R-10618

Spread of Tb by Ferrets in the Northern South Island High Country

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Project and Client

Research to determine the risk posed by scavenging of ferret carcasses as a potential source of bovine tuberculosis (*Mycobacterium bovis*; Tb) for other wild animals, and the potential for geographic spread of Tb by young ferrets, was undertaken by Landcare Research for the Animal Health Board (Project R-10618), between January 2003 and June 2004.

Objectives

Determine the key processes and rates of Tb transmission among ferrets and from ferrets to other wildlife vectors in a high-Tb area, by:

- Measuring the potential for geographic spread of Tb by young ferrets during dispersal
- Monitoring the fate of at least 10 ferret carcasses in summer
- Monitoring the fate of 20 ferret carcasses placed in the field in winter.

Methods

- Twenty-two radio-collared young ferrets were tracked at least once a week from January to March 2003 to determine their survival and distances moved away from the mother's home range (calculated as the straight-line distance between first and final locations).
- Ten of the collared ferrets survived until early April 2003 when they were captured, euthanased, and necropsied. Pooled lymph nodes were sent for Tb culture.
- Four carcasses of radio-collared ferrets that died were monitored using infrared-triggered camera systems to determine the nature, frequency and duration of behaviours of wildlife species visiting the carcasses. A further nine ferret carcasses were video-monitored in summer and early autumn (January to May 2003) to increase the sample size to 13.
- Wildlife visiting 20 ferret carcasses were video-monitored in winter and spring (Aug–Oct 2003) for comparison with the behaviours of visiting wildlife observed in summer.

Results

- Dispersal distances of the ferrets (7 males and 3 females) that survived until early April 2003 ranged from 0 to 10.7 km (median 2.5 km) from their likely location of birth.
- Of those 10 ferrets, three males were infected with Tb and had moved straight-line distances of 1.5 km, 3.5 km, and 10.7 km from the locations they were first captured.
- The four radio-collared ferrets that died and had their fates video monitored had travelled 0.4, 0.5, 1.0 and 2.4 km. Two of these were scavenged by other ferrets.
- Cameras recorded for a mean of 4.4 days at each carcass in summer (total recording time 57 days on 13 carcasses), and 7.1 days per carcass in winter (142 days on 20 carcasses).
- In summer, 8 of 13 ferret carcasses (62%) were scavenged. In winter, 4 of 20 carcasses (20%) were scavenged.
- Fifteen different species visited ferret carcasses: in summer most visits were by ferrets and possums; in winter most were by possums and cats. Pigs did not visit ferret carcasses in summer or winter, despite being present in the general area.
- Australasian harriers and hedgehogs were the only species that scavenged ferret carcasses in both summer and winter. Ferrets and cats also scavenged ferret carcasses in summer.
- Ferret carcasses were not scavenged by possums in either season, but in winter, two different carcasses were licked briefly by possums.

- In summer, two possums sniffed ferret carcasses after the gut cavities had been opened up by scavengers; in winter, two possums and at least five cattle sniffed similar carcasses.
- Most wildlife visits to ferret carcasses resulted in behaviours that could be 'risky' for Tb transmission (i.e. sniffing, licking, rolling on the carcass, or scavenging).

Conclusions

- This study confirms predictions from simulation modelling which suggest that diseased juvenile ferrets are capable of extending the boundary of a Tb-endemic area by transporting Tb outside VRAs.
- Young ferrets were observed scavenging on potentially infected pig carcasses soon after weaning, so the probability of them contracting Tb while still quite young is high.
- Based on the recorded interactions with ferret carcasses, the risk of transmission of Tb from dead ferrets to pigs and possums (two key wildlife species in the NSIHC) was found to be negligible. The potential risk to other wildlife species, such as ferrets, cats, and perhaps Australasian harriers, was low to moderate.
- 'Opening up' of carcasses by harriers, ferrets and cats might increase their infectiousness to possums (through scattering viable bacilli around the carcass), but if infected carcasses become available only at a low density in the landscape, the probability of creating a new focus of infection in possums would be extremely low.
- The risk of infecting other ferrets is likely to be higher, and will vary with the population density at which Tb can be maintained independent of other wildlife disease sources.
- The frequency with which live ferrets transmit bovine Tb to livestock remains unknown.
- The frequency with which possum, ferret, and livestock interactions with ferret carcasses result in actual transmission of Tb is also largely unknown.

Recommendations

- In regions containing ferrets, pigs, and possums, ferret control should be carried out concurrently with possum and pig control in order to reduce reactor rates most rapidly.
- The AHB needs to maintain a buffer of at least 10 km around areas of established infection, in order to provide both control and ongoing surveillance, and to prevent infected dispersing ferrets from either infecting livestock or dying naturally and becoming infectious to other wildlife species.
- In areas with large numbers of feral pigs and possums, the AHB may need to conduct ferret control even when ferrets are below the nominal maintenance threshold for Tb, because of their ability to contract Tb when young, and transport it long distances.
- In areas of high ferret density outside established VRAs, there is a moderate risk of naturally dispersing ferrets (originating from inside the VRA) creating a new focus of infection in the ferret population. The AHB should therefore intensify the suggested surveillance/control programme outside VRAs where local ferret population densities are high enough to maintain Tb independent of possums.
- The AHB should support the empirical validation of Caley's (2002) proposed threshold for maintaining Tb in ferrets. Until field estimates are placed on the probability of ferret populations being able to maintain the disease in the absence of possums, vector managers will not be able to make a realistic assessment of the risk posed by moderate-to-high ferret populations outside VRAs.
- Clearly ferrets are capable of transmitting bovine Tb to livestock, but further research is required to determine the frequency with which this occurs, and the exact mechanism(s) of transmission. The availability of new technologies such as proximity detectors could help quantify the nature of interactions between ferrets and livestock, and provide better estimates of the probability of such interactions occurring.

1. Introduction

This report describes a two-stage project undertaken by Landcare Research to examine the potential for ferrets to spread bovine tuberculosis (*Mycobacterium bovis*; Tb) in the northern South Island high country (Muzzle Station). Stage 1 of the project was funded by the Foundation for Research, Science and Technology, and commenced in January 2003 to determine the potential for geographic spread of Tb by young ferrets and the risk posed by scavenging of ferret carcasses as a source of Tb for other wildlife species in summer. Stage 2 was funded by the Animal Health Board (R-10618: Spread of Tb by Ferrets [Stage 2: Winter]), and commenced in July 2003 to determine the risk posed by scavenging of ferret carcasses as a potential source of Tb for other wildlife species in winter.

2. Background

Estimating the extent of disease transmission among and within species is a prerequisite to the effective control of undesirable diseases such as bovine Tb (Caley & Hone 2004). In the northern South Island high country (NSIHC), control and eventual eradication of bovine Tb poses some major challenges. In this region, three key species (possums (*Trichosurus vulpecula*), feral pigs (*Sus scrofa*), and ferrets (*Mustela furo*)) play a role in both the persistence and spread of the disease in a vast and largely unforested landscape. Investigations of the routes of Tb infection among those species, and the frequency with which transmission might occur through close contact and/or scavenging, have been initiated only recently (Nugent et al. 2003; Yockney & Nugent 2003).

Ferrets are generally regarded as a spillover host of bovine Tb in New Zealand (Byrom 2001). However in some areas, rapid expansion of VRAs has been linked to long-distance movements by ferrets. Infected ferrets may travel large distances before they transmit infection to cattle and deer, and/or spread infection to other wild animals (including other ferrets) at their new location (Livingstone 1996). Based on available data, simulation modelling of ferret movements suggests that this hypothesis is plausible (Nugent et al. 2003), but it has not been tested empirically. Caley & Hone (2002) identified the most likely hypothesis for transmission of Tb to ferrets as being diet-related (ingestion of infectious material from the age of weaning). This being the case, it would be possible for young ferrets to contract Tb at their birthplace, or to pick up the disease during dispersal and transport it to a new location.

Furthermore, observed behaviour of ferrets and other wildlife species at ferret carcasses suggests that transmission of Tb could occur through scavenging of infected material (Ragg et al. 2000). However, the frequency, nature and duration of such interactions with ferret carcasses remain largely unquantified. Those interactions may also vary seasonally depending on ecological and environmental factors such as the activity and abundance of wildlife species present and the general condition (level of hunger) of animals in the population.

The aims of this study were twofold. First, to quantify the potential for young ferrets (nominally infected with Tb) to transport the disease during dispersal in the NSIHC. Second, to determine which species of wildlife are most likely to encounter and scavenge on ferret carcasses in the NSIHC, and therefore to characterise the likely fate of Tb present in infected carcasses (and potential routes of transmission back to other wildlife species). These related pieces of information are critical in assessing whether ferrets pose a risk in both the persistence and spread of Tb in the landscape, and therefore in determining how much emphasis should be placed on ferret control in vector management programmes in New Zealand. They also provide crucial data for modelling Tb transmission among wildlife species.

3. Objectives

Determine the key processes and rates of Tb transmission among ferrets and from ferrets to other wildlife vectors in a high-Tb area, by:

- Measuring the potential for geographic spread of Tb by young ferrets during dispersal
- Monitoring the fate of at least 10 ferret carcasses in summer
- Monitoring the fate of 20 ferret carcasses placed in the field in winter.

4. Methods

4.1 Geographic spread of Tb by young ferrets

In January and early February 2003, 22 young ferrets (13 males and 9 females) were live-trapped in yellow plastic treadle box traps (manufactured by M. Holden, Amberley), and radio-collared with 25-g Sirtrack mortality-sensing ferret collars. Young ferrets were captured late enough in the season to be independently trappable (Caley & Morriss 2001), but early enough to still be located in family groups and close to their mother's home range (Byrom 2002). Collared ferrets were radio-tracked on the ground or from the air (using a Robinson R-22 helicopter with a skid-mounted antenna) at least once a week throughout the main dispersal period (January to late March 2003) to determine their survival and to calculate distances moved away from the mother's home range. New Zealand Map Grid east and north coordinate locations were obtained using a hand-held Garmin GPS (Global Positioning system) receiver each time a ferret was located. Dispersal distances for all surviving ferrets were calculated as the straight-line distance between first and final locations for each ferret (after Caley & Morriss 2001; Byrom 2002).

Of the 22 young ferrets originally radio-collared, 10 (7 males and 3 females) survived until early April 2003 when they were captured, euthanased, and necropsied to determine their Tb status. Peak dispersal occurs in mid-to-late February (Caley and Morriss 2001; Byrom 2002), so these ferrets were assumed to have completed their dispersal movements. Pooled lymph nodes from each ferret were frozen at –4°C immediately after necropsy until they were sent for culture. Ten radio-collared ferrets (5 males and 5 females) died during January–March 2003. Of those, four were video-monitored where they died to determine the fate of their carcasses (see section 4.2). The other two radio-collared ferrets (one male and one female) were lost within 1–4 weeks of collaring (the radio signal could no longer be picked up and it was assumed either that the collar had malfunctioned or that these individuals had moved very long distances out of tracking range). It was not possible to monitor the fate of the remaining six ferrets on video (or to obtain Tb cultures from them), either because they were shot (*n* = 1), died in kill traps as part of another study (*n* = 1), died underground in dens (*n* = 2) or because they were not discovered for several days after death and their carcasses were too decomposed to monitor (*n* = 2). Of the two that died aboveground, visual inspection of the carcasses indicated that they were not scavenged by other wildlife.

Because only a small number of carcasses of the original sample of radio-collared young ferrets (*n* = 4) were video-monitored, a further nine ferret carcasses (obtained elsewhere on Muzzle Station) were video-monitored at sites known to contain pigs, possums, and other ferrets in order to increase the sample size of ferret carcasses monitored in summer to 13.

4.2 Fate of ferret carcases

During summer and autumn 2003 (January–May), and again in winter and early spring 2003 (August–October), Trailmaster™ infrared-triggered video camera systems were used to determine which wildlife species visited ferret carcasses, and the nature and frequency of the resulting interactions. Sites at which ferret carcasses were located were spread over approximately 8 km of accessible river flat and terraces of the Clarence River known to be occupied by pigs, ferrets and possums. Thirteen ferret carcasses were monitored in summer (including four that had been radio-collared; see section 4.1) and 20 in winter. Each carcass was staked to the ground with an aluminium peg to prevent it being removed. Carcasses were monitored for at least 3 days in summer (sometimes longer) and for 1 week in winter.

Methods used to record and analyse the behaviours observed at each ferret carcass were similar to those used in Project R-10577 (‘Scavenging of potentially tuberculous feral pig carcasses in the Northern South Island High Country’; Yockney & Nugent 2003). The 8-mm and Digital 8 video camera systems were activated and began recording only when the body heat and movements of animals visiting a carcass were detected by the infrared sensor. Occasionally the system was triggered by flies (particularly in summer), and at such times the available tape was used up early in the period and had to be replaced every 1–2 days. Typically however, tapes were replaced every 3 or 4 days. For recording at night, lighting was provided by a 30W red-filtered spotlight, which was controlled by the Trailmaster™ software. As with Project R-10577, occasional malfunctions occurred with the video-monitoring equipment, resulting in incomplete records of events at each carcass and widely varying operational times. Operational times for each camera system on each ferret carcass are shown in Appendix 2.

Tapes were reviewed on a large-screen TV. Each camera recorded on film both the current date and time and the time-elapsed time. Time to discovery of the carcass (from when it was first placed in front of the camera) was recorded for each wildlife species. A ‘visit’ by each type of species was recorded if the animal approached to within 1 m of the carcass. The type of behaviours observed at each carcass and the duration of each behaviour were also recorded for each visit by each wildlife species. The minimum number of individuals of each species visiting each site was also recorded. This is likely to be an underestimate, as individuals were only distinguishable by easily recognisable differences (e.g. radio-collared or not (ferrets), clearly different fur colour (possums and ferrets), or differences in body size (cats, ferrets and harriers)).

5. Results

5.1 Geographic spread of Tb by young ferrets

Dispersal distances of the 10 young ferrets (7 males and 3 females) that survived until early April 2003 ranged from 0 to 10.7 km from their likely location of birth (Fig.1), with a median distance dispersed of 2.5 km. Of those 10 ferrets, three (all males) were infected with bovine Tb. The three infected ferrets had moved straight-line distances of 1.5 km, 3.5 km, and 10.7 km from the location they were first captured.

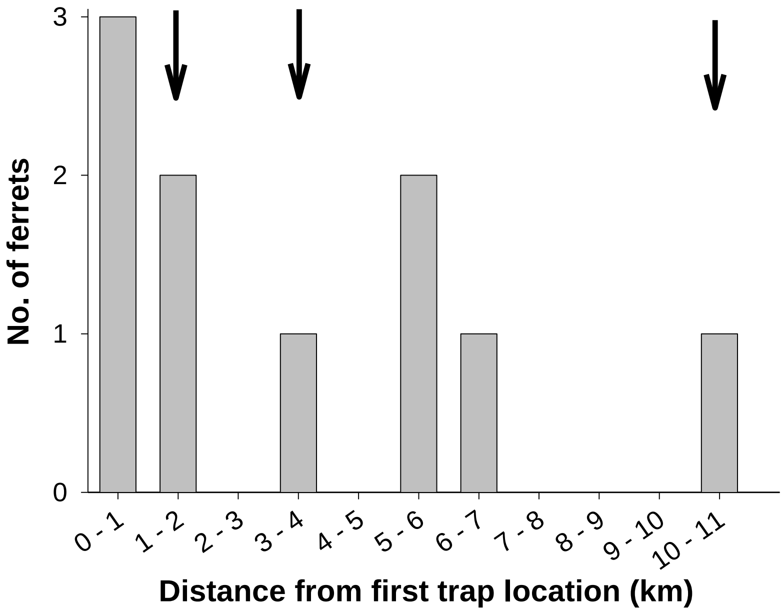

Fig. 1 Dispersal distances of 10 young ferrets in the northern South Island high country in Summer 2003. Arrows show the distances dispersed by three infected male ferrets.

The four radio-collared ferrets that died and had their fates monitored on video had travelled 0.4, 0.5, 1.0 and 2.4 km from their original trap locations (obviously it was not possible to determine where these ferrets would have finally settled had they remained alive). Of these four, two (the ferrets that moved 1.0 and 2.4 km) were scavenged by other ferrets. The other two ferret carcasses were not visited or touched by any other wildlife. The fates and minimum dispersal distances of radio-collared young ferrets are shown in Appendix 1.

Because Project R-10577 (scavenging of pig carcasses) was running concurrently, radio-collared ferrets were observed on film visiting both pig and ferret carcasses. In one instance, a family of four young ferrets (and the adult female) were observed scavenging on a pig's head, so young ferrets potentially were contracting Tb through scavenging, prior to dispersal.

5.2 Fate of ferret carcasses

The operational times for each camera ranged from 0.1 to 15 days at each of 13 sites in summer (a mean of 4.4 days per site, and a total recording time of 57 days), and from 3.3 to

29 days at each of 20 sites in winter (a mean of 7.1 days per site, and a total recording time of 142 days). Malfunctions of the cameras and sensors did occur, which effectively reduced the amount of time spent monitoring each carcass. More 'nuisance' triggering of the recording systems by flies occurred in summer than in winter.

In summer, 8 of 13 ferret carcasses (62%) were scavenged (Appendix 2). Of these, five carcasses had the gut cavity almost completely eaten out (i.e. >50% of the soft tissue taken). Three carcasses had the gut cavity only partially eaten (<50% of the soft tissue taken). In winter, 4 of 20 carcasses (20%) were scavenged. Of these, one had the gut cavity completely eaten out (>50% soft tissue taken), and two carcasses had the gut cavity partially eaten (<50% soft tissue taken). One ferret carcass monitored in winter had the hindquarters scavenged but not the gut (Appendix 2).

A total of 15 different species visited ferret carcasses. Of these, eight (blackbirds (*Turdus merula*), thrushes (*Turdus philomelos*), chaffinches (*Fringilla coelebs*), pipits (*Anthus novaeseelandiae*), quail (*Callipepla californica*), Paradise ducks (*Tadorna variegata*), magpies (*Gymnorhina tibicien*) and farm dogs (*Canis familiaris*)) were regarded as 'minor' species and are not considered further in this report (none of those species scavenged on ferret carcasses). Two livestock species (sheep (*Ovis aries*) and cattle (*Bos taurus*)) and five wildlife species (Australasian harriers (*Circus approximans*), ferrets, possums, cats (*Felis catus*), and hedgehogs (*Erinaceus europaeus*)) approached to within 1 m of ferret carcasses and interacted with them in some way. Ferrets and possums accounted for most of the visits by wildlife to ferret carcasses in summer, whereas in winter possums and cats accounted for most of the visits (Table 1). Pigs did not visit ferret carcasses in summer or winter, despite being present in the general area.

Table 1 Percentage of ferret carcasses visited by each of 5 wildlife species and two livestock species in summer and winter, with average time to first discovery for carcasses visited, and the percentage of carcasses touched or sniffed, licked, or fed upon. There were 13 ferret carcasses in summer, and 20 in winter.

Species	Season	% carcasses visited	Average time to discovery (h)	% carcasses touched or sniffed	% carcasses licked	% carcasses scavenged
Possum	Summer	38	21	38	0	0
	Winter	55	49	45	10	0
Ferret	Summer	38	11	38	0	31
	Winter	10	128	10	5	0
Cat	Summer	31	57	31	0	24
	Winter	30	12	30	15	0
Australasian harrier	Summer	31	105	31	0	31
	Winter	15	20	15	0	15
Hedgehog	Summer	31	27	31	0	5
	Winter	25	72	25	5	5
Cattle	Summer	-	-	-	-	-
	Winter	25	54	25	0	0
Sheep	Summer	8	100	8	0	0
	Winter	5	97	5	0	0

Australasian harriers and hedgehogs were the only species that scavenged ferret carcasses in both summer and winter. Ferrets and cats also scavenged ferret carcasses in summer. Ferret carcasses were not scavenged by possums in either summer or winter, but in winter, two different carcasses were licked briefly by possums. Behaviours observed at ferret carcasses in each season are recorded in Table 2.

Multiple events, including scavenging, occurred at several ferret carcasses by different wildlife species. In summer, there were an average of 2.7 visits per carcass by all species. In winter, there were an average of 2.6 visits per carcass. Many visits lasted only a few seconds or a few minutes; with the exception of Australasian harriers, the total time spent by each species at ferret carcasses was usually less than 45 minutes in both seasons (Table 2).

Table 2 Number (*N*), total duration (min), and average duration (min; in brackets) of five behaviours observed during visits (recorded as 'approach <1 m') to each ferret carcass by wildlife and livestock, in summer and winter. Behaviour classes are exclusive (e.g. an animal that sniffed or fed on a carcass is not included in the 'approach <1 m' category, even though it would have done so).

Species	Season	Approach <1 m		Sniff		Lick		Roll		Scavenge		Total	
		N	Time (min)	*N*	Time (min)	*N*	Time (min)	*N*	Time (min)	*N*	Time (min)	*N*	Time (min)
Possum	Summer	2	3 (1.5)	10	5 (0.5)	-	-	-	-	-	-	12	8 (0.7)
	Winter	17	10 (0.6)	14	11 (0.8)	2	1 (0.5)	-	-	-	-	33	22 (0.7)
Ferret	Summer	9	9 (1.0)	10	12 (1.2)	-	-	-	-	4	24 (6.0)	23	45 (2.0)
	Winter	-	-	1	1 (1.0)	1	1 (1.0)	-	-	-	-	2	2 (1.0)
Cat	Summer	4	4 (1.0)	5	1 (0.2)	-	-	1	1 (1.0)	3	17 (5.7)	13	23 (1.8)
	Winter	3	3 (1.0)	9	10 (1.1)	3	6 (2.0)	4	9 (2.3)	-	-	19	28 (1.5)
Australasian harrier	Summer	2	3 (1.5)	-	-	-	-	-	-	9	199 (22.0)	11	202 (18.4)
	Winter	-	-	-	-	-	-	-	-	4	42 (10.5)	4	42 (10.5)
Hedgehog	Summer	4	2 (0.5)	9	4 (0.4)	-	-	-	-	1	1 (1.0)	14	7 (0.5)
	Winter	6	3 (0.5)	4	2 (0.5)	1	1 (1.0)	-	-	1	2 (2.0)	12	8 (0.7)
Cattle	Summer	-	-	-	-	-	-	-	-	-	-	-	-
	Winter	9	20 (2.2)	7	4 (0.6)	-	-	-	-	-	-	16	24 (1.5)
Sheep	Summer	-	-	1	1 (1.0)	-	-	-	-	-	-	1	1 (1.0)
	Winter	2	4 (2.0)	1	1 (1.0)	-	-	-	-	-	-	3	5 (1.7)

Possum interactions with ferret carcasses

Possums were the most common visitor to ferret carcasses in both seasons, visiting 5 of 13 carcasses in summer (38%) and 11 of 20 carcasses in winter (55%). In both summer and winter, up to three individually recognisable possums separately visited a ferret carcass. In both seasons, possums discovered ferret carcasses within 1–2 days, on average. Many of the carcasses encountered by possums were sniffed by them, for a total duration of 5 minutes in summer and 11 minutes in winter. In both seasons, two possums sniffed ferret carcasses after the gut cavity had been ‘opened up’ by other scavengers. In addition, two carcasses were licked briefly by possums in winter. However, the remainder of the total time spent at ferret carcasses by possums (8 minutes in summer and 22 minutes in winter) was simply passing within 1 m of the remains, and possums did not scavenge ferret carcasses in either season.

Ferret interactions with ferret carcasses

Ferrets equalled possums as the most common visitor to ferret carcasses in summer, but not in winter. In summer, 5 of 13 ferret carcasses (38%) were visited by ferrets whereas in winter, 2 of 20 carcasses (10%) were visited. In summer, a high percentage of visits (80%) resulted in scavenging of the carcass, whereas no such scavenging was recorded in winter. Sniffing and feeding on ferret carcasses accounted for more than three-quarters of the total time spent at carcasses by ferrets in summer (45 minutes). Similar proportions of time were spent by ferrets sniffing and licking carcasses in winter, but the total time spent was greatly reduced compared to summer (2 minutes).

When scavenging by ferrets occurred (in summer), ferrets typically ‘opened up’ the gut cavity and fed on the soft mesenteric tissue. In some instances, a great deal of tugging and jerking of the head was required by individual ferrets to remove edible chunks, which resulted in nominally Tb-infected material being scattered around the carcass site.

Although discovery of ferret carcasses by ferrets was rapid in summer (on average, 0.5 days), ferrets took more than 5 days (on average) to discover ferret carcasses in winter. Ferrets visited ferret carcasses alone in both seasons. However, in summer up to three recognisably individual ferrets visited a single carcass whereas in winter, only one ferret visited each carcass. No ferrets were trapped in winter 2003 in the general area of video-monitoring of ferret carcasses, so either their activity and trappability were greatly reduced in winter or they were at relatively low population densities (or both).

Feral cat interactions with ferret carcasses

Cats visited 4 of 13 ferret carcasses in summer (31%), and 6 of 20 carcasses in winter (30%). In summer, ferret carcasses appeared to be visited by only one individual cat, whereas in winter, two different individuals were observed at a single ferret carcass. In this case the two cats were not recorded together, i.e. cats visited ferret carcasses alone.

Cats spent about equal amounts of time at ferret carcasses in summer and winter (21 and 26 min respectively). However in summer, cat visits were likely to result in the cat feeding on the carcass whereas in winter, visits by cats resulted in rolling, licking and sniffing of carcasses, but no scavenging. Cats took more than 2 days to discover ferret carcasses in summer (on average), but unlike ferrets, discovery time by cats in winter was short (0.5 days on average). Like ferrets, cats fed mainly on the gut contents of ferret carcasses.

Australasian harrier interactions with ferret carcasses

Harriers were not the most frequent wildlife visitor to ferret carcasses, but their visits always resulted in scavenging of a carcass when they encountered it. Harriers visited 4 of 13 ferret carcasses (31%) in summer and 3 of 20 carcasses (15%) in winter, although their time to discovery of the carcasses in summer (more than 4 days, on average) was much greater than in winter (less than one day, on average). Harriers were not recorded feeding together at ferret carcasses in either season, although in summer, up to three recognisably different individual harriers were observed at single ferret carcasses.

Harriers spent a total of 199 minutes feeding at ferret carcasses in summer, and 42 minutes in winter (an average of 22 minutes and 10.5 minutes per feeding bout respectively). As with ferrets and cats, harriers fed primarily on the gut contents of ferret carcasses, commonly scattering chunks of tissue over a c. 0.5-m radius around them as they did so.

Hedgehog interactions with ferret carcasses

Hedgehogs were recorded at 4 of 13 ferret carcasses in summer (31%), and at 5 of 20 carcasses in winter (25%). Hedgehogs mainly approached and sniffed ferret carcasses, with only brief periods of scavenging in either season (1 and 2 minutes in summer and winter respectively). In summer, hedgehogs took about one day, on average, to discover a ferret carcass, and about 3 days in winter (a likely function of their reduced activity and/or density in winter).

Visits to ferret carcasses by livestock (cattle and sheep)

In both seasons, sheep approached and sniffed at ferret carcasses for brief periods. No visits to ferret carcasses were recorded by cattle in summer, but in winter, cattle approached or sniffed at ferret remains for a total of 24 minutes. At least five cattle sniffed at ferret carcasses (and made actual nose contact) after the carcasses had been scavenged by other species.

Potential for Tb transmission from ferret carcasses

When ferret carcasses were encountered by other wildlife species, many of those encounters resulted in behaviours that could be considered ‘risky’ in terms of Tb transmission (i.e. rolling on the carcass, sniffing, licking, or actual scavenging) (Table 3). The average duration of risky behaviours was usually half a minute or more (Table 2). In addition, risky behaviours occurred occasionally after the carcass had been ‘opened up’ by scavengers such as harriers or ferrets. In summer, two possums sniffed ferret carcasses after the gut cavities had been opened up by scavengers. In winter, two possums and at least five cattle sniffed carcasses after they had been opened up by scavengers.

Table 3 Percentage of ferret carcasses at which key behaviours (rolling, sniffing, licking, or scavenging) were observed once the carcass was encountered by an animal, in summer and winter. There were 13 ferret carcasses in summer, and 20 in winter.

Season	Behaviour	Species	% of total available carcasses at which behaviour occurred	% of sites at which behaviour occurred given carcass was encountered
Summer	Sniff	Possum	38	100
		Ferret	38	100
		Cat	24	75
		Hedgehog	31	100
		Sheep	8	100
	Lick	-	-	-
	Roll	Cat	8	25
	Scavenge	Ferret	31	80
		Cat	24	75
		Harrier	31	100
		Hedgehog	8	25
Winter	Sniff	Possum	45	82
		Ferret	5	50
		Cat	30	100
		Hedgehog	20	80
		Cattle	15	60
		Sheep	5	100
	Lick	Possum	10	18
		Ferret	5	50
		Cat	15	50
		Hedgehog	5	20
	Roll	Cat	10	33
	Scavenge	Harrier	15	100
		Hedgehog	5	20

6. Conclusions

This study focused on two related issues: (1) quantifying the potential for young ferrets (nominally infected with Tb) to spread the disease large distances in the landscape; and (2) examining the risk posed to other wildlife species and to livestock when a (nominally infected) ferret dies and becomes available to be scavenged. These issues are directly related, because together they determine the potential for a dispersing ferret to create a new focus of infection far from the original source.

6.1 Landscape-scale spread of Tb by young ferrets

This study confirms predictions from simulation modelling by Nugent et al. (2003), which suggest that diseased juvenile ferrets are capable of extending the boundary of a Tb-endemic area by transporting Tb outside VRAs. Although it is still not clear whether young ferrets always pick up the disease before leaving their mother’s range, Caley and Hone’s (2002) hypothesis that Tb is acquired through scavenging infected material soon after weaning suggests that this is possible. Furthermore, ferrets dispersing from within a Tb-endemic area such as the NSIHC could contract the disease ‘on route’ and still pose a risk far from the original Tb source. In this study, the maximum distance moved by a young ferret was 10.7 km, but dispersal distances of 25–55 km have been recorded elsewhere (Caley & Morriss 2001; Byrom 2002; G. Norbury, Landcare Research, pers. comm.).

In a related study at Muzzle Station (R-10577), Yockney & Nugent (2003) found that ferrets were the primary scavengers of pig heads, guts, and whole carcasses in summer. In that study, several radio-collared ferrets were observed scavenging on pig remains. Most of those were juvenile ferrets that were radio-collared as part of this study. Clearly therefore, young ferrets were scavenging on potentially infected pig carcasses soon after weaning. In one instance, a family of four young ferrets (and the adult female) was recorded scavenging on pig remains. All four were subsequently radio-collared, and one young male (the ferret that dispersed 3.5 km) was later found to be infected with Tb. Generally, young ferrets have lower prevalences of Tb than adults (Lugton et al. 1997; Caley & Hone 2002) but the figure in this study (3 of 10 ferrets infected less than 3 months after weaning) shows high prevalence of the disease in young ferrets compared to many ferret populations in New Zealand (Byrom 2001).

All three infected ferrets killed in April 2003 were males, but this result should be treated with caution because most of the ferrets surviving until then (7 of 10) were males, and the original sample of ferrets collared was biased towards male ferrets (13 of 22). However, a higher prevalence of Tb in male ferrets compared with females has been observed elsewhere (Lugton et al. 1997; Ragg 1998) and is hypothesised to occur because males are thought to be more likely to find and scavenge infected material than females. Results from this study cannot confirm this, but do suggest that young male ferrets are at high risk of contracting the disease in the northern South Island high country.

6.2 Potential for transmission of Tb from ferret carcasses

Assuming diseased ferrets are capable of extending the boundary of a Tb-endemic area by transporting Tb outside VRAs, what is their potential for creating new foci of infection? Based on the recorded interactions with ferret carcasses in this study, the risk (through scavenging) of transmission of Tb from dead ferrets to pigs and possums (two key wildlife species in the NSIHC) was found to be low. However, the risk to species such as ferrets, cats, and Australasian harriers was moderate, at least in summer. In addition, the frequency and duration of behaviours other than scavenging (sniffing, licking, and rolling on the carcass) were high enough, on average, for species such as cattle and possums to be exposed to viable Tb bacilli if they were present. We emphasise that the frequency with which wildlife and livestock interactions with ferret carcasses might result in actual transmission of Tb is still not known.

Possums

Unlike Ragg et al. (2000), no scavenging by possums on ferret carcasses was observed in this study. However the results presented here confirm, with large numbers of video-monitored ferrets in summer and winter, that such occurrences are likely to be relatively rare in nature. Sniffing of carcasses occurred more frequently. In summer, possums sniffed all of the ferret carcasses they visited, and in winter they sniffed 82% and licked 18% of the carcasses they visited. Even if not all these events result in transmission of Tb, ferret carcasses therefore probably pose a low risk to possums, particularly if viable bacilli contained within carcasses have previously been exposed by other scavengers.

Ferrets

In summer, ferrets sniffed and scavenged at a high proportion (100% and 80% respectively) of ferret carcasses they encountered. Typical feeding behaviour of ferrets involved tugging at the mesenteric tissue once they had opened up the gut cavity, scattering potentially infectious material (from the mesenteric lymph node) around the carcass site. In winter, only two visits by ferrets to ferret carcasses were recorded, with sniffing and licking of the carcass occurring on only one of those occasions. Based on the results obtained in this study, the likelihood of ferrets contracting the disease by eating other ferrets would therefore be higher in summer than in winter. The role ferrets might play in transmission and maintenance of Tb in the NSIHC is discussed further in section 6.3 below.

Cats

Feral cats interacted in some way (sniffed, licked, rolled on, or scavenged) with a high proportion of ferret carcasses they encountered in both seasons. In addition, cats showed similar behaviour to ferrets when feeding on ferret carcasses, opening up the gut cavity and scattering potentially infectious material around the carcass site by feeding on mesenteric tissue. Therefore, although cats are not thought of as maintenance hosts for bovine Tb, they could contribute to infection of species such as cattle and possums by exposing those species to infection through their scavenging behaviour.

Australasian harriers

Harriers, too, were observed repeatedly tugging at potentially infectious material (primarily mesenteric tissue) when feeding on ferret carcasses, and scattering it around the carcass site. Therefore, although harriers are not regarded as hosts for bovine Tb, scavenging by them might increase the probability that animals sniffing or licking the carcass would come in contact with the disease. Yockney and Nugent (2003) also discussed the possibility that birds can become infected with bovine Tb if they are exposed to high enough doses, or are able to excrete viable bacilli when they eat large amounts of infected material, which would further increase the likelihood that harriers play a role in the co-scavenging cycle of Tb in the northern South Island high country.

Pigs

Ferret carcasses were often placed in areas where feral pigs were known to be present in both summer and winter, yet pigs did not visit those carcasses in either season. On two occasions, ferret carcasses were located close to the pig traps used for project R-10577 in summer, when the traps were being pre-fed. Although visitation by pigs to the trap sites was high (pers. obs.), ferret carcasses were not approached by pigs. Yockney and Nugent (2003) suggested that the lack of pig visits to pig carcasses implied actual avoidance of those sites. Similar avoidance of ferret carcasses by pigs might have been occurring in this study. Whatever the reason for pigs not being observed scavenging ferret carcasses, the results from this study show that scavenging of ferrets by pigs is an extremely rare occurrence, if it occurs at all.

6.3 Role of ferrets in Tb cycling in the South Island High Country

To calculate the landscape-scale probability of the risk posed by Tb-infected ferret carcasses we propose the following, accepting that it contains many untested assumptions.

- Young (1998) found that 15% of ferrets die in places accessible to scavenging species.
- Ferret densities in South Island high country are commonly 3/km^2 (Norbury & Efford 2004), and exceed this in many areas, particularly during seasonal peak production.
- A ferret density of 3/km^2 gives about 200 ferrets per 66 km^2.

- Annual mortality in a ferret population in the South Island high country can be as high as 50% (Caley et al. 2002).
- That level of mortality would produce 100 dead ferrets per 66 km^2 per year.
- Using the above figures, of every 100 ferrets that die, 15 would be available to scavengers.
- Assume Tb prevalence is about 30% (high but not unusual for endemic areas of the South Island high country; Byrom 2001).
- About five of the 15 ferrets that die and are available to be scavenged are therefore likely to be infected.
- In this study, scavenging occurred at 62% of ferret carcasses in summer (about two-thirds).
- Therefore, about three of the five infected carcasses 'produced' annually in a 66-km^2 area would be scavenged, if summer scavenging rates are applied year-round.
- Or very approximately, one scavenging event would occur on an infected ferret carcass every ~20 km^2 (2000 ha).
- Scavenging rates in winter were lower (this study), so the average number of infected ferret carcasses scavenged annually might be less than one per 2000 ha.

This analysis estimates an *average* risk posed by infected ferret carcasses at a landscape scale. In Tb-endemic areas of the NSIHC, it is important to also estimate the *maximum* risk (using higher population densities of ferrets, extreme levels of Tb prevalence, greater mortality in ferret populations, greater proportion of carcasses available to be scavenged etc.). Nevertheless, the figures presented here (with associated confidence intervals), data on scavenging by ferrets and possums on pig remains (Yockney and Nugent 2003), and data on scavenging of possum carcasses by pigs (Barber 2004) is useful information with which to model disease transmission among and within key species (pigs, possums, and ferrets) in the NSIHC.

The role of ferrets in cycling bovine Tb in the NSIHC landscape depends on five factors:

1. The likelihood that ferrets will contract the disease by scavenging on infected material (the focus of Project R-10577; Yockney & Nugent 2003).
2. Their ability to transport the disease large geographic distances (this study).
3. The probability that ferrets will transmit the disease to other wildlife species if they die (this study).
4. The population density at which the disease can be maintained in a ferret population independent of other wildlife sources (Caley 2002).
5. The probability that live or dead ferrets will transmit the disease to livestock (only partially addressed by this study).

Yockney & Nugent (2003) showed that ferrets were one of the main wildlife species to scavenge potentially infected pig remains in the NSIHC in summer, and that the disease could readily be 'amplified' through whole family groups of ferrets feeding on pig carcasses (factor 1). In addition, results from this study and simulation modelling (Nugent et al. 2003) confirm that infected ferrets are capable of transporting the disease large geographic distances in the NSIHC (factor 2).

However, the probability of the disease being transmitted back to other species of wildlife through scavenging (particularly by key species such as pigs and possums) appears to be low in summer, and declines still further in winter (factor 3). In this study, scavenging of ferret carcasses occurred primarily by Australasian harriers, ferrets, feral cats and (to a much lesser extent) hedgehogs. Clearly, the risk of pigs and possums becoming infected from scavenging infected ferret carcasses is very low or non-existent, given the large spatial scale at which infected ferret carcasses are likely to become available in the landscape and the extremely low probability of those species scavenging the carcass. ‘Opening up’ of carcasses by harriers, ferrets and cats might increase their infectiousness to possums. However, at a density of one (infected and scavenged) carcass per 2000 ha, the probability of creating a new focus of infection in possums would still be low.

The risk of infecting other ferrets is likely to be higher, and will vary depending on the population density of ferrets at which Tb can be maintained independent of other wildlife sources of the disease (factor 4) (Nugent et al. 2003; Caley & Hone 2004). Caley (2002) hypothesised a threshold population density for disease maintenance in ferrets of about 2.9/km^2. Results from live-trapping for young ferrets in this study suggest that ferret densities were only moderate for typical rabbit-prone country. At higher population densities of ferrets, it is conceivable that both the number of infected carcasses becoming available annually to be scavenged, and the probability of them actually being fed upon, would be proportionally greater. Empirical validation of this threshold density may be possible now that a reliable technique for assessing ferret density is available (Norbury and Efford 2004).

The remaining ‘unknown’ is the probability of ferrets transmitting bovine Tb to livestock (factor 5). They must play some role in infection of livestock, because the incidence of Tb in cattle was reduced by controlling ferrets in north Canterbury (Caley et al. 1998). However, with the exception of a study of the behaviour of livestock around ‘sick’ ferrets (where drugged ferrets exhibiting behaviours similar to Tb-infected animals were ‘nosed’ and sniffed by livestock; Sauter & Morris 1995), this probability remains largely unquantified in New Zealand and would benefit from further investigation. Cattle did investigate ferret carcasses in winter in this study, sniffing and making nose contact on several occasions (and on at least five of those occasions, after potential exposure of Tb bacilli had occurred through scavenging by other species). Whether such behaviours result in transmission of Tb to livestock, and the frequency with which they might occur, are not known.

7. Recommendations

- In regions containing ferrets, pigs, and possums, ferret control should be carried out concurrently with possum and pig control in order to reduce reactor rates most rapidly.
- The AHB needs to maintain a buffer of at least 10 km around areas of established infection, in order to provide both control and ongoing surveillance, and to prevent infected dispersing ferrets from either infecting livestock or dying naturally and becoming infectious to other wildlife species.
- In areas with large numbers of feral pigs and possums, the AHB may need to conduct ferret control even when ferrets are below the nominal maintenance threshold for Tb, because of their ability to contract Tb when young, and transport it long distances.
- In areas of high ferret density outside established VRAs, there is a moderate risk of naturally dispersing ferrets (originating from inside the VRA) creating a new focus of infection in the ferret population. The AHB should therefore intensify the suggested surveillance/control programme outside VRAs where local ferret population densities are high enough to maintain Tb independent of possums.

- The AHB should support the empirical validation of Caley's (2002) proposed threshold for maintaining Tb in ferrets. Until field estimates are placed on the probability of ferret populations being able to maintain the disease in the absence of possums, vector managers will not be able to make a realistic assessment of the risk posed by moderate-to-high ferret populations outside VRAs.
- Clearly ferrets are capable of transmitting bovine Tb to livestock, but further research is required to determine the frequency with which this occurs, and the exact mechanism(s) of transmission. The availability of new technologies such as proximity detectors could help quantify the nature of interactions between ferrets and livestock, and provide better estimates of the probability of such interactions occurring.

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Appendix 1 Minimum dispersal distances and fates of radio-collared ferrets

Fates and dispersal distances of 20 young ferrets radio-collared at Muzzle Station in summer 2003. A further two ferrets were lost and their fates are not known. A * shows ferrets that were found to be infected with bovine Tb.

Ferret ID	Dispersal distance or distance to location of death	Sex	Fate	Approximate date of death
Q0921	0.8	F	Survived to April 2003; necropsy/culture lymph nodes	-
Q0807	1.2	F	Survived to April 2003; necropsy/culture lymph nodes	-
Q0843	5.5	F	Survived to April 2003; necropsy/culture lymph nodes	-
Q0819	0	M	Survived to April 2003; necropsy/culture lymph nodes	-
Q0901*	1.5	M	Survived to April 2003; necropsy/culture lymph nodes	-
Q0841	5.5	M	Survived to April 2003; necropsy/culture lymph nodes	-
Q0818*	3.5	M	Survived to April 2003; necropsy/culture lymph nodes	-
Q0905*	10.7	M	Survived to April 2003; necropsy/culture lymph nodes	-
Q0903	0.9	M	Survived to April 2003; necropsy/culture lymph nodes	-
Q0874	6.4	M	Survived to April 2003; necropsy/culture lymph nodes	-
G367	0.4	M	Died naturally; video monitored; not scavenged	15/1/03
Q0949	0.5	M	Died naturally; video monitored; not scavenged	31/1/03
Q0876	1.0	F	Died naturally; video monitored; scavenged by ferret	14/2/03
Q0839	2.4	F	Died naturally; video monitored; scavenged by ferret	14/2/03
Q0922	4.4	F	Shot	12/2/03
G396	0.8	M	Died naturally in den	31/1/03
Q0926	0.1	F	Died naturally in den	14/2/03
G362	3.2	F	Died naturally; decomposed	11/3/03
Q0905	0.3	M	Died naturally; decomposed	31/1/03
Q0813	0.3	M	Killed in trap as part of Project R-10577	28/2/03
G367	Unknown	M	Lost after 4/2/03	-
G386	Unknown	M	Lost after 13/2/03	-

Appendix 2 Camera operational times at each site, and fate of ferret carcasses

* Indicates carcasses of young ferrets that were radio-collared for measurement of dispersal distances.

Carcass no.	Season	Operational time (days)	Observed fate of carcass
1	Summer	3.0	>50% gut eaten
2	Summer	2.8	>50% gut eaten
3	Summer	15.1	>50% gut eaten
4	Summer	0.1	Not opened up*
5	Summer	2.0	>50% gut eaten*
6	Summer	2.1	Not opened up
7	Summer	12.8	<50% gut eaten
8	Summer	3.5	<50% gut eaten
9	Summer	2.4	<50% gut eaten
10	Summer	1.8	Not opened up
11	Summer	6.1	>50% gut eaten*
12	Summer	1.2	Not opened up*
13	Summer	3.9	Not opened up
Summary (summer)		Not opened up	*n* = 5 (38%)
		<50% gut eaten	*n* = 3 (24%)
		>50% gut eaten	*n* = 5 (38%)
		Total scavenged	*n* = 8 (62%)
1	Winter	4.5	Not opened up
2	Winter	5.8	Not opened up
3	Winter	5.8	Not opened up
4	Winter	5.7	Not opened up
5	Winter	4.6	<50% hindquarters eaten
6	Winter	7.0	Not opened up
7	Winter	3.3	Not opened up
8	Winter	6.9	Not opened up
9	Winter	7.2	Not opened up
10	Winter	5.9	Not opened up
11	Winter	6.9	Not opened up
12	Winter	5.7	Not opened up
13	Winter	6.7	Not opened up
14	Winter	6.2	<50% gut eaten
15	Winter	5.3	Not opened up
16	Winter	5.6	>50% gut eaten
17	Winter	4.7	Not opened up
18	Winter	10.1	Not opened up
19	Winter	29.0	Not opened up
20	Winter	4.9	<50% gut eaten
Summary (winter)		Not opened up	*n* = 16 (80%)
		<50% hindquarters eaten	*n* = 1 (5%)
		<50% gut eaten	*n* = 2 (10%)
		>50% gut eaten	*n* = 1 (5%)
		Total scavenged	*n* = 4 (20%)