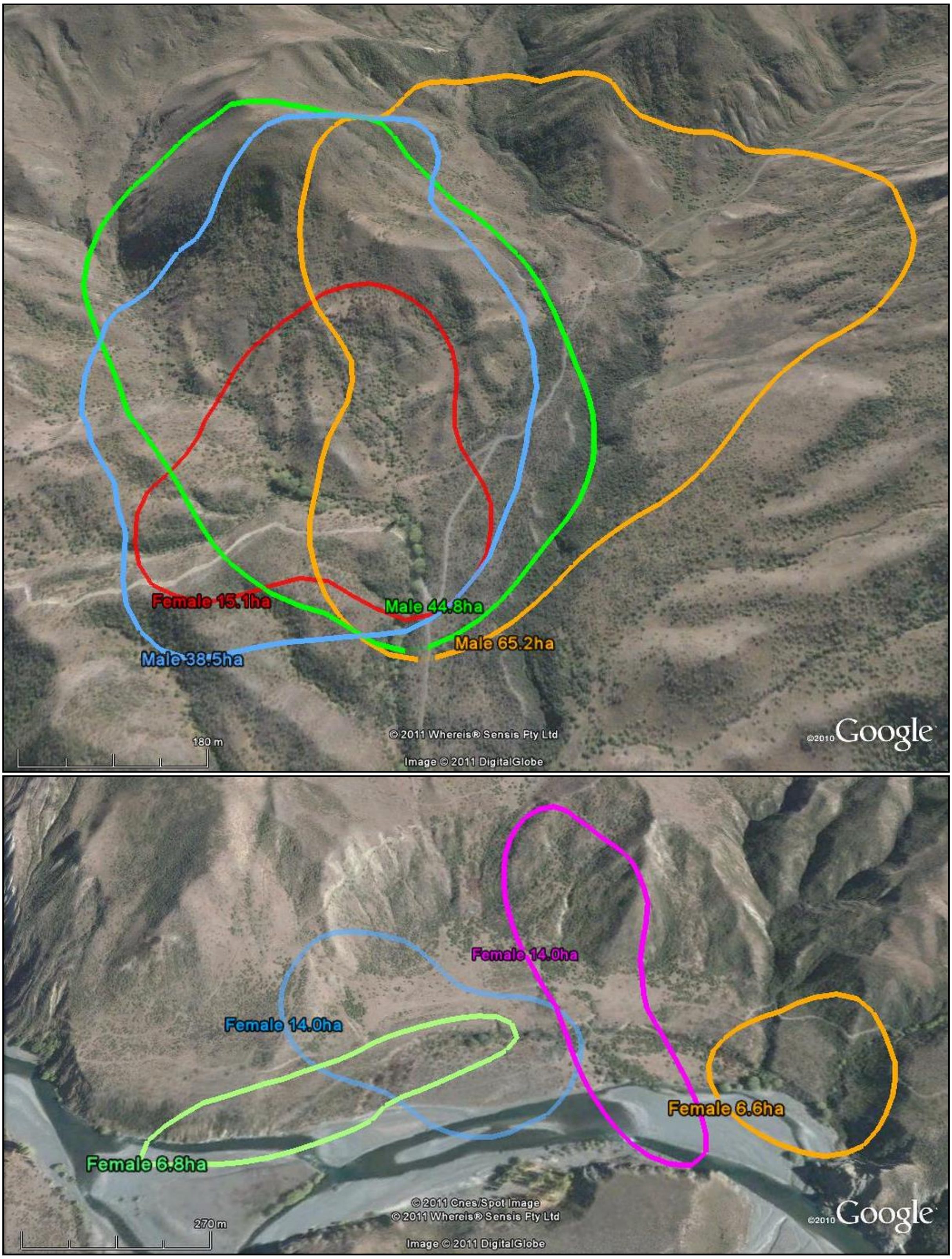

Figure 7 Illustrative examples of the possum home ranges recorded. In the lower image,the apparent extension of the boundary for the 95% home range into (and even slightly across) the river is likely to reflect both the smoothing effects of the kernel calculation method and errors in the GPS locations recorded (rather than possums actually being across the river).

5.5 Low-cost aerial 1080 poisoning

Of the 18 radio-collared possums present immediately before poisoning in the two blocks treated with prefed 1080 bait sown in clusters at 0.25 kg/ha, 17 (94%) were killed. Of the 33 radio-collared possums present immediately before poisoing in the two blocks treated with unprefed 1080 bait sown in clusters at 0.05 kg/ha, 25 (76%) were killed.

Total operational costs (excl.GST) for prefeeding were $2,166 for bait and bait transport, and 5 hours' helicopter time (Robinson R44; ferry $550, sowing $5,512). This equates to about $4.09 per hectare.

For the four poisoned blocks combined, bait and bait transport costs (excl. GST) were $2,465 and 5.4 hours' helicopter time (Squirrel; $900 ferry, $9,457 sowing). Assigning these costs in a 1:5 ratio, the flying cost for sowing toxin in the 0.25-kg/ha blocks was about $4.32 per hectare, and just $0.86 for the 0.05-kg/ha blocks.

Adding in the bait and prefeeding costs, the overall direct operational costs for 0.25-kg/ha blocks was about $9.42 per hectare, compared with $1.07 per hectare for the 0.05-kg/ha blocks.

6 Conclusions

6.1 Possum population recovery

The 2008 aerial 1080 baiting operation appeared initially to have successfully reduced possum numbers (Yockney & Nugent 2008; Nugent et al. 2009). For the 32 chewcard/waxtag transects monitored throughout this study, the intitial reduction in the abundance indices was initially estimated at 92–94%. That appeared to be an acceptably good kill given that the operation was not prefed. However, the subsequent rapid increase in all of the indices to 45–55% of pre-control levels in the ensuing 2 years appears to be well beyond the reproductive capability of possums. That suggests that the indices recorded immediately after control may have been biased low, or the pre-control indices may have been biased high, or both (thereby overstating the actual reduction in possums' abundance). Part of that bias undoubtedly reflects the longer period over which pre-control indices were assessed (as a result of the delay in the timing of the poisoning). However, previous work has indicated that most interference occurs within the first week (G. Nugent, unpubl. data).

In addition there were some anomalies in the data (specifically, CCIs of zero recorded before control on some transects where moderately high CCIs were recorded), but these were too few and localised to explain the consistent overall pattern. Likewise, the pattern was the same in all blocks, regardless of coverage, and on sites outside the area actually poisoned, so immigration is unlikely to fully explain the increase. Intuitively, the large size of the area controlled relative to possum home range size, and relative to the limited areas of possum habitat left uncontrolled also make mass immgration an unlikely explanation.

The remaining explanation is that the assumed linear relationship between possum density and the various indices changed between the surveys. There are several possibilities.

- Firstly, the few possums that survived could have been predominantly those with very small home ranges at that time of the poisoning, which therefore had a lesser chance of encountering bait and being killed and also a lesser chance of encountering a detection device. This possibility would have resulted in the post-control estimate being biased low, overstating the percentage reduction.
- Secondly, the possums that survived may have done so for reasons that were unrelated to movement behaviour and detectability, so the estimate of kill is unbiased. However, the reduction in possum density may then have prompted an expansion of home range size (as has been documented previously) resulting in increased detectability. In this case, the rate of recovery would be overstated.
- A third possibility is that there was some mix of both of these alternatives.

The possum movement data collected in parallel with this study (Section 5.4) indicate that possums tend to range much more widely in this landscape than is usual for possums that live entirely within continuous native forest (where ranges are usually with the 1–5 ha range; Cowan & Clout 2000). The findings reported here contrast sharply with the estimated activity areas of 0.2–19.5 ha (mean 5.1 ha) for 29 possums radio-tracked in the western parts of Molesworth Station for up to 12 months (Glen et al. 2011). One explanation for the difference is that the activity areas reflected the distribution of den locations, as the data used to estimate these were collected during daylight hours. If so, the much larger home ranges recorded here suggest possums range widely each night. This is supported by new data from the Central Otago drylands, where possum home range size estimates based on night-time activity were 10 times the size of those based at den locations (Rouco and Glen 2011). In this study, even the smallest ranges (6–10 ha) were likely to be more than 200 m across at their narrowest, and the average distances moved between successive locations recorded only a few hours apart was >70 m for all 25 possums. It therefore seems unlikely that many possums will not have encountered bait during the 2008 poisoning, suggesting that post-control expansion of range is the more plausible of the two explanations above for what we presume must have been an increase in possum detectability.

The wide ranging behaviour of possums on Molesworth Station makes it likely that the relationship between possum density and the indices of possum abundance differs from that in areas where possum ranges are much smaller. We suggest the same is likely to be true for the Residual Trap Catch Index as well, given our inference that possums in this area cover more ground each night and so are more likely to encounter traps. If so, the '5% RTCI = 1 possum/ha' calibration provided by Ramsey et al. (2005) appears, to us, likely to substantially overestimate actual possum density if applied to Molesworth Station.

Regardless of the cause, the results suggest possum numbers could soon be close to or higher than the levels at which is it presumed (from the historical persistence of TB in the area) that the disease can persist in the possum populations there.

Excluding what we believe were transects with anomalous pre-control data, the indices of possum abundance were closer to pre-control levels in the areas with low coverage than in those with high coverage. However, the rates of increase appeared to be the same in both high- and low-coverage areas, so the difference appears to reflect the differences in residual density immediately after control, which in turn appears to reflect differences in pre-control density.

6.2 Effect on TB levels in pigs

Historically, TB levels in pigs in the eastern part of Molesworth Station were very high, with almost all adult pigs infected. In fact, it is likely that some, probably most, of the apparently uninfected adults we recorded had been infected but had largely resolved any detectable infection (Nugent & Whitford 2008). For the youngest age-classes, we calculated an annual incidence rate of 2.88 (Table 1), suggesting an average of one infectious encounter every 4 months for the year just before the poison operation. In contrast, on the Clarence Reserve, the annual incidence in young pigs was much lower at that time.

By 2010, this pattern had strongly reversed, partly because of an increase in the incidence in young pigs on the Clarence Reserve and, more importantly, partly because of a decrease in incidence in the poisoned area. Overall we estimate that the poison operation had reduced TB levels in pigs in the poisoned area by about 80% within 2 years. Although this trend is obviously in the desired downward direction, it is less dramatic than the decline recorded in the Bullen Hills area to the south-west, which was aerially poisoned (without prefeed, and using 2.5 kg/ha cereal baits of 6–8 g) in 2003. There, the prevalence of culture-confirmed TB in pigs fell from 77.8% to 9.7% within 2 years with the strong likelihhod that the few cases of infection recorded in 2006 were immigrant pigs from an area where possums were not controlled (Nugent et al. 2011a).

However, in this study, the young age of many of the infected residents, and the continued detection of TB in released sentinels in 2010/11, in pigs never known to have ranged outside the poisoned area, makes it highly unlikely that pigs were importing all, or even most of the TB we detected. The detection of TB in both sentinels and residents in all four blocks also indicates that the source of TB remains widespread. Given that pigs rarely spread TB to other pigs, at least while alive, we conclude that TB-infected possums were still present in substantial numbers in 2010–11.

6.3 Effect on TB levels in cattle

The continued incidence of TB in the ‘first calver’ herd of which half are overwintered in the poisoned area is obviously consistent with the continued incidence recorded in pigs, and adds weight to the inference that TB has persisted in possums there. The crude estimate of annual incidence (0.006) compared with that recorded in unvaccinated cattle on the Clarence Reserve (0.6–0.07; G. Nugent, unpubl. data) is also consistent with the inference that TB levels in possums in the baited area are now lower on Molesworth than on the grazed areas of the Clarence Reserve.

However, no TB-positive reactors were detected in the Molesworth herd in 2008–09, indicating that the incidence in cattle overwintered in the baited area immediately before poisoning was very low. The possible reason(s) for that are not clear. Possibly the majority of cattle overwintered mainly in the western parts of the area in that winter, where possum densities were low even before control.

6.4 Combined use of sentinel and resident pigs for TB surveillance

This study has demonstrated that on-site rearing of TB-free sentinels for release to the wild is feasible. The approach used here could be streamlined and scaled, and the cost reduced, if the rearing site was closer to human habitation. Although not quantified and reported above, regular use of a fixed-wing plane for periodic monitoring of sentinel location and status was more efficient and effective than use of a helicoper.

Use of GPS collars obviously provided much more precise depiction of where pigs had been than did 4- to 6-weekly checks of location using the VHF transmitters. Whether the extra cost is warranted is unclear; however, at the scale of whole blocks the small numbers of VHF checks were sufficient to confirm that the sentinels had remained in the area they were released.

Despite the non-recovery of about one-third of released sentinels, and the comparatively high cost of using them compared with residents, the high level of confidence they provided that TB was still present in all four blocks was sufficient to warrant their use. We consider that the combined use of residents and released sentinels (both as Judas and TB detectors) is likely to provide the most cost effective approach to TB surveillance in this area.

6.5 Summary

Assuming that the 28 000-ha area contained, on average, between 0.5 and 1.0 possum per hecare, with a pre-control prevalence of about 1% (Byrom et al. 2008), a 92–94% reduction could still have left more than 100 infected possums. If so, and coupled with the apparently rapid recovery of the possum population, the continued incidence in pigs is perhaps not surprising.

Overall, and assuming pigs do not transmit TB among themselves (Nugent et al. 2011a, in press), the continued widespread infection in pigs indicates continued widespread infection in possums after 2008. This is despite RTCIs of only 0.4% and 0.8% being recorded in the two high-coverage blocks (where pre-control TCI was predicted to exceed 5%), and 1.1% and 1.8% for the two low-coverage blocks (where pre-control TCI was predicted to exceed 10%) (Yockney & Nugent 2008). The outcome therefore suggests that the epidemiology of TB infection in possums on Molesworth, and in similar areas, differs from that inferred for higher density populations in better and more continuous possum habitat. Simulation modelling using the spatial possum-TB model developed by Ramsey and Efford (2010) suggests that the far larger ranges of possums on Molesworth Station are likely to increase the ability of TB to persist at low possum densities, but only if a much higher transmission rate (β = 0.8–1.0) than that normally assumed for forest-dwelling possums (β = 0.3). The implication is that the behaviour and ecology of possums on Molesworth is somehow much more conducive to TB transmssion than is usual. If so, then leaving parts of the habitat with a predicted 5–10% RTCI uncontrolled in 2008 was, with hindsight, probably a mistake. However, we do note that TB also persisted in the high-coverage Block 3, where the parts of the area not poisoned were similar to that that historically had not been treated in previous Molesworth operations (based on land manager and operator perceptions of what was and was not possum habitat).

If so, then eradication of TB from possums is likely to require either much more intensive and complete (with respect to coverage) possum control than was applied in 2008, or 2008 operations would need to be repeated several times at short (2- to 4-year) intervals.

The experimental low-cost aerial baiting treatements above (Section 5.5), the 0% RTCI recorded in a small area west of Block 1 in 2008 where the cluster-sowing treatment used in the main operation were complemented by prefeeding (Yockney & Nugent 2008), and the success of prefed aerial cluster sowing in beech forest at Mariua in 2010 (Nugent & Morriss 2011) suggest that high possum kills would be obtained using the AHB's current specifications for cluster baiting and would achieve the desired high kill at relatively low cost. These specifications are strip prefeeding at 0.5 kg/ha, using 2-g baits, followed by aligned cluster-sown 1080 baits at 0.7 kg/ha. The possum movement data reported here indicate that a flight path spacing of up to 200 m would still put all possums at risk.

7 Recommendations

We recommend:

- That the low-coverage strategy suggested as a way of reducing aerial baiting costs not be used in future, as it appears possible that TB could persist in some part of the area that is excluded from coverage (given that it has persisted for at least 2 years at the reduced possum densities of all four baited blocks).
- That further TB surveillance is conducted using resident pigs, in 2012 and/or 2013, to determine whether TB levels in wildlife remain at (or decline from) current reduced levels, or have begun to increase as a result of the possum population recovery. The outcome would provide guidance on the frequency of possum control (by aerial 1080 baiting) needed to eradicate TB from this area.
- That AHB and Landcorp consider reapplying aerial baiting of this area (and other high risk parts of Molesworth Station) as soon as is feasible within the funding resources available. We suggest that the AHB's specification for cluster baiting (including aligned prefeeding) should enable the area to re-baited at a similar or less cost than the 2008 operation in which 1080 bait was applied at 2.5 kg/ha without prefeeding. Alternatively, prefed aerial broadcasting with large (12-g) baits and a wide (200–250 m) flight path spacing could be used.

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Appendix 1 – GPS implants and radio telemetry

Procedures for implanting GPS radio-tracking units:

About 10 minutes before implantation, pigs were injected intramuscularly by pole syringe (Paxarms, Timaru) with an anaesthetic (Zoletil 100 (dry powder) reconstituted with 5 ml of 5% Xylazine) at a rate of 2 ml per 40 kg body weight. This combination provided a smooth induction and recovery, and adequate time for the surgery, which usually took about 15 minutes. Each pig was then weighed, measured, TB-tested (skin test in right ear), ear-tagged and a blood sample collected before being shaved on the right side from behind the right ear back to the shoulder.

Surgical procedure: All loose hair is brushed off and the skin scrubbed with Biocil scrub. Following this, Biocil solution or alcohol is liberally poured over the surgical site. The surgical site is draped with a paper drape held in place with four towel clamps. The surgical procedure is started with 10 ml of local anaesthetic infused along the site of the skin incision. This is a 60–80 mm incision parallel to and about 40 mm below the midline of the neck. The caudal end of the incision is about 10 mm forward of the shoulder. Once through the skin, blunt dissection between the skin and muscle layers is used to prepare the site for the implant. This is immediately forward of the anterior border of the scapula. The VHF unit is then placed and sits snugly in the hollow in front of the shoulder. With this procedure there is very little bleeding. If concerned about asepsis the wound is irrigated well with saline. There is very little dead space and no need to suture the fascia or fat. Surgical closure is achieved by simply suturing the skin with three horizontal mattress sutures, using either PDS II (O) or Supramid (O).

All pigs were given a post-op injection of long-acting penicillin (Duplocillin LA) and the wound dressed after the operation with an antibacterial aerosol (Aerotet Forte). Recovery was usually uneventful and to date we have had no issues with wound breakdown or rejection of the implants. On recovery the pigs showed no evidence of discomfort.

Radio telemetry procedures:

Radio tracking was conducted with both helicopter and fixed-wing aircraft using directional Yagi antennas and an ATS 2000 receiver (Advanced Telemetry Solutions, MN, USA) (Gilmer et al. 1981; Telonics 1997; Gregory et al. 2002).

Fixed-wing telemetry was conducted using a high-wing Maule Mx7 aircraft (Wildlife Surveillance, Christchurch) with the pilot's headset directly connected to the receiver via an accessories input. The Maule aircraft was equipped with dual (left and right) wing-strut-mounted Telonics RA-2A antennas (Telonics, AZ, USA) wired through a two-way (left and right) switch box to an ATS 2000 receiver.

Helicopter tracking was conducted in a Robinson R-44 helicopter (Amuri Helicopters, Hanmer). The ATS telemetry receiver was connected to both the pilot's headset and shooter's helmet via a Flightcell® Pro™ multi-link communication hub to enable both pilot and shooter to receive tracking signals.