Project No. R-10577 (Part 2 of a three-part project)

Scavenging of Potentially Tuberculous Feral Pig Carcasses in the Northern South Island High Country

Ivor Yockney and Graham Nugent

Project No. R-10577 (Part 2 of a three-part project)

Scavenging of Potentially Tuberculous Feral Pig Carcasses in the Northern South Island High Country

Ivor Yockney and Graham Nugent

Landcare Research
PO Box 69, Lincoln 8152
New Zealand

Landcare Research Contract Report: LC0304/059

PREPARED FOR:
Animal Health Board
PO Box 3412, Wellington

DATE: December 2003

Reviewed by:	Approved for release by:
Andrea Byrom Scientist Landcare Research	Phil Cowan Science Manager Biosecurity and Pest Management

DOI: https://doi.org/10.7931/ww6y-jf49

Contents

Summary

Project and Client

Research to determine the risk posed by scavenging of pig carcasses as a potential source of bovine tuberculosis (Tb) for other wild animals was undertaken by Landcare Research for the Animal Health Board (Part 2 of R-10577), between January and November 2003.

Objectives

To assess the fate of pig carcasses, heads and offal left in situ in the field, by:

- assessing the survival of culturable Tb in pig heads in both summer and winter
- monitoring the fate of pig heads, guts and whole carcasses in two seasons (summer and winter) in an area known to contain ferrets, possums, and feral pigs.

Method

The study was carried out on Muzzle Station, northern South island high country. In both summer and winter 2003, six infected pig heads were placed in scavenger-proof cages and the mandibular lymph nodes were swabbed at regular intervals to estimate how long culturable Tb bacilli survived after the death of the pig. Using motion-activated video cameras, we monitored the nature, frequency, and duration of interactions of wild animals with whole pig carcasses, and/or pigs' heads and offal, placed at a variety of field sites during both summer (January–March, 12 sites) and winter (July–September, 10 sites) in 2003.

Results

- Swabbing of typical mandibular lesions in pigs' heads produced few positive results on culture. In summer, *Mycobacterium bovis* was recovered from two of six heads after 3 days, but from none of four heads swabbed after 10 days. Decay was rapid, with tissues unrecognisable after 8–12 days. In winter, one positive culture was obtained after 3 days, and three after 10 days.
- Carcass sites were monitored effectively for 63 video-days in summer and 114 in winter. In summer, all of 12 heads and 12 offal piles, and 9 of 10 whole carcasses were scavenged. In winter, all 10 heads and all 10 offal piles were fed on, but none of 10 whole carcasses.
- Australasian Harriers were observed at 69% of summer and 100% of winter sites, feeding for 9 min per average feeding bout. Harriers fed on heads and offal, and on whole carcasses that had been opened up by other species, in a way that could spread bacilli over the carcass.
- No ferret visits were recorded in winter, but ferrets fed at 77% of summer sites, feeding for about 6 min per average feeding bout. Up to five ferrets fed at a site at the same time. Ferrets fed on heads, offal, and whole carcasses, easily 'opening up' the latter.
- Cats fed at 61% of summer and 50% of winter sites, for about 5 min per average feeding bout, never opening up a whole carcass but feeding on those opened up by ferrets in summer.
- Possums visited 23% of summer and 50% of winter sites – a total of 45 visits. Possums sniffed at the remains on 18 occasions, collectively spending 15 min doing so. Possums fed at two (25%) of eight sites they visited, feeding on three occasions for 5.5 min total.

- Cattle visited four sites in winter, making a total of 30 visits. On eight visits, cattle sniffed at the carcass remains for a collective total of about 4.5 min.
- Pigs visited one summer and one winter site, and nuzzled one offal pile but did not feed for more than a few seconds, if at all.

Conclusions

- Pigs' heads decay quickly in summer, but some contain live *M. bovis* for at least 3 days, and many heads were scavenged within this period. Heads remain infectious for longer in winter.
- Most pig remains are visited and fed on by other wildlife, particularly ferrets, harrier hawks, and cats. Possums and cattle also made direct contact with and/or fed on carcasses. Messy feeding by the principal scavengers may increase the risks to possums and cattle, but there appears little risk of transmission to other pigs via cannibalism, at least in this area.
- Overall, this study indicates that feral pigs probably play a greater role in inter-specific transmission of Tb than previously suspected, especially via hunter-killed pig's heads, and especially in the long-distance spread of Tb to uninfected ferret populations. The key unknown is the frequency with which possum and ferret interactions with infected carcasses results in Tb transmission. Unless that frequency is near zero, inter-specific transmission is likely to occur often enough to contribute significantly to Tb spread. Within VRAs, the 'recycling' of spillover Tb in pigs back to ferrets and occasionally to possums may extend the time required to eradicate Tb.

Recommendations

The risk of Tb spread by pigs needs to be better quantified by determining under what circumstances the rate of transmission of Tb from pig carcasses to possums and/or ferrets exceeds more than a few percent of encounters.

Assuming, under the precautionary principle, that pigs play an important role in the long-distance spread of Tb we repeat the recommendations from part one of this study:

- The AHB should educate hunters about the risk of Tb spread via carcasses (particularly the dumping of heads and offal outside VRAs) and the shifting of potentially infected pigs to new Tb-free locations.
- Pig populations at the margins of VRAs should be intensively surveyed annually, both to reduce overall pig population densities and to provide precise information on the location and prevalence of Tb in pigs.

The AHB should also consider helping farmers reduce pig numbers on their land (and therefore the risk of Tb spread) by contributing to the development and registration of a farmer-usable bait-and-toxin for pigs. Where possible, carcasses should be recovered and buried, but as that will usually be impractical, such control should at least be undertaken in winter, when ferrets are less likely to scavenge on infected pigs.

1. Introduction

This report is the second of three arising from a project funded by the Animal Health Board (R-10577: Should feral pigs be targeted during Tb-vector control operations?). The first, a literature review ('Pigs as hosts of bovine tuberculosis in New Zealand – A review') was completed May 2003. This report identifies the risk posed by pigs' carcasses as a potential source of bovine tuberculosis (Tb) for wild animals. The study was undertaken by Landcare Research in the northern South Island high country (Muzzle Station), between January and November 2003. The third report will not be completed until 2005 and focuses on the effect of possum control on Tb prevalence in feral pigs.

2. Background

Feral pigs (*Sus scrofa*) have traditionally been considered a spillover end host for bovine Tb (McInerney et al. 1995; Nugent et al. 2003), despite the feral pig populations in some Vector Risk Areas (VRAs) having extremely high prevalences of Tb. There is, however, increasing awareness of the possibility that feral pigs may play some role in spreading the disease to other species, particularly scavengers, and to other places, as pigs can disperse long distances (Knowles 1994), may be illegally liberated in new locations (Fraser et al. 2000), or transported and disposed of outside VRAs as hunter-killed carcasses. Unlike deerstalkers, pig hunters typically carry out the entire carcass of killed pigs, including the head (the key site of infection in pigs;) (Nugent et al. 2003). The head is sometimes then disposed of near the hunter's home, which can be well outside the VRA. Known dumping sites include riverbeds, road-side rest areas or scrub land (Nugent et al. 2003) where they are potentially available to infect other wildlife, particularly scavengers. This suggests a potential mechanism by which hunters may be inadvertently spreading Tb, particularly since most of them are unaware that the pigs they kill are often infected.

Anecdotal reports and more formal monitoring of carcasses using video cameras have shown that the list of potential scavengers includes not only the species considered as mainly carnivorous (e.g. ferrets (*Mustela furo*) and cats (*Felis catus*)) but also omnivores such as pigs and hedgehogs (*Erinaceus europaeus*) and 'herbivores' such as possums (*Trichosurus vulpecula*), with the latter being crucially important as the primary wildlife maintenance host of Tb in New Zealand. Ragg et al. (2000) documented scavenging by both possums and ferrets (and other species) on ferret and rabbit carcasses, and possums have also been filmed feeding on deer carcasses (G. Nugent, unpubl. data).

In this largely qualitative study we aimed to confirm the likelihood that these two species (ferrets and possums) would also scavenge on pigs carcasses, and, more broadly, to characterise the likely fate of the reservoir of Tb present in infected pigs and pig carcasses. This information is crucial in assessing the risk that Tb-infected pigs pose in either maintaining or spreading Tb, and therefore whether or not pig control should be part of the vector management programme in New Zealand.

3. Objectives

To assess the fate of pig carcasses, heads and offal left in situ in the field, by:

- assessing the survival of culturable Tb in pig heads in both summer and winter
- monitoring the fate of pig heads, guts and whole carcasses in two seasons (summer and winter) in an area known to contain ferrets, possums, and feral pigs.

4. Methods

4.1 Survival of Tb in dead pigs' heads in the field

During both summer (January–March) and winter (July–September) 2003, six grossly tuberculous pigs heads were put in scavenger-proof cages and placed both in direct sunlight (n = 3) and shady areas (n = 3). A small (c. 2 cm) incision was made through the skin exposing the mandibular node, which was cut open with a scalpel to allow access to the *Mycobacterium bovis* lesions within. The lesions were swabbed using transport-medium-modified swabs (Eurotubo®, Barcelona, Spain) after 3 days, then at approximately weekly intervals thereafter. In summer, rapid decay meant individual tissues and lesions were highly desiccated and unrecognisable after 8–12 days, so only 3- and 10-day samples were taken. In winter, samples were collected regularly up to 49 days after death. Swabs were frozen immediately, and kept frozen (-4°C) until sent for culture. Although swabs were taken from most heads on the first day that each was placed in the field, these swabs were not cultured.

4.2 Fate of pig carcasses, heads, and offal

During summer 2003, and again in winter 2003, Trailmaster™ infrared-triggered video camera systems were used to determine which wildlife species visited sites with pig remains, and the frequency and nature of the resulting interactions. The pig remains used at each site consisted either of a pig's head, an offal pile, or a whole carcass, or some combination of the three. In most instances, all three types of remains were placed at the monitored sites. Sites were spread over approximately 5 km of accessible river flat and terraces known to be occupied by pigs, ferrets, and possums, with about equal numbers of sites in sun and shade. Thirteen sites were monitored in summer, and ten in winter, but data from one summer site were lost.

The 8-mm and Digital 8 video camera systems used did not record continuously, but rather were activated when the body heat and movement of an animal visitor was detected by the infrared sensor. The 2-hour videotapes were changed every 1–2 days as required, but sometimes all of the available tape had been used up early in the period (typically when the system was activated by flies, or there were long periods of scavenging by Australasian harrier hawks (*Circus approximans*) or ferrets). In addition some systems malfunctioned at times, or the cameras were (for example) bumped by cattle and no longer filmed the area of interest, so the record of events at each site was seldom complete (Appendix 10.1). Effective 'operational' times were calculated by assessing the total time each system was capable of recording an event. Although camera systems were in place for at least 2 weeks at most sites, or at least until all of the pig remains had been removed, operational times were often substantially shorter than this.

The cameras used had two time codes, which are displayed during analysis: one for current date and time, and one for tape-elapsed time. Lighting was provided via a 30W red-filtered spotlight, which is controlled by the Trailmaster™ software during night events.

Tapes were reviewed on a large-screen TV, and the time, duration, and nature (species and behaviour) of each visit by wildlife recorded. The minimum number of individuals of each species visiting each site was determined, as was the time until the first recorded visit to each site by each species. The minimum number of individuals (only presented here for ferrets) is likely to be an underestimate as individuals were only distinguishable by easily recognisable differences (i.e. radio collar/no radio collar) or where more than one individual of that species was filmed at the same time. For analysis, event duration was recorded as both the minimum duration of the event as actually seen on tape (tape-elapsed time), and as the maximum time based on both the date/time code on the camera and total tape-elapsed-time code. As an example of the difference, when a cat visited a site, the system would record automatically for 2 min (recorded as maximum event duration) but if the cat was only visible in the field of view for 0.5 min, a minimum duration of 0.5 min was recorded. Data presented here are based on minimum times (actual viewable recorded time) unless otherwise stated.

5. Results

5.1 Survival of culturable Tb in dead pigs' heads in the field

Summer

The average midday temperature over the 12-day study period was 31°C (range 25–36°C, SD = 4°C). All the pig heads rapidly became flyblown and most tissue had either been eaten by maggots or became completely desiccated and hard within 10 days, so no swabs were taken after 10 days because the lymph nodes were no longer recognisable. For one pig, the head was too decayed at 10 days for a swab to be taken. Only two of six swabs taken at day 3 were positive, and none of the four taken after 10 days (Table 1).

Winter

Midday temperatures in winter ranged from 0°C to 20°C, with night-time temperatures usually below zero. As a result, the heads were often frozen in the morning, and, as a consequence, little decay of material occurred until after 2–3 weeks. Most of the mandibular lesions swabbed (and the swabs themselves) during the first 10 days of the trial contained easily recognisable calcified, almost 'granulated', material typical of Tb. The lesions and nodes containing them became progressively less recognisable, with none at all recognisable by 48 days.

Only one of the swabs taken after 3 days was positive, but three of those taken after 10 days and four of those taken after 29 days (Table 1) cultured positive. None taken after 48 days were culture positive. The failure to detect Tb in three 3-day samples from heads that later proved to still have viable *M bovis* bacilli present after 29 days indicates the swabbing approach used in this study was relatively insensitive in detecting Tb presence.

Table 1 Outcomes of mycobacterial culture for *M. bovis* from swabs taken from the submandibular lymph node of six pigs' heads in both summer and winter 2003. A dash (–) indicates no sample was taken because there was no recognisable lymph tissue remaining that could practicably be swabbed.

	Site	3 days	10 days	29 days	48 days
Summer	1	–ve	–ve	–	–
	2	+ve	–	–	–
	3	–ve	–ve	–	–
	4	–ve	–	–	–
	5	–ve	–ve	–	–
	6	+ve	–ve	–	–
Winter	1	–ve	+ve	+ve	-ve
	2	–ve	–ve	-ve	-ve
	3	–ve	–ve	+ve	-ve
	4	+ve	+ve	+ve	-ve
	5	–ve	-ve	-ve	-ve
	6	–ve	+ve	+ve	-ve

5.2 Fate of carcasses

Cameras were in place for 5–15 days at all sites, but camera malfunctions, sensor malfunctions, or complete utilisation of available recording time before the next servicing visit reduced the effective monitoring time at many sites. In total the 12 summer (January–March) sites were effectively monitored for a total 63.0 days (a mean of 5 days per site) while the 10 winter (July–September) sites were filmed for 114.2 days (mean of 11 days per site). The difference between seasons largely reflects the high levels of 'nuisance' triggering of the recording system by flies in summer, and the large amounts of recording time used up by the numerous ferret visits in summer (ferrets were not recorded in winter; see below).

In summer, all of the 10 heads monitored were scavenged, as were all 10 offal piles at the same sites, and 9 of the 10 whole carcasses monitored that season (Appendix 10.1).
More than half of heads and offal were considered largely scavenged (i.e. most edible tissue removed and >50% of entire head/offal material scavenged), as were 40% of the whole carcasses.

In winter, all 10 heads and all 10 offal piles were at least partly scavenged (<50% of material scavenged), with 70% and 20% respectively considered to have been largely scavenged. In contrast to summer, none of 10 whole carcasses were eaten, apparently because no ferrets visited these sites – all of the whole carcasses scavenged in summer were initially opened up by ferrets.

Excluding small birds and insects, a total of 10 species was recorded visiting these sites, but three species (sheep (*Ovis aries*), rabbits (*Oryctolagus cuniculus*), and hares (*Lepus europaeus*)) did not approach to within 1 m of any of the pig remains. Of the seven species that did approach to within 1 m of the remains, Australasian Harriers (*Circus approximans*), ferrets, cats, and possums accounted for most of the visits (Tables 2 and 3; Appendix 10.1).

Table 2 Number of sites with pig remains (head, offal and whole carcass) visited by each of seven wildlife species, in summer and winter, with average time to first discovery by each species for each site actually visited, and the percentage of visited sites approached to within 1 m, sniffed, and actually fed upon. There were 13 summer sites and 10 winter sites. Three species (sheep, hares, rabbits) that did not approach to within 1 m of carcasses are not included.

Species	Season	No. sites visited	Average time to discovery (h)	% Pig remains approached to < 1m	% Pig remains touched or sniffed	% Pig remains scavenged
Australasian Harrier	Summer	9	4	100	100	100
	Winter	10	45	100	100	100
Ferret	Summer	10	59	100	100	100
	Winter	0	–	–	–	–
Cat	Summer	8	41	100	100	100
	Winter	5	76	100	100	100
Possum	Summer	3	15	100	66	0
	Winter	5	55	80	80	40
Hedgehog	Summer	3	122	100	100	100
	Winter	0	–	–	–	–
Cattle	Summer	0	–	–	–	–
	Winter	4	70	50	50	0
Pig	Summer	1	92	100	100	100
	Winter	1	18	100	100	0

Table 3 Number (*n*) and total duration (min) of five behaviours observed during the visits to each site, by species, for each season. The behaviour classed are exclusive, in that an animal that sniffed or fed on a carcass is not also included in the 'close approach' category, even though it obviously did so.

Species	Season	Passing		Fighting		Close approach		Sniff		Scavenging		Total	
		n	Time (min)	n	Time (min)	n	Time (min)	n	Time (min)	n	Time (min)	n	Time (min)
Australasian Harrier	Summer	11	10.0	1	1.0					78	538.0	90	549.0
	Winter	15	15.5			6	11.0			97	1182.0	118	1209.0
Ferret	Summer	31	29.5	4	3.0			18	15.5	234	1270.0	287	1318.0
	Winter											0	
Cat	Summer	10	8.0					14	13.0	32	124.0	56	145.0
	Winter	11	18.0			1	1.0	9	6.0	42	285.5	63	310.5
Possum	Summer	7	5.0			1	0.5	5	6.0			13	11.0
	Winter	13	11.5			3	4.0	13	9.0	3	5.5	32	30.0
Hedgehog	Summer	4	4					3	2.5	2	4	9	10.5
	Winter											0	
Cattle	Summer											0	
	Winter	21	86.0			1	1.0	8	4.5			30	91.0
Pig	Summer							2	0.8	1	1.0	3	1.8
	Winter					1	1.5	1	1.5			2	3.0

Australasian Harrier

Australalasian Harriers were the most common visitor in both seasons, visiting 9 (69%) of the 13 summer sites and 10 (100%) of the winter sites. Harriers mostly visited sites alone, and fed on carcasses for a total of 80% of the 90 visits in summer, and 82% of the 114 visits in winter. The duration of each feeding event was about 7 min in summer and 12 min in winter (Table 3).

Harriers fed on heads and on offal piles, but not on whole carcasses unless ferrets had previously opened up the carcass. When feeding, harriers typically hold the flesh with their talons and pull off pieces of tissue with the beak, sometimes with a shake of the head that has the potential to spray lesion contents over the surrounding area. When feeding on the alimentary tract, harriers tended to concentrate on the mesenteric tissue. Recognisably individual harriers revisited the same site numerous times, either during the same day or on successive days.

Ferrets

Ferrets visited 10 (77%) of the 13 sites in summer, and fed on the remains at all of them. At least two different ferrets were identified at more than half the sites visited by ferrets. The number of visits by individual ferrets per visited site ranged from 2 to 85, the upper figure reflecting multiple visits by a family group of five ferrets. This group of five ferrets fed repeatedly at the same site, often clambering over each other and the carcass to gain access. All of them were later captured and radio-collared as part of another concurrent study. The juveniles in this group subsequently dispersed and were recovered from points a maximum of 5 km apart. One of the recovered juveniles was subsequently found to be infected with Tb (A. Byrom, pers. comm). Although ferrets found one set of remains within 6 hours of it being placed at the site, other visited sites were not found up till 6 days after. Most ferret visits resulted in the ferret approaching the carcass (92%) and feeding on it (80%). The exceptions tended to be when a ferret or group of ferrets had already fed extensively on the remains but remained in the vicinity and returned to the site soon after feeding.

The 287 ferret visits in summer resulted in 230 feeding events with a total duration of 1270 min (2.1 hours per visited site; Table 4). The duration of individual feeding events averaged 5.6 min, although for one site the average duration for 9 feeding events was 13 min.

Ferrets fed on heads, offal piles, and whole carcasses, with four whole carcasses being almost completely consumed by ferrets. The intact skin of whole carcasses was no impediment to ferrets, which usually gained initial access through the soft skin under the throat – incidentally very close to the mandibular lymph nodes. In one instance three ferrets were seen at a carcass, with movement of the pig's skin indicating one ferret was feeding while totally inside the carcass. It subsequently emerged through a small opening in the pig's abdomen. In every instance in which a whole carcass was scavenged, ferrets were responsible for the initial opening of the carcass, which was sometimes then fed on by other species

No ferret visits were recorded at any of the 10 winter sites. This reflects a much reduced winter density and/or activity of ferrets, as no ferrets were trapped in winter 2003 in a concurrent study whereas 53 were trapped in summer (A. Byrom, pers. comm.)

Table 4 Ferret interactions at each site, summer 2003 (no ferret visits were recorded in winter). The number of individuals identified is a minimum, as not all ferrets visiting at different times could be distinguished from each other.

Site	Visits (*n*)	Individuals identified (*n*)	Time to discovery (h)	Close approaches <1 m (*n*)	Total duration, close approach (min.)	Sniffs (*n*)	Feeding events (*n*)	Total duration, actual contact (min.)
MC2	80	5	32.2	76	190.0	1	75	189.0
3228	26	4	78.1	19	200.0	4	15	196.0
OSWG	12	1	5.7	9	131.0	2	7	130.0
MC4	0							
MC3	0							
F1	10	2	148.1	10	37.5	1	9	37.0
2763	26	2	107.3	22	241.0	5	17	236.0
2767	85	3	10.6	83	206.5	3	69	194.0
2749	5	1	20.7	4	10.5	0	4	10.5
3160	4	1	30.4	4	18.5	1	3	18.0
3193	36	3	9.4	32	256.5	1	30	256.0
3173	2	1	150.3	3	16.0	1	1	15.0
PH1	0							
Totals	286	23	-	262	1307.5	19	230	1281.5
Means		2.3	59.2	26.2	130	6.6	23	12.8

Cats

Cats visited 61% of the summer sites and 50% of the winter sites, and fed at all of them. However, cats fed on only 57% of summer visits and 66% of winter visits, although the average duration of feeding bouts (4.0 min in summer and 6.7 min in winter) was similar to the average for ferrets in summer (5.6 min). On two occasions individual ferrets displaced a feeding cat. In contrast to ferrets, the total amount of feeding by cats was greater in winter (280 min) than in summer (124 min). Cats never opened up a whole carcass but did feed on those that had been opened up by ferrets in summer.

Possums

Possums were the fourth most frequent visitors to the carrion sites, with three (23%) of sites visited in summer and five (50%) in winter (Table 5). Possums always visited sites singly (Tables 3). In the main, the possums were much less interested in the remains than the species above, simply passing by without coming within 1 m of the carcass on 19 of 44 possum visits recorded (44%). On 25 occasions, the visiting possum approached within 1 m of the remains but did not feed, although on 18 of these occasions the possum sniffed at the carcass. In total, possums spent 15 min sniffing at the remains. On three occasions (two at one site and one at another) in winter, possums actually fed on the carcasses, as follows:

1. One possum visited a pig gut pile and in 2 min ate a small quantity of mesenteric tissue and fat before quickly departing.
2. Most likely the same possum (at the same site but during the next night) fed on mesenteric fat and tissue for 3 min, pulling the tissue free in largish strips that were then held in its paws while the possum tugged and chewed off smaller bite-sized pieces (see Fig. 1).
3. Another possum at a different site appeared to scavenge very briefly (0.5 min) from gut material, but as it was filmed with its back to the camera it was difficult to ascertain how much material was consumed.

Table 5 Possum interactions, for each visited site, in summer and winter 2003.

Site	Season	Visits (*n*)	Close approaches (<1 m) (*n*)	Total duration of close contact (min)	Sniffs (*n*)	Feeding bouts (*n*)	Total duration of actual contact (min)
MC3	Summer	1	1	1.0	1	0	0.0
F1	Summer	1	1	0.2	1	0	0.0
2767	Summer	10	4	5.0	3	0	0.1
Totals		12	6	6.2	5	0	0.1
1031	Winter	1	1	1.0	1	0	0.0
1130	Winter	1	0	0.0	0	0	0.0
1036	Winter	10	8	11.0	4	2	5.5
1034	Winter	14	6	4.5	4	1	0.5
1035	Winter	6	4	3.5	4	0	0.0
Totals		32	19	20.0	13	3	6.0

The total duration of feeding by possums was only 5.5 min (a mean of 1.8 min per feeding bout), substantially lower than that for hawks, ferrets, and cats. Note that possums fed at two (25%) of the eight sites they visited.

Fig. 1 Possum at site 1036 during winter, feeding on mesenteric tissue and fat held in its forepaws. White mesenteric tissue is also scattered on the ground behind the gut pile in front of a whole pig carcass.

Cattle

Cattle visited four of the sites in winter (none in summer), but on 70% of the 30 visits simply passed by (Table 3). However, on nine occasions, they approached to within 1 m of the remains, and on eight occasions sniffed at the carcass for a total of about 4.5 min. This sniffing behaviour appeared to involve actual nose contact with the surface of the carcass in most instances.

Hedgehogs

Hedgehogs visited three (23%) summer sites but none of the winter sites, presumably because they were hibernating (Moss 1999) (Table 3). They approached to within 1 m of all three sites visited, and fed on the remains at two of them. This consisted of nine visits including 4 min of scavenging and 2.5 min of sniffing.

Pigs

Pigs visited one (8%) of the summer sites and one (10%) of the winter sites. On both occasions the close-contact visits were by two radio-collared domestic pigs that had been released as sentinels for Tb detection as part of another study. In summer, these two pigs spent a total time of 1.8 min at the carcass, rolling over part of the gut bag with their noses, and one appearing to briefly 'taste' the contents. A wild pig was also seen to pass in the background at this summer site, but showed no interest in the carcass. In winter, the same two pigs visited one site twice, approaching to within 1 m, but no closer, on one occasion, and on the other occasion sniffing at the carcass over about 1.5 min but not actually feeding.

The low number of pig visits recorded is not because pigs were absent from the area. The area as a whole contains moderately high pig densities, and hunting was prohibited in the main gully used for this study to maximise the chances of pig interaction. Pigs were seen within 200–300 m of the carcasses in this valley on several occasions, and pigs fed on sheep and cattle carcasses within 200 m of one camera site during the study period. Pigs would certainly have detected many, if not all, of the carcasses through smell, indicating that they either avoided the sites or at least were not attracted to them by the pig carrion.

The whole carcasses of four pigs that had died or been shot in an area with a high density of pigs (mobs 10 or 17 pigs observed in the immediate vicinity (within 50 m) of particular carcasses) remained untouched even when the carcasses had largely decomposed. Likewise, none of the whole carcasses of four pigs and nine piglets that died within 1-ha pens within our study area (containing a mixture of about 10 other wild and domestic pigs) were eaten. However, one skinned and gutted pig carcass left outside one pen was scavenged in early winter, most likely by a group of radio-collared sentinel pigs.

6. Conclusions

6.1 Transmission of Tb from carcasses

Most previous research on inter-specific transmission of Tb in New Zealand has tended to focus on either the infection of cattle, deer or possums through environmental contamination (Jackson et al. 1995; Morris et al. 1994), or direct interactions between cattle and deer and live but terminally ill possums (or ferrets) that are behaving abnormally (Sauter & Morris 1995a, b). As cattle (and presumably deer) need large doses of infection via the alimentary route, environmental contamination and ingestion is believed to be relatively unimportant as an inter-specific transmission route (Jackson et al. 1995). The scarcity of infection in sympatric sheep and rabbits supports that conclusion (Lugton 1997). As a result, we consider there has been a tendency to see transmission from live terminally ill possums as being the most likely route of transmission from wildlife to livestock.

However, this study, a preceding unpublished study of the fate of deer carcasses, and a previous study of the fate of ferrets and ferret scavenging by Ragg et al. (2000) show that a wide range of species do frequently interact with and feed on carcasses and the remains of carcasses.

The probability that an infected carcass will infect other wildlife depends on the:

- amount and distribution of infective material present in the carcass
- length of time that that material remains infective once the animal is killed
- frequency with which susceptible animals come into direct contact with the carcass
- nature and duration of that contact
- relationship between the number of bacilli ingested (or inhaled) and the frequency with which new infection becomes established.

We are unaware of any quantitative data relating infection rates to 'dosage' via feeding, licking, or sniffing, but this and the related studies cited above provide some insight about the first four factors.

6.2 Amount of infective material in pigs

Pigs are highly susceptible to Tb but adults, at least, appear able to contain the disease well, (Lugton 1997; Nugent et al. 2003). The submandibular nodes are almost always lesioned in infected pigs, followed next by the alimentary tract. Lesions can be large and liquefactive, but more typically, well-established lesions tend to be hard, 'dry' and heavily calcified or have extensive fibrosis. Heavily infected pigs can have large numbers of lesions, especially along the chain of mesenteric lymph nodes. The numbers of bacilli in lesions in pigs tend to be much lower than for other species (Montgomery 1995; Lugton 1997).

Pig populations in long-established vector risk areas with widespread infection in possums generally have very high prevalences of Tb, approaching 100% in adults (Nugent et al. 2003). In this study we have recorded culture-confirmed Tb in 53% of adult pigs (>6 months age) on Muzzle Station.

The nature of the lesions observed in pigs on Muzzle Station differs from that recorded in the Hauhungaroa Ranges, central North Island (see Nugent & Whitford 2003 for details), and in Hochstetter Forest on the West Coast (Nugent et al. 2002), being typically smaller, less liquid and much more heavily calcified and dry in appearance, so we suspect that the number of bacilli in lesions is even lower than usual for pigs. Consistent with this, only 53% of lesions classed as typical Tb on Muzzle Station were culture positive compared with 67% for Hauhungaroa Range and 89% for Hochstetter Forest (G. Nugent, unpubl. data).

6.3 Duration of infectivity

The results of the swabbing trial suggest that the viability of *M. bovis* declines quickly in summer, with only two of the six 3-day swabs being positive in summer, and none of the swabs from the four heads with at least vaguely recognisable tissue after 10 days. In winter four of six heads still contained culturable Tb after 29 days, and this is possibly conservative as one-third of the swabs from heads that were definitely infected at the time of swabbing did not detect Tb presence.

We now consider the approach used (slicing open of the mandibular lymph nodes to permit swabbing at the start of the study, in order to confirm infection, and then repeated swabbing of the same site) may have accelerated decomposition of the lymph node. With hindsight, a better and more realistic approach would have been to have placed about 10 heads from a population known to have a high Tb prevalence at each of a variety of sites with different microclimates, and then necropsied one head at each site at regular intervals (1–2 days in summer, 4–5 days in winter). This approach would also permit some assessment of the numbers of colony-forming units of *M. bovis* present in each sample. The high number of pigs readily available in the area would make this approach much more practical than we originally envisaged.

Our results probably therefore represent a worst-case scenario, but even so, the trial demonstrated that Tb remained present in some heads for at least a few days in summer, and for more than a week in winter. A high proportion of the heads were scavenged within those periods, particularly by ferrets in summer. Only pigs and hedgehogs had an average time until discovery that was longer than 3 days in summer, and all species had average discovery times less than 10 days in winter.

6.4 Frequency and nature of interactions with pig carcasses and remains

Most of the interactions and feeding recorded involved (not surprisingly) species known to commonly use carrion (i.e. ferrets, harriers, cats, and hedgehogs). However, possums also made direct contact with and/or fed on, albeit comparatively briefly, the remains at a third of sites they visited.

Australasian Harriers

Although birds are not regarded as hosts for bovine Tb, trials in Michigan, USA, with a variety of bird species have shown they can become infected if exposed to high enough doses, and even if they don't become infected are able to excrete viable bacilli when the volume of infected material consumed is large (S. Fitzgerald, Michigan State University, pers. comm.). Their habit of defecating on or near carcasses could potentially expose other scavengers to Tb both at the site with the infected carcass and also at uninfected carcasses visited in the day or so after feeding on an infected carcass. Likewise, their habit of flicking their heads sideways occasionally while feeding could conceivably spray infective material over the carcass, especially if the lesions were semi-liquid. This would increase the likelihood that any animal licking the carcass (as was observed for cattle, see below) would pick up Tb bacilli.

Ferrets

On Muzzle Station, pig densities are comparatively high, but ferret densities appear only moderate for unforested rabbit-prone land. We therefore consider that the number of ferret interactions recorded and the high proportion of remains fed upon, in summer at least, were typical or below average for 'ferret' country. Ferrets tended to remove almost all of the edible tissue, especially for heads and offal. The implication for Tb transmission is that most of the infective material in pig heads and offal left in ferret country will be consumed by ferrets, with a strong likelihood that more than one ferret will eat infective material from any one pig, at least in summer. The risk is lower for whole carcasses, simply because of the greater volume of material available. The other striking feature of the summer trial was the tendency for multiple ferrets to feed at each site, the implication being that the remains of one infected pig could potentially infect whole litters of ferrets, amplifying the numbers of tuberculous wildlife.

The lack of ferret activity around carcasses in winter cannot be readily explained. Concurrent limited trapping for another project (R-10618) is unlikely to have been anywhere intensive enough to account for the 100% decline, the video cameras were spaced well apart, including in some areas that were never trapped for ferrets during the concurrent study, and trapping for ferrets in the same area during winter produced no animals (A. Byrom, Landcare Research, pers. comm.).

More broadly, these results confirm previous suspicions that natural dispersal or transport of pig carcasses (or live pigs) by hunters has the potential to spread Tb long distances, and to expose ferrets and cats in particular to Tb. We consider that a pig–ferret–livestock sequence of transmission could conceivably explain some of the outbreaks of Tb in livestock in areas with low possum densities and well removed from the nearest substantial source of infected possums.

Possums

The low level of possum interaction with carcasses reflected the limited numbers of possums in this largely unforested landscape (plus the effect of informal possum control and/or harvesting for fur carried out during our winter trials). Likewise, visits that result in close contact or actual feeding were few and brief compared with harriers, ferrets and cats. This study confirmed, however, that possums not uncommonly feed briefly on carrion, as shown for rabbits and ferret carcasses (Ragg et al. 2000), deer carcasses (G. Nugent, unpubl. data), and meat baits used for ferret trapping (Caley 1998). In the deer carcass study, possums fed on deer remains in two of five geographic areas studied (Mt Thomas, and Kaikoura in Canterbury), and at four (25%) of the total of 12 carcass sites monitored in that study. In this study, they fed two of the eight sets of remains visited by possums. In both instances, the possum fed on the mesenteric tissue and fat, a site commonly containing multiple tuberculous lesions in pigs with moderately generalised Tb. Again the crucial unknown is the frequency with which these sniffing and scavenging events translate into actual transmission events. However, given the much higher density of possums in many other places, it seems certain that pig-to-possum transmission occurs occasionally. Arguably this mechanism could help explain the spread of Tb in places where pigs are common (e.g. Hawkes Bay) and the failure of Tb to spread through areas such as the eastern Kaimanawa and Ruahine ranges where pigs are absent or scarce.

Cattle

Although cattle did not feed on the pig carcasses, they did sniff and contact some of the remains, potentially exposing themselves to Tb bacilli spread over the carcass surface by the activities of ferrets and harriers. Previous monitoring of the interactions between livestock and live and dead possums and ferrets (Sauter & Morris 1995a) emphasised the interaction with live animals as being a far more risky encounter. However, the difference in relative risk is reduced when the period over which infective carcasses are available to be encountered is compared with the presumably short time a terminally ill possum or ferret is likely to be behaving abnormally, especially in winter.

Pigs

Pigs do feed on pig carcasses occasionally, as a gutted and skinned carcass (not monitored by a camera) was eaten by released domestic pigs during the study, and this behaviour has also been observed in the eastern Hauhungaroa Range during winter 2002 (J. Whitford, Landcare Research, pers. comm.). It appears, however, to be a relatively rare occurrence. We are certain that wild pigs were present in the vicinity of the carcass sites, and that they would have detected, by smell, most if not all of them. The very low number of visits therefore implies actual avoidance of the sites. Likewise, at least four pig carcasses not monitored with cameras remained completely untouched, as were pigs that died in the large 1-ha pens in the study area in winter 2003, whereas cattle, sheep and goat carcasses in the broader area were often fed upon. In other studies, feral pigs were routinely captured in pens on Mt White Station, Canterbury, using sheep and cattle carrion as bait (K. Barber, pers. comm.), and in the same area, a large boar was filmed consuming the entire alimentary tract of a deer during a single feeding bout (G. Nugent, unpubl. data). These anecdotal observations help confirm that pigs routinely scavenge carrion other than their own species.

6.5 Conclusions

The majority of pigs that die naturally, and of pig remains left in the field by hunters, are likely to be visited and fed on by a wide variety of wildlife species. The head poses the greatest risk to the classical scavengers (ferrets, harrier hawks, and cats), because the submandibular node is the most frequently infected tissue in pigs, because the volume of edible tissue available is small (relative to a whole carcass or even to an offal pile containing heart, lungs, and liver), and because scavengers appear to feed first and most completely on the heads. Exacerbating that risk, in the context of Tb spread, is the behaviour of hunters who typically carry out the head with the pig and dispose of it elsewhere, whereas the offal pile is typically left at the kill site inside the area where Tb is already established (Nugent et al. 2003).

We speculate that the feeding behaviour of harrier hawks and ferrets, in particular, could easily spread Tb bacilli widely over the surface of the remains. This would presumably increase the risk of transmission to possums and cattle via sniffing, the most commonly observed interaction between them and pig carcasses. Even if the risk per encounter is low, however, transmission to possums appears likely wherever possum densities are high, and some tens or hundreds of infected carcasses are available to them annually. If 25% of carcasses are fed on by possums (this study), and assuming only 1% of those feeding events resulted in infection in possums, there would be 2.5 transmissions to possums per 1000 pigs killed. In 1988, 100 000 pigs were killed in New Zealand (Nugent 1992), and almost 40% of New Zealand is now classified as having Tb present in wildlife.

The risk to other pigs appears to be low, and may explain why pigs are end hosts for other pigs even when the population prevalence of Tb is very high.

Overall, this study indicates that feral pigs probably play a greater role in inter-specific transmission of Tb than previously suspected, especially via hunter-killed carcass remains, and especially in the long-distance spread of Tb to uninfected ferret populations. The key unknown is the frequency with which possum and ferret interactions with infected carcasses results in Tb transmission. Within VRAs, the ‘recycling’ of spillover Tb in pigs back to ferrets and occasionally to possums may extend the time required to eradicate the disease slightly, but appears unlikely to be of great consequence if possum and ferret densities are held well below the Tb-maintenance threshold densities for those species.

7. Recommendations

The risk of Tb spread by pigs needs to be better quantified by determining whether the frequency of transmission from pig carcasses to possums and/or ferrets is anything other than very low (<1%). We propose a large-pen field trial to measure this.

Assuming, from the currently incomplete evidence, that pigs might be an important or even occasional source of infection responsible for long-distance spread of Tb and its establishment in wildlife at new locations, or re-establishment in previously cleared areas, precautionary action to prevent or reduce this risk is required. We repeat the recommendations from the review that constituted the first part of this study:

- the AHB should educate hunters about the risk of Tb spread via carcasses (particularly the dumping of heads and offal outside VRAs) and the shifting of potentially infected pigs to new Tb-free locations.
- pig populations at the margins of VRAs should be intensively surveyed annually, both to reduce overall pig population densities and to provide precise information in the location and prevalence of Tb in pigs.

The AHB should also consider helping farmers reduce pig numbers on their land (and therefore the risk of Tb spread) by contributing to the development and registration of a farmer-usable bait-and-toxin for pigs. High pig numbers this year (2003) has seen the initiation of many private pig control regimes. The AHB should support systematic and sustained initiatives and endeavour to make farmers aware of the Tb risks posed by using recreational hunters, and of leaving carcasses or part carcasses available to scavengers. Where possible carcasses should be recovered and buried, but as that will usually be impractical, such control should at least be undertaken in winter, when ferret numbers are low.

8. Acknowledgements

We thank Colin and Tina Nimmo (Muzzle Station) for all their help, accommodation provided and permission to have this project conducted on their property; this work relied heavily on landowner assistance, which was always forthcoming. Lance Godfrey (wage worker, Kaikoura), Colin Nimmo and Andrea Byrom (Landcare Research) helped with camera set up, checking and maintenance, swabbing, and pig collection. Shaun Monk and Toby May donated their time to provide pig heads and whole carcasses for filming. We also thank Land Information New Zealand and the Department of Conservation for granting access to this site during summer. Gary Yates (AgResearch, Wallaceville) carried out culture of swabs. Christine Bezar completed editing and Wendy Weller completed final word processing.

9. References

Caley, P. 1998: Broad-scale possum and ferret correlates of macroscopic *Mycobacterium bovis* infection in feral ferret populations. *New Zealand Veterinary Journal 46*: 157–162.

Fraser, K. W.; Cone, J. M.; Whitford, E. J. 2000: A revision of the established ranges and new populations of 11 introduced ungulate species in New Zealand. *Journal of the Royal Society of New Zealand 30:* 419–437.

Jackson, R.; de Lisle, G. W.; Morris, R. S.1995: A study of the environmental survival of *Mycobacterium bovis* on a farm in New Zealand. *New Zealand Veterinary Journal 43*: 346 – 352.

Knowles, G. J. E. 1994: Use of Judas pig methodology for controlling tuberculosis in feral pigs (*Sus scrofa*). MAF Quality Management Contract Report 73/90 (unpublished). 22 p.

Lugton, I. W. 1997: The contribution of wild mammals to the epidemiology of tuberculosis (*Mycobacterium bovis*) in New Zealand. Unpublished PhD thesis, Massey University, Palmerston North.

Mclnerney, J.; Small, K. J.; Caley, P. 1995: Prevalence of *Mycobacterium bovis* infection in feral pigs in the Northern Territory. *Australian Veterinary Journal 72*: 448–451.

Montgomery, R. H. 1995: Some observations on the histological appearance of *Mycobacterium bovis* infection in cattle, deer, and feral pigs. *In:* Griffin, F., de Lisle, G. *eds.* Tuberculosis in wildlife and domestic animals. Dunedin, Otago Conference Series 3, University of Otago Press. Pp. 236–238.

Morris, R. S.; Pfeiffer, D. U.; Jackson, R. 1994: The epidemiology of *Mycobacterium bovis* infections. *Veterinary Microbiology 40*: 153–177.

Moss, K. A. 1999: Diet, nesting behaviour, and home range size of the European hedgehog (*Erinaceus europaeus*) in the braided rivers of the Mackenzie Basin, New Zealand. Unpublished MSc thesis, University of Canterbury, Christchurch.

Nugent, G. 1992: Big-game, small-game and gamebird hunting in New Zealand: Hunting effort, harvest, and expenditure in 1988. *New Zealand Journal of Zoology 19*: 1–16.

Nugent, G.; Whitford, E.J. 2003: Epidemiology of bovine tuberculosis in wild deer. Landcare Research Contract Report LC0203/165 (unpublished).

Nugent, G.; Whitford, E.J.; Young, N. 2002: Use of released pigs as sentinels for *Mycobacterium bovis*. *Journal of Wildlife Diseases 38:* 665–677.

Nugent, G.; Reddiex, B.; Whitford, J.; Yockney, I. 2003: Pigs as hosts of bovine tuberculosis in New Zealand – A review. Landcare Research Contract Report LC0203/098 (unpublished).

Ragg. J. R.; Mackintosh, C. G.; Moller, H. 2000: The scavenging behaviour of ferrets (*Mustela furo*), feral cats (*Felis domesticus*), possums (*Trichosurus vulpecula*), hedgehogs (*Erinaceus europaeus*) and harrier hawks (*Circus approximans*) on pastoral farmland in New Zealand: Implications for bovine tuberculosis transmission. *New Zealand Veterinary Journal 48*: 166–175.

Sauter, C. M.; Morris, R. S. 1995a: Behavioural studies on the potential for direct transmission of tuberculosis from feral ferrets (*Mustela furo*) and possums (*Trichosurus vulpecula*) to farmed livestock. *New Zealand Veterinary Journal 43*: 294–300.

Sauter, C. M.; Morris, R. S. 1995b: Dominance hierarchies in cattle and red deer (*Cervus elaphus*): Their possible relationship to the transmission of bovine tuberculosis. *New Zealand Veterinary Journal 43*: 301–305.

10. Appendices

Appendix 10.1 Camera operational times at each site, and fate of pig remains.

A dash (–) indicates no remains of that type available. Where remains were completely removed from the site, the percentage that had been scavenged at the time of the last check before removal is shown.

Site	Season	Operational time (days)	Type of remains		
			Head	Gut	Whole carcass
MC2	Summer	0.8	>50%	>50%	–
3228	Summer	5.0	>50%, removed	>50%	>50%
3187	Summer	Data lost	–	–	<50%
OS	Summer	4.6	–	–	<50%
MC4	Summer	0.1	<50%	<50%	–
MC3	Summer	1.3	<50%, removed	>50%	–
F1	Summer	9.0	>50%	<50%	–
2763	Summer	8.6	>50%	<50%	>50%
2767	Summer	6.5	>50%	<50%	>50%
2749	Summer	17.9	<50%	>50%	<50%
3160	Summer	2.1	<50%	>50%	0%
3193	Summer	1.5	>50%, removed	>50%, removed	>50%
3173	Summer	2.8	<50%, removed	<50%, removed	<50%
PH1	Summer	2.8	<50%	>50%	<50%
Summary (summer)					
% untouched			0	0	10
% <50% eaten			50	42	50
>50% eaten			50	58	40
% removed			23	15	0
1129	Winter	0.5	>50%	<50%	0%, decomposed
1033	Winter	27.0	>50%	<50%	0%, decomposed
1033b	Winter	15.2	>50%	<50%	0%, decomposed
1031	Winter	1.8	>50%	removed	0%, decomposed
1032	Winter	14.1	>50%	<50%	0%, decomposed
1130	Winter	3.4	removed	removed	0%, decomposed
1034	Winter	14.1	removed	<50%	0%, decomposed
1035	Winter	25.5	>50%	<50%	0%, decomposed
1036	Winter	9.8	>50%	<50%	0%, decomposed
1131	Winter	2.7	removed	<50%	0%, decomposed
Summary (winter)					
% untouched			0	0	100
% <50% eaten			0	80	0
% >50% eaten			70	0	0
% removed			30	20	0