Animal Health Board Project No. R-10678

Is Residual Tb Infection in Deer and Pig Populations Important?

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Landcare Research Contract Report: LC0708/053

PREPARED FOR:
Animal Health Board
PO Box 3412, Wellington

DATE: November 2007

ISO 14001

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DOI: https://doi.org/10.7931/hsx4-ba67

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Project and Client

An investigation to determine whether residual Tb infection in deer and pig populations is likely to lead to re-establishment of bovine Tb in possum populations control was undertaken by Manaaki Whenua – Landcare Research, Lincoln, for the Animal Health Board (AHB), (Contract No. R-10678), between September 2006 and September 2007.

Objective

- To determine whether residual (post-possum-control) infection in pigs and deer is likely to lead to the re-establishment of bovine Tb in possum populations from which the disease has been eradicated, by quantifying the frequency with which deer and pig heads are scavenged by possums (and other animals).

Methods

- Pen trials were undertaken to determine the concentration and volume of rhodamine (RB) dye needed to reliably mark possum whiskers following the consumption of RB-laced venison and pork.
- Following the pen trials, consumption of meat baits (simulating hunter-discarded deer and pigs' heads) laced with 0.2 ml of an RB slurry was monitored for 6 weeks in three different epidemiological settings in the North and South islands. About 6 weeks after exposure to dyed meat, possums were killed at the bait sites and their whiskers examined for RB-dye marking.

Results

- Captive possums usually consumed deer lymph nodes smeared with peanut butter when the volume of RB slurry was zero or less than 0.5 ml, but were less inclined to do so when the node contained >4 ml of RB. Fluorescent banding was evident in the whiskers of all of the possums that ate RB-dyed nodes but was very faint when the volume was small.
- Possums visited almost all meat bait sites in all three areas, with 2.5 possums killed per site in the Esk Head (Canterbury) area, 3.5 in the Orongorongo Valley (Wellington), and 4.5 in the West Coast area. Most of the meat baits were fed upon in the first week after deployment and after 6 weeks the carrion had been completely consumed at most sites, particularly those discovered by hawks or weka.
- Where hawks or weka were most abundant (Esk Head and West Coast areas respectively) the RB dye initially contained within lymph nodes was frequently spread over much of the remnant tissue and on the ground around the bait. This occurred far less frequently in the Orongorongo Valley, where weka was absent and hawks did not find some of the baits.
- Possums were confirmed as scavengers at the Esk Head site by the presence of RB-stained pieces of meat in the stomach of one possum, deer hairs in the stomachs of three others, probable RB staining around or in the mouth or on the stomach wall of four others, and one occurrence of RB-stained possum faeces.
- For 2 (7%) of 29–30 randomly selected possums from both the Esk Head and Orongogrongo sites there was clear RB banding in the whiskers that indicated RB uptake,

but none from the West Coast site. In all three areas, however, another 2–3 (7–10%) of the possums examined had weak fluorescent banding that suggested these animals had also ingested or absorbed small amounts of RB dye.

Conclusions

- In areas where weka or hawks are common, animals that die in areas accessible to these species appear likely to be largely consumed by them provided there is some opening in the carcass. Scavenging by hawks and weka often exposed and spread the RB dye more widely over the meat bait and onto the ground, increasing the likelihood that any possum subsequently visiting the site would come into contact with the dye.
- This study further confirms that although possums seldom eat large quantities of carrion, there is nonetheless a significant probability they would ingest infectious material inside any Tb lesions within such carrion. The discarding of heads of Tb-infected pigs and deer by hunters therefore creates a risk of spillback transmission of Tb to possums. This risk appears likely to increase when scavenging by weka and hawks in particular exposes and spreads Tb-lesion contents, a phenomenon that may partly explain historical and geographical patterns of Tb occurrence in possums.
- The key implication is that, because spillback infection could occur, possum numbers should not be left to recover to levels capable of maintaining Tb within less than a decade in areas where the prevalence of Tb in deer and/or the density of deer was initially high. However, there are probably now only a few places with the combination of moderate or high deer density, high initial prevalence of Tb in deer, and abundant in-forest avian scavengers for spillback to be a major concern.
- Spillback from Tb-infected pigs is less likely to be important in re-establishing Tb within an area, because pigs tend not to live as long as deer. It is, however, potentially important in areas where pigs could re-import Tb from distant unmanaged sources.
- This study indirectly lends weight to the hypothesis that weka and hawks increase the likelihood of possums being exposed to infectious material contained in possum carrion. If so, it is possible current RTCI targets may not be low enough to reliably eliminate Tb where weka and hawk scavenging is frequent.

Recommendations

- The risk of spillback from deer and pigs should continue to be factored into vector control planning for Tb eradication. This risk should be given greatest consideration where cessation of possum control is being considered within about a decade of prevalence having been high (>10%) in deer, and where infected pigs have a high probability of reimporting Tb into an area. The AHB should consider development of a simple model or decision support system for vector managers to use in assessing the risk in any particular area.
- The impact of weka scavenging on Tb-eradication targets for the West Coast should be investigated to ensure that current possum-control targets are set sufficiently low to reliably prevent Tb persistence.

1. Introduction

An investigation to determine whether residual Tb infection in deer and pig populations is likely to lead to re-establishment of bovine Tb in possum populations recovering after control was undertaken by Manaaki Whenua – Landcare Research, Lincoln, for the Animal Health Board (AHB), (Contract No. R10678), between September 2006 and September 2007.

2. Background

Wild deer in New Zealand are not considered to be true maintenance hosts of Tb, with most infection resulting from transmission from possums (Lugton et al. 1998; Nugent 2005). However, once infected, some deer appear able to survive in an infected state for a decade or more (Nugent 2005). They therefore form a medium-term reservoir of Tb that can potentially infect other species, including possums, the primary maintenance host. This has two important potential consequences. Firstly, young male deer infected with Tb before they disperse could easily carry the disease long distances (up to 30 km), and cause new outbreaks in previously Tb-free possum populations. Secondly, where Tb has been eradicated quickly (<5 years) from possums through the application of intensive control, vector managers will want to stop possum control. However, the possum population would then increase to above the Tb-maintenance level. The survival for 10–15 years of a few adult deer (mainly females) infected with Tb before possum control could therefore lead to the re-establishment of Tb in possums.

For pigs, the re-establishment risk is probably low as pigs have a shorter lifespan than deer. However, the risk of spread is amplified by the transport of live pigs by hunters and their subsequent release into Tb-free areas, and by the transport of whole pig carcasses from hunting grounds inside VRAs to distant Tb-free areas (Nugent et al. 2003).

The importance of both these risks (spread and re-establishment) depends largely on the frequency with which Tb is transmitted from infected deer and pigs to possums. This appears most likely to occur through scavenging of carcasses by possums (and ferrets), a behaviour that has now been recorded in several video-monitoring surveys (Ragg et al. 2000; Yockney & Nugent 2003; Byrom 2004; Nugent 2005). In some studies about one-quarter of the deer and pig carcasses monitored were encountered, contacted, and sometimes scavenged by possums (and pigs and ferrets). What is not known, however, is whether this high proportion is generally typical, what proportion of these interactions is likely to result in the transmission of Tb, and whether that proportion differs according to species.

This project aimed to assess whether the maximum potential transmission rate is high enough to be important in planning how long possum control needs to be maintained by the AHB. As an affordable and measurable proxy of the actual transmission rate, the project aimed to measure the rate at which possums (and other scavengers) ingest measurable quantities of potentially infectious lymph node tissues. In both deer and pigs, lesions occur most frequently in the tonsils and/or lymph nodes of the head, and we assume that it is this infectious material that is most likely to become available to possums, especially when the head is removed from the carcass by a hunter. We conversely assume that there is a low risk of direct respiratory transmission from live or dead deer and pigs to possums (or other hosts); i.e. it is assumed that contact with, and/or ingestion of, lesioned material contained with lymph nodes or tonsils is the most important interspecies transmission route.

Because it did not appear to be practical or politically sensible to measure actual Tb transmission rates to wild possums in Tb-free areas where results would not be confounded by existing infection, we used uptake of a marker dye as a proxy for Tb transmission. We endeavoured to emulate the presence of large quantities of infectious mycobacteria by injecting slurry of the chosen dye (rhodamine B) into pig and deer lymph nodes, and presented these to wild possums and other scavengers as part of a lump of pig or deer meat that nominally represented the discarded head of a hunter kill. The aim was to determine whether any possums in the vicinity came into sufficiently close contact with this material to be marked by the dye, on the assumption that that level of contact was likely to result in Tb transmission if the lymph nodes had contained Tb lesions rather than dye.

A second related aim was to assess whether scavenging of the nominal heads by other species, especially weka (*Gallirallus australis*) and harrier hawks (*Circus approximans*), increased the likelihood of possums being marked. The hypothesis was that the opening up and partial scavenging of a Tb-infected carcass by weka or hawks might expose more of the highly infectious contents of tuberculous lesions, and also spread those contents widely over the carcass and the surrounding area, thus increasing the risk to possums that subsequently visit and investigate the carcass.

3. Objective

- To determine whether residual (post-possum-control) infection in pigs and deer is likely to lead to the re-establishment of bovine Tb in possum populations from which the disease has been eradicated, by quantifying the frequency with which deer and pig heads are scavenged by possums (and other animals).

4. Methods

4.1 Consumption of meat baits by captive possums

To assess how readily possums ate meat, 8 wild-caught possums that had been acclimatised to captivity for 4 weeks (and were therefore well-fed) were offered small pieces of venison and pork for two non-consecutive nights. Possums were fed with fruit alone (instead of their usual combination of fruit and cereal pellets) 24 hours before being presented with the meat baits, which were available for 4 hours. On the second night, 8 of the 48 possums were offered venison and pork pieces smeared with peanut butter.

4.2 Amount of RB dye required to mark possums

To determine the minimum volume of rhodamine B marker dye (RB) needed to reliably mark possums, 35 possums were offered deer lymph nodes injected with varying volumes of a concentrated (30% w/w) aqueous solution of RB, following the same procedure as above. Because these captive possums showed no interest in the unlured lymph nodes, the nodes were smeared with peanut butter for the final two hours the baits were available. The RB volumes injected into the nodes were chosen to approximate the volume of Tb lesions 1, 2, 5, and 10 mm in diameter. The number of possums that ate the nodes was recorded, and 8 weeks later the possums were killed and 4–8 vibrisscae (whiskers) were plucked from each possum. Whiskers were inspected with a microscope for evidence of fluorescent banding that typically occurs when animals have ingested sufficient quantities of RB (Fisher 1999), following the methods described by Spurr (2002). We used a Zeiss Photomicroscope III fitted with Incident Light Fluorescence equipment and a high-performance filter set for TRITC and RB 200, comprising band pass interference exciter filter BP546/12, barrier filter LP590, and chromatic beam splitter FT580. A ×2.5 objective was used throughout.

4.3 Consumption of meat baits in the field

To obtain an estimate of the frequency at which possums might ingest infectious material from deer and pig carcasses, we monitored the consumption of RB-laced meat baits (and whether that resulted in RB marking of possums). The baits were placed 150–200 m apart on three widely spaced transects (>2 km apart) in each of three different areas (Fig. 1), with 10-11 baits per transect.

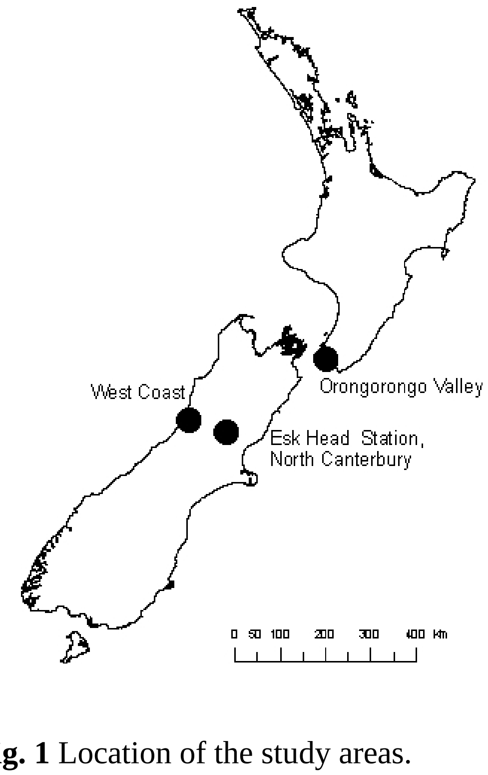

Fig. 1 Location of the study areas.

The three areas were chosen to represent different epidemiological settings, as follows:

Marsden, West Coast: This site has a variable (moderate–high) possum density and the vegetation is a mixture of regenerating native forest, pine forest, and roadside scrub. There are high numbers of weka present, but few other scavenger species, with forest cover typically making access difficult for harrier hawks.
Orongorongo Valley, North Island: This site has a high possum density and the vegetation is dominated by podocarp–broadleaf forest. There are moderate numbers of rodents, stoats and cats, but no weka, ferrets or pigs, and again the forest cover makes access difficult for hawks.
Esk Head Station, North Canterbury: This site has a moderate-to-low possum density overall and the vegetation is unforested dryland dominated by matagouri and briar. No weka are present; but baits were placed at the margins of shrub cover so were much more accessible to hawks than at the other sites. There were a few pigs present and possibly some ferrets.

The meat baits were intended to roughly emulate the discarded heads of decapitated deer or pigs killed by hunters. In such heads the lymph nodes and/or tonsils at the back of the head, which are the most common sites of Tb infection in both species, are much more readily accessible to scavengers than they would be in whole carcasses. Young domestic pigs and deer were purchased, killed, and cut into head-sized baits. The heads were used whole and 0.2 ml of 30% w/w aqueous RB concentrate was injected into the retropharyngeal nodes of the deer and the submaxillary lymph nodes of pigs. However, the majority of baits comprised pieces of meat (0.5–1.5 kg) at least half-covered with skin but with one side of exposed flesh (e.g. the skin-covered foreleg of a pig; Appendix 1). For these baits two RB-containing lymph nodes were pushed inside small slits in the exposed flesh.

To obtain some indication of whether possums has visited the bait sites, and also to provide a measure of relative abundance, chew cards (CC) smeared with peanut butter (Nugent et al. 2007) were placed at each meat bait site, and also approximately evenly at two locations between each bait site.

The baits (10–11 per transect, with a deer and a pig bait at each site) and cards (30 per transect) were deployed in May or June 2007, checked 7–8 days later, and checked again after 28 days (Orongorongo only) and 42–46 days (all areas). At each check we identified and recorded the species responsible for any bite marks on the chew cards, subjectively assessed the percentage of each bait that had been eaten (if any), and recorded any incidental observations such as scavengers seen either feeding or in the vicinity of baits, the presence of RB-stained faeces, pig tracks, and the presence of RB staining on the ground.

After the final check, possums visiting the meat bait sites were killed using either leg-hold trapping (Orongorongo and West Coast , 4 traps per site for 3 or 4 nights) or cyanide paste (Esk Head, 3 baits per site for 3 nights). At Esk Head and on the West Coast, sites were pre-fed approximately one week before the killout session using a bran–molasses–sugar meal at Esk Head and RS5 pellets on the West Coast. Leaning-board raised sets (100 cm off the ground) were used for the West Coast trapping, and ground sets in Orongorongo Valley. The details of killed possums were recorded and 4–8 whiskers were later plucked from each to check for fluorescent banding as above.

At Esk Head only, we also stapled small pieces (c. 200 g) of venison soaked in 500 ml of rhodamine solution (0.5% w/w) to a shrub trunk at each meat bait site on the same day the cyanide poison was first laid. Killed possums were checked for staining of the paws, mouth and stomach, and the stomach contents were inspected for meat and dye.

5. Results

5.1 Consumption of meat baits by captive possums

Well-fed captive possums seldom ate lymph node tissue unless it was covered in peanut butter, with 100% of 'buttered' nodes eaten but just c. 7% of unlured tissue. Subjectively there was no evidence of any major difference in the consumption between deer and pig nodes.

5.2 Amount of RB dye required to mark possums

Captive possums usually consumed deer lymph nodes smeared with peanut butter when the volume of RB dye was less than 0.5 ml, but were far less inclined to do so when the node contained c. 4 ml of RB (Table 1). Fluorescent banding was evident in the whiskers of all of the possums that ate RB-dyed lymph nodes but the banding was very faint in the group injected with the smallest volume. Based on these results we chose to inject the meat baits used in the field trial with 0.2 ml of the RB slurry, to maximise the likelihood of successful marking when nodes were eaten without making the nodes too aversive.

Table 1 Consumption of deer lymph nodes and presence of RB fluorescence in captive possums offered peanut-butter-covered lymph nodes injected with 30% w/w aqueous RB dye.

Diameter of simulated lesions and approximate RB volume	No. possums	No. possums that ate nodes	No. possums with RB fluorescence
10 mm (4.189 ml)	8	1	No data[a]
5 mm (0.524 ml)	8	4	4
2 mm (0.33ml)	7	5	4
1 mm (0.005 ml)	7	6	6
Control (0.000 ml)	5	5	0
TOTAL	35	21	14

[a] The one possum that ate one of the large 10mm diameter "lesions" died soon afterward, so no whiskers were collected.

5.3 Consumption of meat baits in the field

Species encountering bait sites

Possums were frequent visitors to the meat bait sites in all three areas, with possums being killed at 67–97% of sites on the first night of the respective ‘killouts’ (Table 2). Over the 3 or 4 nights, possums were killed at all but five of the 93 bait sites (three at Esk Head and just one each at the West Coast and Orongorongo sites). Overall, 2.5 possums were poisoned per meat bait site at Esk Head, 3.5 were trapped per site in the Orongorongo Valley, and 4.5 trapped per site on the West Coast.

Possum interference with chew cards (CC) was also detected at almost all head sites (and at almost all the intermediate sites) within one week of the meat baits being deployed, except at Cockeye Creek and Ogilvies Road on the West Coast (Table 3). The low CC interference at Ogilvies Road is consistent with the low numbers of possums trapped there. At Cockeye Creek, however, 3–8 possums were trapped at every site, so the lack of CC interference at half of the sites indicates that previous cage trapping and/or other activity at these sites (as part of a separate research project) had somehow made the possums card-shy.

Overall, possums were trapped or detected at all but two of the head sites, and three-quarters of the sites were visited in the first week after deployment while the meat baits were still relatively fresh.

In the West Coast area, weka had previously been recorded feeding on possum carcasses at some of the Cockeye Creek sites that were also used in this study. Weka were frequently seen or heard near meat bait sites and weka tracking was evident at many, but these data were not recorded. Weka peck marks were detected on chew cards at three meat bait sites.

Table 2 Number of possums caught in killouts, and percentage of meat bait sites at which possums were killed on the first night of the killout.

Site	Line no. /name	No. baits/ traps	% sites with 1st night kills	Possums killed, by night (*n*)				
				1	2	3	4	Total
Esk Head	Line 1	33	82	11	5	7		23
Esk Head	Line 2	33	64	18	2	3		23
Esk Head	Line 3	33	55	6	13	10		29
Total		99	67	35	20	20		75
Orong.	OVFS	40	100	30	17			47
Orong.	Red Rock	40	40	4	12	11		27
Orong.	Wottons	40	100	19	14			33
Total		120	80	53	43	11		107
W. Coast	Card Crk	40	100	33	17	12	3	65
W. Coast	Cockeye Crk	40	100	19	10	13	8	50
W. Coast	Ogilvies Rd	40	90	14	4	2	0	20
Total		120	97	66	31	27	11	135
All areas			81	154	94	58	11	317

Table 3 Chew Card indices (% sites with species present) of animal visits to meat bait sites, for the first week (possums only) and across all surveys. For possums, the percentages of sites where possums were trapped, and detected or trapped, are shown for comparison.

		Possum				Rat	Mouse
Replicate	Line name	CCI 1 week	CCI all	Trap freq.	CCI+ Trap freq. all	CCI all	CCI all
Esk Head	Line 1	90	100	100	100	0	0
Esk Head	Line 2	100	100	80	100	0	0
Esk Head	Line 3	90	100	100	100	0	0
Total		93	93	93	100	0	0
Orong.	OVFS	100	100	100	100	60	0
Orong.	Red Rock	80	90	90	90	30	60
Orong.	Wottons	90	100	100	100	20	0
Total		90	90	97	97	37	20
West Coast	Card Creek	90	100	100	100	20	30
West Coast	Cockeye Creek	10	50	100	100	20	30
West Coast	Ogilvies Road	40	50	90	90	20	30
Total		47	47	97	97	20	30
Overall total		76	76	96	98	19	17

Hawks were seen feeding on baits at Esk Head and on the West Coast, including one tall-forest site in Card Creek, West Coast. Both baits at the adjacent site had disappeared completely and we presume they had been carried away by hawks.

No mice or rats were detected at Esk Head, but were recorded (CCI) at 20–37% of baits sites in the other two areas (Table 3). One Orongorongo meat bait had a number of rat faeces on it.

A pig and a cat were also recorded as having visited Esk Head bait sites, with the cat seen actually feeding on a bait.

Frequency and intensity of scavenging

Most of the meat baits were fed upon in the first week after deployment, with just 18% overall not appearing to be have been fed on at all (Table 4). Assuming from the pen trial above that possums would prefer the peanut butter used to lure the CC cards to the meat baits, the consumption of some meat at sites with no CC evidence of a possum visit (CC−ve columns, Table 4) indicates scavenging by species other than possums. Conversely the absence of scavenging at some sites visited by possums indicates that not all possum visits resulted in scavenging (Table 4).

Table 4 Heads scavenged or not scavenged (%) in each area, according to whether possums encountered (CC+ve) or did not encounter (CC−ve) each ‘head’ site, in the first 7–8 days after head placement.

	No. sites	CC−ve Not scavenged	CC−ve Scavenged	CC+ve Not scavenged	CC+ve Scavenged
Esk Head	28	0	7	7	86
Orongorongo	30	3	6	23	67
West Coast	30	10	43	10	37

The frequency of scavenging (i.e. the percentage of sites with at least some meat eaten) in the first week was highest at Esk Head (93%), presumably reflecting the high density of, and/or ease of access for, harrier hawks. First-week scavenging frequency was also high on two of the three West Coast lines, with at least some meat eaten at 90% and 100% of the Card and Cockeye Creek sites respectively, but only 50% of meat baits along Ogilvies Road had some evidence of scavenging.

The differences between areas in the intensity of scavenging (the average amount, in percentage terms, of meat eaten) during the first week were even more marked (Fig. 2; Fisher’s Exact test $P < 0.0001$). At Esk Head, 70% of the edible meat and fat (i.e. excluding skin and bone) had been consumed (84% pig, 59% deer) after 8 days, and all had been consumed after 41 days. On the West Coast, 54% of the meat had been consumed (58% pig, 50% deer) after 7 days, and all had been consumed after 40 days. In contrast, at Orongorongo, only 6% of the meat had been consumed (10% pig, 2% deer) after 7 days, although this increased to 34% (36% pig, 32% deer) after 28 days, and to 60% (63% pig, 58% deer) after 46 days. Scavenging intensity at Orongorongo was particularly light in the first week with about half the scavenged sites having <2% of the meat eaten, whereas in the other two areas, over half the meat at scavenged sites was eaten in the first week. Overall, almost all the carrion at sites known to have been found by hawks was completely eaten, making it likely that some other species was responsible for the light scavenging at Orongorongo. Scavenging continued to occur at Orongorongo sites even when the meat was 4–6 weeks old.

The various scavengers preferred pork to venison. The percentage of pig meat eaten after one week (78%) was higher than the percentage of deer meat eaten (65%) consistently across all three areas, and at a quarter of the 73 sites with some scavenging, pig meat alone was eaten at 22 sites, whereas there were no sites where deer meat alone was eaten (Fisher exact test $P < 0.0001$).

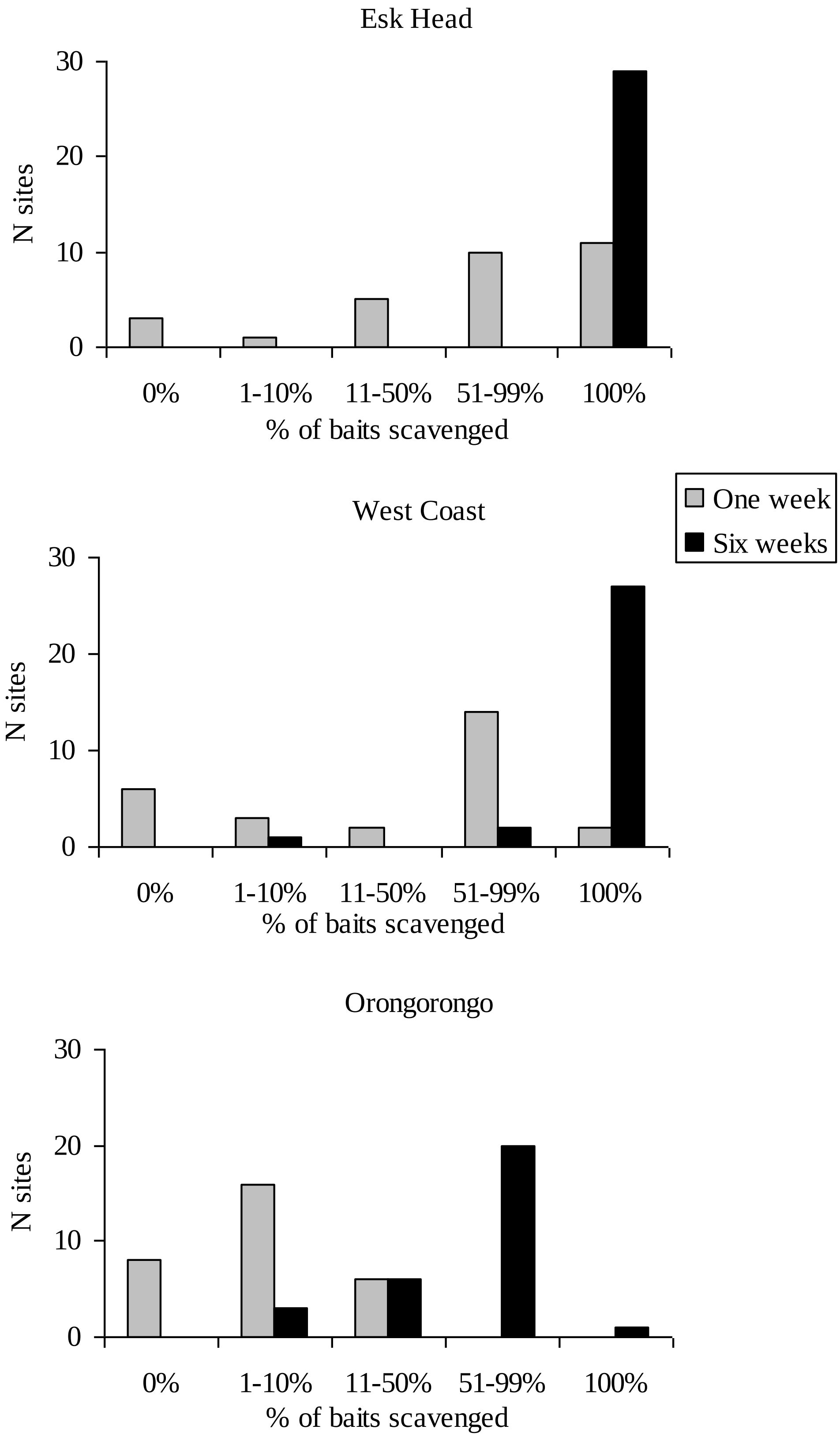

Fig. 2 Frequency distributions of the percentage of each pair of meat baits eaten 1 and 6 weeks after being placed in the field, by area.

At Esk Head and on the West Coast, the RB dye initially contained within lymph nodes was frequently spread over much of the remnant tissue and on the ground around the bait. This was sometimes due to RB leakage from the nodes, but staining of bones and skin not initially exposed to the dye (Appendix 1) indicated that scavenging has greatly exacerbated RB spread. Spread to the ground was greatest when the meat was dragged well away from where it was placed, with some West Coast and Esk Head baits being moved up to 10 m. Hawks appeared to be the greatest RB spreaders as, at Esk Head, RB dye was recorded on the ground at 93% of 27 sites scavenged one week after deployment, compared with 58% of 24 West Coast sites and just 14% of 22 Orongorongo sites.

RB marking of scavengers

RB-stained faeces of weka were observed at one West Coast site (Appendix 1), and of hawks at 11 Esk Head and two Orongorngo sites.

Possums were unequivocally confirmed as scavengers at the Esk Head site by the presence of RB-stained possum faeces. Pink staining was not observed on the paws of any Esk Head possums (which were killed on or after the night that RB-stained venison was made available), but probable RB staining (albeit without fluorescence) was seen on the tops and roof of the mouth of three and the stomach wall of another. Another possum had RB-stained pieces of meat in its stomach and three others had 1–2 deer hairs in their stomachs. Curiously, one of these had a piece of latex glove in its stomach.

We examined the whiskers of 29–30 randomly selected possums from each of the three areas. In each of the Esk Head and Orongorongo areas there was clear RB banding in the whiskers of two possums (7%) that indicated RB uptake. In all three areas another 2–3 (7–10%) of the possums had fluorescent banding that was more marked than in the control animals used in the pen trials, suggesting these animals had also ingested or absorbed small amounts of RB. There was no evidence of a significant difference between areas in the percentages of possums with definite, possible, and no marking (Fisher's exact test, 3×3 table, $P = 0.70$).

A further 12 possums from Esk Head with other indications of their having somehow interacted with meat baits were also checked. These included those with deer hairs or RB-stained meat in their stomach, or staining on stomach lining, lips, or mouth etc. Of these, one (8%) was classed as having definite RB marking and three (25%) others as having possible RB marking.

Table 4 Number and percentage of possums classified as having RB-stained whiskers. The possums analysed were randomly selected (separately for each area) subsamples of all possums killed.

Site	No. possums checked	Possible RB marking (*n*)	Definite RB marking (*n*)	% RB staining
Esk Head	30	3	2	7–17
Orongorongo	29	2	2	7–14
West Coast	30	3	0	0–10
Overall total	89	8	4	5–14

6. Conclusions

6.1 Nature and frequency of scavenging

Most animals that die in the three areas studied appear likely to be largely consumed by scavengers, at least in winter, and at least where the amount of meat available is only 1–2 kg and where the meat is directly available (i.e. is not completely covered by skin). The latter caveat is based on previous work in which hawks were unable to open up pig carcasses (Yockney & Nugent 2003) and on video-records from a 2007 study in Cockeye Creek in which weka were unable to scavenge possums that did not have a break in the skin (G. Nugent unpubl. data.).

There was too little sign of pigs, cats, stoats, or ferrets to suggest that these species might have eaten much of the carrion, and the large quantities eaten and scavenging sign were not consistent with scavenging by rats, mice and hedgehogs. Thus, although we were seldom able to identify the scavengers with certainty, we are confident that weka and, to a lesser extent, hawks were the primary scavengers at the West Coast sites, while hawks were the main scavengers at the scrub-margin sites at Esk Head, and also in forest at Orongorongo. We guess that one or other of these two bird species will have eaten 90% of the carrion consumed. Too few possums were marked for them to have been responsible for the typically near total consumption of the baits at the Esk Head and West Coast sites.

Previous studies (Yockney & Nugent 2003; Byrom 2004; Nugent 2005) have shown that avian scavengers tend to be messy feeders compared with mammals such as ferrets, cats, and pigs. The latter tend to consume large amounts of carrion at a time without moving it around much, and pigs can consume a whole possum carcass in a single meal (Coleman et al. 2005). In contrast, hawks and weka ate relatively small amounts of meat during each of multiple visits, resulting (in this study) in bait remnants in which the RB dye was exposed and spread over both the meat itself and the surrounding ground. This undoubtedly increased the likelihood that any possum subsequently visiting the site would come into contact with the dye.

6.2 Scavenging by possums

This study adds further weight to previous largely qualitative studies showing possums do sometimes feed on carrion, whether it be the carcasses of other possums or of other common Tb hosts (deer, pigs, and ferrets). It indicates that although possums seldom appear to eat large quantities of such carrion, there is nonetheless a high probability they would ingest the infectious material inside any Tb lesions within such carrion (Table 4), at least when the lesions are close to the surface of the carrion and where previous scavenging (particularly by weka or hawks) has exposed and spread the lesion contents. We therefore infer that the discarded heads of Tb-infected pigs and deer killed by hunters would pose a significant risk of spillback transmission of Tb to possums for as long as infection persisted in those spillover hosts. We have previously estimated that the duration of that risk for deer is about a decade after Tb levels in possums are greatly reduced, and half that for pigs (Nugent 2005).

Our inference that bird-assisted spillback infection is likely to be an uncommon but not negligibly infrequent event appears to provide a plausible explanation for some previously unexplained aspects of the history of Tb in New Zealand wildlife. Historically Tb appears not to have spilled over into possums until about the 1960s, with some indications that it was present in both deer and pigs before that. Nugent (2005) suggests that the advent of commercial deer hunting at around that time resulted in a large increase in the number of deer being killed, and, more importantly, in the likelihood they would be decapitated and the head left in the field – i.e. that the likelihood of transmission from deer to possums was hugely increased at that time. Although pigs were also commercially harvested, they were sold whole and so not decapitated in the field. Consistent with the inferred role of avian scavengers, the first outbreak in possums was on the West Coast where weka remains common. Likewise, it is possible that the tendency for Tb prevalence to be higher near forest edges (Coleman 1988; Caley et al. 2001) could partly reflect a greater likelihood of scavenging by hawks of infected possum carcasses at forest margins.

6.3 Management implications

The crucial implication is that it would appear unwise to allow possum numbers to recover to levels capable of maintaining Tb within a decade in areas where the prevalence of Tb in deer and/or the density of deer was initially high. A simple deterministic model was used to explore where the risk might be important. We assumed a 1000-km^2 area contained a moderate-to-high density of deer (5/km^2) and (from Nugent 2005) that the prevalence of infection in deer declined by about 40% per year after implementation of effective possum control.

From this study we first assumed (as a worst-case scenario based on the upper limit of the percentage of possums marked in this study) a spillback rate of 17%; i.e. that 17% of infected deer were killed by hunters and then scavenged in such a way that possums became infected. Under this extreme scenario, continued spillback (i.e. at least one case per year) was still predicted after a decade for any initial prevalence of infection in deer greater than about 10%.

However, a spillback rate of the order of 5% appears more realistic than the 17% based on scavenging rate above. This is because not all infected deer are killed by hunters, not all infected deer kills have lesions that are large and/or easily exposed, not all encounters with infectious material would result in transmission, and, perhaps most importantly, few deer are now harvested commercially (c. 5000 in the year to 30 June 2007 (K Briden, pers. comm.) compared with about 140 000 p.a. in the mid-1970s) and those that are not now decapitated in the field. In addition, at the low possum densities that prevail after control, the numbers of possums encountering a deer head is likely to average substantially less than one. At a 5% spillback rate, significant spillback would cease after 5–8 years for initial prevalences of 10–30% respectively. Overall, there are probably now relatively few places with the requisite combination of moderate-to-high deer density, high initial prevalence of Tb in deer, and abundant in-forest avian scavengers for spillback to be a major concern.

Another potentially important context is spillback from Tb-infected pigs. Prevalence rates can be extremely high in pigs, approaching 100% in areas where Tb is common in possums (Nugent et al 2003; Nugent & Whitford 2007), and pigs can be extremely wide ranging (Knowles 1994). Offsetting that, they do not appear to live as long as wild deer on average. The primary risk from pigs is therefore one of reimportation of Tb from some distant source, the implication being that the scale of management for the local eradication of Tb needs to take into account the potential scale of pig movements. There appears little point, for example, in attempting Tb eradication from somewhere like Molesworth Station without either controlling possums on adjacent land or reducing and keeping pig numbers very low.

In confirming high levels of scavenging by weka, and demonstrating plausibility of the hypothesis that they increase the likelihood of possums being exposed to infectious material contained in carrion, this study questions whether the accepted models of Tb transmission and epidemiology are adequate for all situations. Although beyond the specific objectives of this study, related FRST-funded research undertaken at the Cockeye Creek study site shows that weka cannot open up possum carcasses by themselves, but will find and feed through even small openings in the skin, including the sinuses created by burst lesions. We hypothesise that the predominance of peripheral sites of infection (inguinal, axillary, and head lymph nodes) in possums with single lesions (M. Cooke pers. comm.) reflects possums becoming infected more frequently by standing on and/or holding infectious material than by inhaling it. If so, then the type of messy scavenging we attribute to weka would increase the transmission rate, resulting in higher prevalences of Tb at lower densities of possums than elsewhere. In line with that, Coleman & Fraser (2005) recorded a 19.4% prevalence of Tb in possums in an area just east of the Cockeye study site (where weka were present) when the RTCI was only about 0.6%. As RTCI targets of 2% are frequently used for West Coast possum control, it is possible that current targets are not low enough to reliably eliminate Tb.

7. Recommendations

- The risk of spillback from deer and pigs should continue to be factored into vector control planning for Tb eradication. This risk should be given greatest consideration where cessation of possum control is being considered within about a decade of prevalence having been high (>10%) in deer, and where infected pigs have a high probability of reimporting Tb into an area. The AHB should consider development of a simple model or decision support system for vector managers to use in assessing the risk in any particular area.
- The impact of weka scavenging on Tb-eradication targets for the West Coast should be investigated to ensure that current possum-control targets are set sufficiently low to reliably prevent Tb persistence.

8. Acknowledgements

We thank Adrian Couchman and his staff at Vector Control Services on the West Coast for their help with this study as well as DOC and Timberlands for access to the three study sites there. We thank James Duckworth for access to Esk Head Station, and Mike Barber for his help with retrieving possums. Ivor Yockney, Roger Carran, Mike Perry and Peter Sweetapple of Landcare Research undertook the fieldwork, and Julie Turner, Andrea Airey, and Penny Fisher helped with the pen trial and undertook the microscopy. Mandy Barron provided useful comments on a first draft and Christine Bezar and Wendy Weller helped with editing and formatting.

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Appendix 1 Examples of RB-dyed meat baits and RB dye spread as a result of scavenging

Typical meat bait used in the study, comprising the foreleg of a pig. The picture was taken at a West Coast site one week after being placed in the field, showing some leakage of RB from the nodes, and during handling, but also spread as a result of scavenging.

RB staining of backbone and inside skin of a weka-scavenged hind leg of a pig at a West Coast site. This cannot have happened as a result of RB leakage.

Remnants of a deer meat bait completely consumed by weka, showing some RB staining of the vegetation and grounds near the bait site.

Heavy RB staining of the ground as a result of the bait being dragged around by the scavenger(s). This is not where the bait was initially placed.