Monitoring rabbits in Otago

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Contents

Part A: Spotlight count indices and other methods to measure rabbit abundance

1. Objective

To assess the merits of rabbit night counts and, where needed, provide recommendations to strengthen a rabbit night count programme.

2. Brief history of rabbit control

The history of rabbit management in New Zealand is well summarised by Norbury & Duckworth (2021), Gibb & Williams (1994), and that in Otago by Rosson (1993). In summary, rabbit control has moved from largely landowner-funding in the early decades of rabbits' invasion of New Zealand, to the more-organised control with the formation of the Rabbit Destruction Council (later the Agricultural Pests Destruction Council) and Rabbit Boards from 1947. The policy then was one of eradication, but this goal was never practical (e.g., Howard 1959) and was finally abandoned in 1971. The goal was 'zero rabbits' so presence/absence was all that was logically required to monitor success.

However, more nuanced targets for rabbit population densities were needed once the goals changed from 'zero' rabbits, as landowners became primarily responsible for rabbit control, and as Regional Councils became responsible for the oversight (and regulation) of rabbit management after 1989 (Rosson (1993). This required better monitoring and was also driven by wider factors such as:

- The extent of taxpayer and ratepayer funding.
- The need to assess or improve the efficacy of major control operations (e.g., Nugent et al. 2012; Latham et al. 2016). In the past, large-scale control operations, largely using aerial baiting with 1080, were conducted by regional or national agencies. However, these are less common nationally since control has devolved onto landowners.
- The need to measure the efficacy of new biocontrol agents (Parkes et al. (2002).
- The need for evidence of the economic costs and benefits and actual impacts on the biomass and composition of the vegetation, e.g., under the Rabbit and Land Management Programme and later by Norbury & Norbury (1996) and Scroggie et al. (2012).

Current control of rabbits in Otago is the responsibility of landowners with the Otago Regional Council setting the regulations that allow control to be enforced under the Regional Pest Management Plan as an instrument under the national Biosecurity Act 1993. Regional Councils assess thresholds for rabbit abundance, using the Modified McLean Scale (MMS). An MMS score above the threshold set in the Plan obliges landowners to control rabbits numbers.

Many Regional Councils also monitor the abundance of rabbits using spotlight count indices which apparently began in 1980 often as part of Ministry of Agriculture research projects, by the need to assess the effectiveness of the Rabbit and Land Management Programme (1990

– 1995) and the efficacy of rabbit haemorrhagic disease virus (RHDV) since 1997 (Table 1). Current spotlight routes in most regions seem to have been a continuation of those set up to assess RHDV. The most extensive use of spotlight count indices has been in Canterbury with nearly 2500 km of routes across all sub-regions (Table 1). Since 2006, these counts were made from motorbikes on single nights in spring by a single contractor (Excell Biosecurity).

Table 1. Spotlight count indices used by other regional/district councils.

Region	Sub-region	Number of routes	Total length (km)	Start and end year[1]
Canterbury Regional Council	Mackenzie Basin	34	538.0	1990 – present
	Omarama	16	222.2	1990 – present
	Kurow	24	383.6	1990 – present
	South Canterbury	21	221.8	1993 – present
	Ashburton	6	108.3	1993 – present
	Plains	8	160.2	1993 – present
	Banks Peninsula	8	141.4	1994 – present
	Ashley	7	136.7	1993 – present
	Waikari	21	262.3	1993 – present
	Amuri	29	313.4	1993 – present
	Kaikoura	4	102.2	1991 – present
	Total	**178**	**2490.1**	
Marlborough District Council	---	**13**	***unknown***	1990 – 2016
Hawke's Bay Regional Council	---	**23**	**472**	1995 – 2017

3. Purpose of spotlight count indices

Spotlight counts provide an objective index of abundance of rabbits and may be used to:

(a) Assess annual patterns or trends in rabbit populations by measuring set routes at set times of the year and analyse the results by property (e.g., to assess the more-continuous conventional control over time or changes in land-use), or by the averages and variances across various regional areas (e.g., to monitor the efficacy of biocontrol agents or to inform policy decisions). The issue here (and shown in Appendix 1) is there are often no long-term trends in the index (up or down), but rather either stability, pulses, or occasional collapses in the index. These can be difficult to interpret unless they coincide with some control event (see below).

(b) Answer more specialist research questions about the progress of an epidemic when frequent counts (e.g., monthly) combined with serological data from shot samples can determine the proportion of the population killed (from the short-term change in spotlight indices) and the proportions either not challenged by the virus and challenged but survived – to be shot and tested for antibodies.

[1] Some routes began under the R&LMP and many have continued until the present. Other regions have conducted ad hoc spotlight counts but generally with no long-term sequences

(c) Provide abundance indices for other small mammals such as hares, wallabies, ferrets, feral cats and possums that may be of interest in Regional Pest Management Strategies. The abundance of many of these pests is driven by the abundance of the rabbits as competitors or prey (Norbury et al. 2002), so one option to managing them is to manage the rabbits. Such data has been collected by ORC irregularly and analysis is out of scope for this report. However, it would be useful for wider ORC biosecurity goals to ensure a consistent record is maintained in the future.

(d) Determine the percent kill achieved by some major control operation by measuring the route(s) just before and just after the control event. The statistical power to detect any changes determines the design of such counts – large changes are easily demonstrated with fewer routes and fewer repeat surveys, while small changes are difficult to demonstrate with spotlight indices.

The purpose of the current ORC spotlight routes is to use the index to show the patterns (or trends where these are clear) by property or site as well as to use the averages and variances in counts across sites and various regional areas to inform or defend more general policy decisions made by the Regional Council.

Identifying the causes of observed changes in spotlight indices and by implication the changes in rabbit populations is difficult. Four current and one future general causes of change are likely to be involved in the mix of causes:

- The extent of conventional rabbit control conducted on the properties covered by the route. This information is not routinely recorded by ORC but might be inferred to have occurred if the Modified McLean's Scale (MMS) indices assessed by ORC (as regulator) had triggered control action. Note: a MMS of about 3 coincides with a spotlight count index of about 5 rabbits/km (Bolton 2010).
- Changes in land use along the route.
- The changing efficacy of rabbit haemorrhagic disease viruses (see Part B).
- Changes is the relationship between rabbits are their predators (see Reddiex 2004).
- It is possible that changes in the climate, particularly rainfall, will make areas more or less suitable for rabbits either by altering the vegetation to favour or disadvantage rabbits, or indirectly by increasing juvenile rabbit mortality in wet springs via, in particular, coccidiosis (Bull 1953).

It would help interpretation if the landowners involved with the spotlight route were surveyed each year on the extent and nature of any conventional rabbit control they conducted. Changes in land use are sometimes noted in the ORC spotlight count records and this could be made as an explicit requirement for the monitor.

Interpreting the impact of changes in RHD would require, as a minimum, ongoing serology and age structure of the population - plus the research information from Landcare Research. Ideally, these data should have been collected from rabbits autopsied in the same area as the spotlight counts but in general this has not been the case in Otago in recent years. A regional 'average' has been interpreted but this approach risks missing the patchiness of both rabbit population age structures and the patchiness of epidemics, e.g., the disease appears not to be active at some sites or every year.

4. Technical protocols

The National Pest Control Agencies best practice guidelines for monitoring rabbits using spotlight count indices (NPCA 2021) have a set of rules that attempt to standardise the way the counts are made to limit the many factors that affect rabbit visibility and behaviour. These guidelines are generally reiterated in Appendix B of ORC's review of night counts (Boardman 2021). Canterbury Regional Council monitors rabbits on 178 spotlight routes (Table 1). Their contractor uses a sealed beam spotlight (100 watt, but this seems variable as 30 watt is also recommended) mounted on the observer's helmet and connected to the trail-bike's 12 volt battery with a detachable plug to allow the observer to dismount when required. LED lights have been tried but they are much heavier and so hard to sustain over many hours (D. Hunter, pers. comm.).

Some best practice guidelines included in Canterbury Regional Council's contracts for their monitors include:

- Using the same observer on each route over the years – where possible.
- Avoid counting on nights with high winds or rain.
- Only one route per observer per night is to be counted.
- Count the route in the same direction each survey.
- Counts to be taken in the first four hours of darkness.
- The speed of travel for the motorbike should not exceed 20 km/h.

I will not repeat the details of the NPCA guidelines here but will address each issue within the guidelines, as required by the terms of reference of this report, with justifications using what data are available where necessary.

4.1 Time of year and frequency of measurement

Most ORC routes are now surveyed once a year in winter or early spring (June to September). This timing is chosen to avoid the lambing season which is generally October – November in the high country. Darkness also falls earlier in the night in winter so counting can start earlier and last longer – in summer it does not get dark enough for spotlighting until after 2200h. The timing is also after the recruitment pulse of young rabbits. Young rabbits remain in their natal nest until they are about 3 weeks old, and juvenile (runners) remain around the natal site and are less likely to be seen than fully-grown rabbits (and shot for the serological samples) for several months. The last young of the breeding season are recruited into the population by early January (Figure 1) and are old enough to behave as adults and be countable by the time of the spotlight counts in winter. The young born at the start of winter are generally too young to be active and seen in spotlight counts – they are, for example, rarely included in winter-shot samples. The counts are therefore a baseline for the population size.

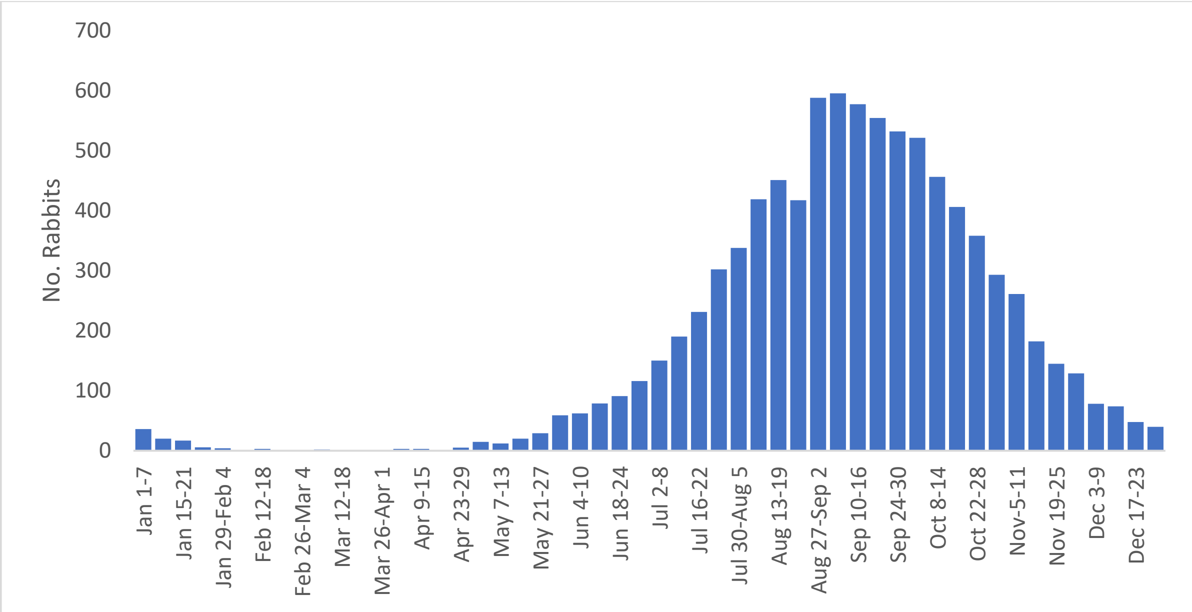

Figure 1: Number of rabbits born per week taken from 8921 juvenile rabbits sampled from Otago, 1990 – 2021 (J. Parkes, unpubl. data). The birth date of juvenile rabbits is calculated from the weight of their eye lens (Myers & Gilbert, 1968)

There are probably seasonal patterns in count indices as recruitment and natural mortality wax and wane. However, these are often masked by control events, especially of broadscale poisoning which is usually done in autumn through winter (NPCA 2021), and by RHD epidemics which are usually most intense in autumn (J. Parkes, unpubl. data and see Part B). No datasets of spotlight counts have been made by season or month at sites in the absence of these masking factors but whether such a research project should be of interest to ORC is a moot point.

There is no strong case for increasing the frequency of measuring the spotlight routes from the annual surveys in winter/early spring, at least under the current general purpose of the monitoring. In fact, there is a stronger case to decrease the frequency of the surveys, especially at routes with very low rabbit abundance indices (routes 3, 6-10, 13-16), by monitoring them less often – perhaps every second or third year – and only increase any frequency again if rabbit numbers start to increase. This would allow new routes (or previously abandoned routes) to be added (at no extra cost, if funds are a constraint) and improve the regional assessments (see section 5).

4.2 Number of nights counted

The ORC spotlight protocol uses the average count taken over two nights (three nights in earlier counts) generally on successive nights. The NPCA best practice recommendations are that ‘only one count should be carried out per route per survey’ – presumably meaning a survey is only a single night (NPCA 2021) and this is also suggested in Boardman (2021) and is current practice in Canterbury. Some rationale for selecting multiple or single nights is:

(a) Different purposes of the spotlight index

Surveying over multiple nights may be desirable when the aim is to compare changes in the spotlight index before and after a control event and with a non-treatment area as an experimental control. Several studies have shown the standard index with only a few nights of counting has the power to detect moderate to large changes in rabbit populations (e.g., Caley & Morley 2002) but poor power to detect smaller changes (e.g., Montague & Arulchelvam 1995).

Baddeley (1985), on advice from Bell & Williams from MAF, recommended counts over four nights. This was to estimate percent kills in rabbit control operations (by implication a major operation such as aerial baiting). The design also included similar measurements in a non-control area, i.e., eight counts in total. Frampton & Warburton (1994) recommended at least three, and preferably up to six, successive counts per route to achieve 'acceptable precision' in the estimated index. However, when the purpose of the index is to show more general patterns in rabbit abundance over time it may be only counts on a single night are adequate and the saved effort more usefully used to increase the number of routes surveyed.

(b) Variability between nights

A preliminary analysis of the variability in counts of routes surveyed on 2 and 3 successive nights (data from the ORC's routes 1998-2021), and 4 and 5 nights within a month (data from Williams & Robson 1985 from the Western Pest Destruction Board region in the North Island) is presented (Table 2).

The results hint at a decline in rabbits observed in subsequent nights, although this is not statistically significant. Such a decline might be expected if the first night was selected because weather conditions were ideal while the chance of such optimal conditions on subsequent nights is more likely to be lower.

Table 2: Variability of spotlight counts with nights each route was sampled.

Nights counted	Mean no. rabbits counted per night	Number routes	Coefficient of variation (%)
ORC 2 successive[2]		286	18.8
Night 1	94.3		
Night 2	92.3		
ORC 3 successive		200	10.9
Night 1	50.9		
Night 2	50.2		
Night 3	47.5		
4 over a month	15.6	42	22.8
5 over a month	11.9	19	29.9

The results show the variability in counts (the coefficient of variation) is decreased with increasing the number of successive nights counted from two to three, but increases as the

[2] Includes the first two nights of the 3-night subset

counts are taken over longer time frames. Presumably, much of the nightly variation is due to different weather conditions (wind, rain, cloud cover, etc) affecting rabbit behaviour.

The spotlighting itself does not appear to affect the rabbits. If it made rabbits more wary (leading to fewer sightings on subsequent nights) we would expect the counts to reflect this. However, there is no evidence that this occurs. Among the 2-night counts, the numbers seen on the first night were not significantly higher than those on the second night (55% versus 45%: $\chi^2 = 1.38$, P = 0.24).

The patterns in the 16 routes currently monitored by ORC make sense. The indices in successive years are generally consistent, there are few erratic outlier years, and most abrupt decreases can be related to changes in the control regime at the property or to changes in land-use as areas are irrigated and/or changed more intensive horticulture and cropping.

(c) Spotlight index versus actual rabbit density

The spotlight count index is not likely to be linear against actual rabbit densities across all rabbit densities because the index is said to saturate at high rabbit densities (Fletcher et al. 1999). However, this is not a problem under the current low to modest densities on the routes in Otago (Appendix 1). Even if rabbit populations should irrupt and reach very high densities, the signal from spotlight count indices that this has occurred would still be clear – just not an accurate measure of the scale of the change.

4.3 Route length

The spotlight index is expressed as rabbits seen/km or per route. A problem arises when the length of the route is not consistently recorded, or changes with no explanation.

The critical factor is the total route length so this needs to be measured carefully either by using an odometer on the ground or by measuring the map-distance using GPS (e.g. Appendix 3). Most routes are divided into marked sections for ease of counting, especially when rabbit numbers are high. Note: regular maintenance of route markers might be advisable especially if the frequency of monitoring is extended as suggested in section 4.1. The sum of these sections has also been used to estimate the length of the route, but this can give unclear results when the records amalgamate sections or delete parts of the route with no explanation, or if the exact route across a section is not consistent, e.g., there are no farm tracks to follow or there are changes in personnel between years.

Changes in rabbit abundance may occur when the habitat changes along the route, i.e., crops replace grassland, areas are irrigated, stocking rates and species change. Noting which sections of the route have changed can help in interpreting the count indices – which is one reason to make the routes' sections coincide with likely boundaries for such habitat changes, e.g., fence lines, paddocks, or topography, rather than a simple 1 km distance.

4.4 Routes versus tenure boundaries

Ideally each spotlight route should be within a single tenure. This may help with relating changes in the index to any different control strategies deployed on individual properties. This appears to be the case for most of the current routes – and is one reason Route 10 (Fruitlands) is often divided into two sub-routes for analysis (Russell and Dunbier). Older routes monitored by ORC and R&LMP sometimes traversed several properties which complicated interpretation at the property level, but not when all routes are pooled by region. This is less of a potential issue once RHDV arrived as the 'treatment' was basically universal and not based on the need or enthusiasm for control by the landowner.

This ideal becomes difficult when property sizes are small and, at least for very small properties, alternative methods to index rabbit abundance may be more suitable (Section 6).

5. Past, present and possible future spotlight routes

Spotlight count indices apparently began in Otago in about 1980 with 164 routes being monitored. The R&LMP monitored 31 routes between 1990 and 1995. Landcare Research monitored two routes between 1994 and 2003. The latter results for the Landcare Research route on Earnscleugh Station in a route above Lake Dunstan are shown in Appendix 1 to compare the spotlight indices in the 1990s with current indices. However, the data for most earlier routes is unavailable or lost. ORC began to count along 27 routes starting in various years after 1998, of which 16 have continued (Table 3, Figure 2; Appendix 1).

The rationale for route selection has changed over time. The 1980 routes were set up to achieve a wide coverage across the region to inform Pest Destruction Boards. For example, the East Otago Pest Destruction Board set up routes in areas where no control was undertaken, i.e., in less prone areas, to check that rabbit numbers remained low, and their 'no-control' decisions were justified. The R&LMP routes were to assess the efficacy of that programme's actions on selected properties in the most rabbit-prone areas, the Landcare Research routes to measure the efficacy of RHDV at sites, and the ORC routes post 1998 were also to assess the effects of RHDV (and conventional control) at the sites and later to give an objective measure of general trends in rabbit populations across wider regions.

Most of the current routes are located in rabbit-prone areas (Appendix 2) with only three routes in the south-east (14 – 16) in areas mapped as lower proneness. The four abandoned routes in the north-east south of Oamaru are also in lower proneness areas. ORC notes that the map in Appendix 2 is dated and predicting rabbit densities based on its parameters (largely soil type) does not take account of many major land-use changes since the map was developed in the early 1980s (Kerr et al. 1986). In other words, the definition of 'rabbit-prone land' as a predictor of the potential or rabbits to reach various densities if left uncontrolled needs to be reconsidered. Today's land managers have better spatial databases and more sophisticated mapping and analytical tools to allow more fine-scale definitions of 'rabbit proneness' to direct decisions on where monitoring such as spotlight indices should be deployed.

Identifying the routes is an issue especially when long-term trends are being analysed. Route numbers are unique to each 'study' while sites are sometimes named by geographic location, sometimes by the property name and sometimes by the property owner - which may change, or the route may cross several tenures. Note: the variable names used for the routes in Figure 2 with those used for serology sites in Figure 4.

The ORC has the opportunity to reconsider the number and locations of its spotlight index system, especially if it reduces the number of nights surveyed within each session and extends surveys to a biennial or triennial frequency for routes with consistent, stable, low indices of rabbit density. The current and historic spotlight routes, some suggested new routes and any 'matching' sites where serology samples are taken are shown in Table 3).

Table 3: Current and suggested spotlight routes.

Route Name	District	Current rabbit density[3]	Suggested monitoring frequency	Nearest serology site name
Current ORC Spotlight routes (1998 - 2021)				
Route 1: Lake McKay	Queenstown Lakes	High	Annual	Wanaka Stn.
Route 2: Queensberry	Queenstown Lakes	High	Annual	
Route 3: Timburn	Central Otago	Low	Biennial	Lindis Crossing
Route 4: Jolly	Central Otago	High	Annual	Ardgour
Route 5: Trevathan	Central Otago	High	Annual	Lindis Cross/Maori Pt.
Route 6: Kawarau	Central Otago	Low	Biennial	Bannockburn
Route 7: Cresslea	Central Otago	Mod.	Annual	Cresslea
Route 8: McKnights	Central Otago	Low	Biennial	Merino Ridges
Route 9: Manorburn	Central Otago	Low	Biennial	Galloway
Route 10: Fruitlands	Central Otago	Low	Annual	Fruitlands/Gorge Creek
Route 11: Haughton	Central Otago	Low	Annual	Roxburgh
Route 12: Gem Lake	Central Otago	High	Annual	Island Block/Perkins
Route 13: Wrights	Central Otago	Low	Biennial	Island Block/Perkins
Route 14: Proudfoot	Clutha	Low	Biennial	
Route 15: Bloxham	Clutha	Low	Biennial	Hillend
Route 16: Table Hill	Clutha	Low	Biennial	Milton
Historic ORC spotlight routes (1998 -). *Note: these and new sites have no recent data on which to base a frequency of monitoring*				
Glencoe	Queenstown Lakes			Morven Ferry
Enfield	Waitaki			
Mt Dasher	Waitaki			
Herbert	Waitaki			
Hyde	Waitaki			
Jones	Central Otago			
Sutton	Central Otago			
Lone Star	Central Otago			
Smailes	Clutha			
Suggested new spotlight routes				
Lauder	Central Otago			
Patearoa	Central Otago			
Motatapu	Queenstown Lakes			
Otago Peninsula site	Dunedin			Penguin Place
Coastal site	Waitaki			Moeraki
Lake Dunstan	Central Otago			Older LCR serology

[3] Based on whether the counts shown in Appendix 1 are above or below the level that might trigger ORC's regulatory interest

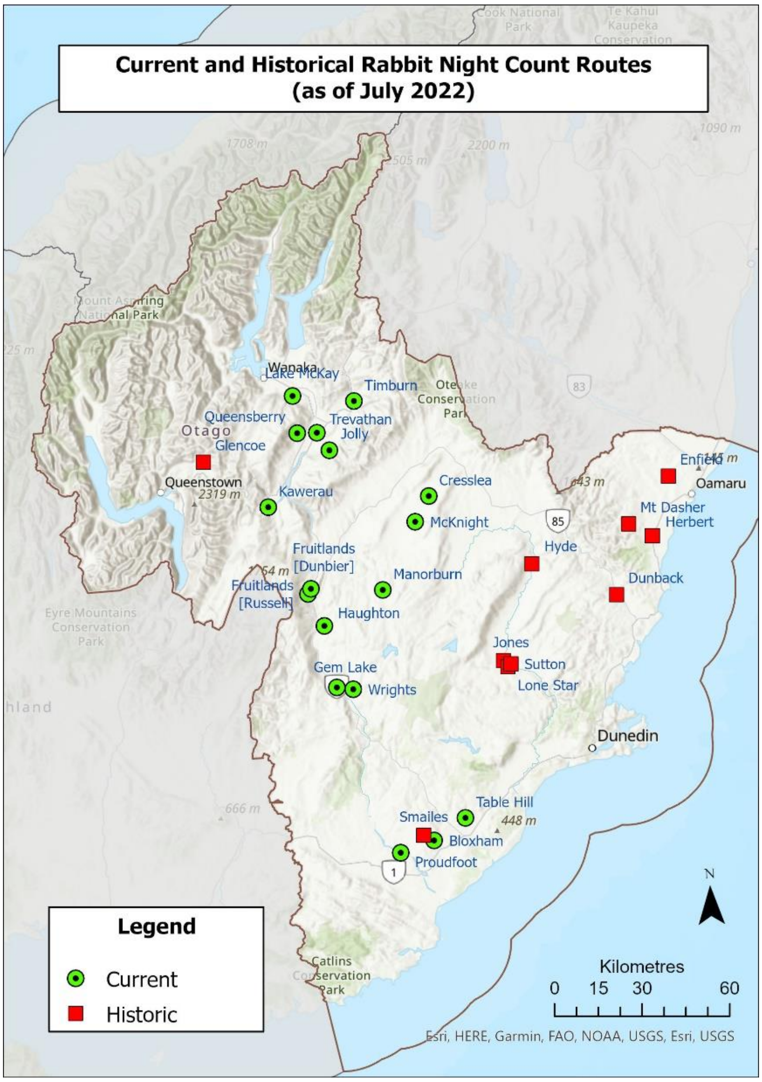

Figure 2: Location of current and recently halted spotlight routes in Otago.

Spotlight count indices and MMS indices (and night shooting indices) all index rabbit densities. The indices can be roughly aligned (Table 3). However, they are used for different purposes, sample at different spatial patterns and scales and presumably have different relationships with actual rabbit densities and habitat types that affect, for example, visibility. Nevertheless, the rough equivalents in Table 4 do give an indication of, for example, the expected MMS if a spotlight route has a certain index.

Table 4: Equivalence of three indices of rabbit densities (after Bolton 2010).

Spotlight Count Index	Modified McLean Scale	Rabbits shot by one person/night
0 – 1.5	1 – 2	<20
1.6 – 2.5	2	30 – 75
2.6 – 5	2 – 3	76 – 150
5.1 – 6	3 – 4	151 – 250
6.1 – 12	4	250 – 400
12.1 +	4 – 5	401 +

Spotlight count indices give an objective measure of rabbit abundance along each route. However, extrapolating the results to a whole property or averaging the results by region is riskier as the routes may not adequately sample a property and are not located at random across the region. Nevertheless, the averages (Figure 3) show patterns over time that coincide with known major perturbations in rabbit control – and so make sense. The Modified McLeans Scale index measures rabbit sign and is a more subjective measure of rabbit abundance. It gives a more complete measure than spotlight counts of the state of rabbits on a property because it allows a wider survey coverage. However, there is no standard way to extrapolate such results to the whole region. The catch-per-unit index can be used to give an overview of rabbit abundance across a region, e.g., from the Easter Bunny Shoot data collected since 1990 (Rouco et al. 2014).

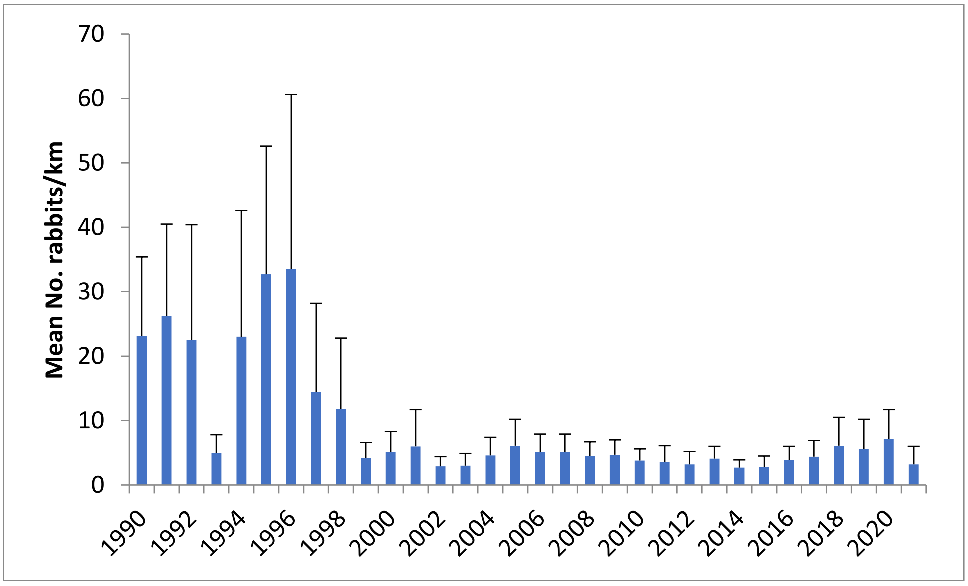

Figure 3: Mean number of rabbits (with SE) per spotlight route in Otago, 1990 to 2021.[4]

Six current routes have indices that indicate potential problems (based on equivalent MMS indices). The other 10 current routes have low to very low rabbit numbers. It appears the current conventional control regimes and/or RHDV are successfully managing rabbits at these sites so a 'watching brief,' is all that is required. I note all or most of these 10 routes are in historically rabbit-prone areas and therefore the risk of an irruption on the population is always present.

Which of the historic or new spotlight routes should be monitored depends on ORC's goals and budget. I assume that the main rationale for the spotlight survey is to provide a regional overview of the status of rabbits and the risks they pose should their numbers begin to return to historic high levels. In this case, coverage is an important consideration. In contrast, if the

[4] The data before 1998 comes from a few routes (mostly on Earncleugh Station – the rest of the earlier data is not accessible). The data post 1998 are all from ORC's routes 1 – 16 (see Appendix 1) plus a few of the ORC historic routes

rationale is simply to focus on sites of interest (from ORC or from the landowner) then sample size per se is of interest – the more routes the better.

If ORC was starting anew to select routes it would be ideal to locate routes in some random way, albeit stratified with more routes in the extreme and high proneness classes and fewer in the lower proneness classes of land (Appendix 2). This would allow more robust extrapolation to the sub-regional and regional levels. It is too late now for a fully randomised design as the 'costs' to abandon the current routes outweigh the benefits of statistical purity. Therefore, coverage is the deployment sought.

I recommend some pragmatic 'rules' to add routes to the portfolio.

- The ORC should not abandon any of the current 16 routes it monitors. It should continue with annual counts on the six routes where the spotlight indices are classed as high or moderate. These indices are all above the equivalent MMS indices that would trigger ORC's regulatory interest, and without some active management (or improved efficacy of RHDV) may result in an eruption of rabbits at the site.
- The frequency of counts on the current routes with low indices should be extended initially to biennial counts and then to triennial counts if the indices remain low.
- It makes sense to match some new spotlight routes with the 13 sites where rabbits are currently autopsied and their serological status measured – assuming future serology is practical (see Part B). The four eastern sites (Dunback, Moeraki, Penguin Place and Creighton Park) are candidates. The Moeraki site has had no evidence of RHD judging by the lack of any seropositive animals in 2017 and 2021 (see Part B). It would be interesting to see what effect this absence has had on rabbit numbers.
- Monitoring sites at Moeraki and Penguin Place, in particular, also extends the regional coverage to these eastern coastal areas.
- The eight routes initially counted by ORC but subsequently abandoned should be considered. The routes in the north-east (Enfield to Lone star in Figure 4) would expand the coverage intent of an expanded spotlight monitoring system. The cluster of sites (Jones, Sutton and Lone Star) should be reduced to a single site – unless there are particular reasons why the landowners wish to restart counts on their properties.
- Table 3 and Figure 4 also notes some new routes suggested by ORC staff or myself for consideration.
- New routes should as far as possible be on single land tenures and the route lengths can be flexible, i.e., shorter routes than the current average are acceptable.
- Decisions on the frequency of counts on the historic or new sites can be adaptive and based on the rabbit densities in the first new survey, i.e., the same adaptive way the survey frequencies for the current 16 sites are proposed – annual when the index exceeds about 5 rabbits/km and biennial or triennial if the indices remain at low levels.
- A portfolio of routes of between 25 – 30 routes will give adequate coverage of the region, i.e., the 16 or 17 current routes, 6 or 7 routes that ORC once monitored, and 4 to 6 new routes.

The regional annual average spotlight index reflects (a) the high index in 1990 (and by assumption before that year) that was (b) reduced to low levels by 1994 by the R&LMP, but (c) rapidly increased again until once landowners had to fund control then (d) RHDV arrived in late 1997 and have kept the average index at low to modest levels thereafter (Figure 3). This is strong evidence that RHDV has continued to kill many rabbits and along with whatever conventional control landowners have been conducting has been, on average, a success in Otago.

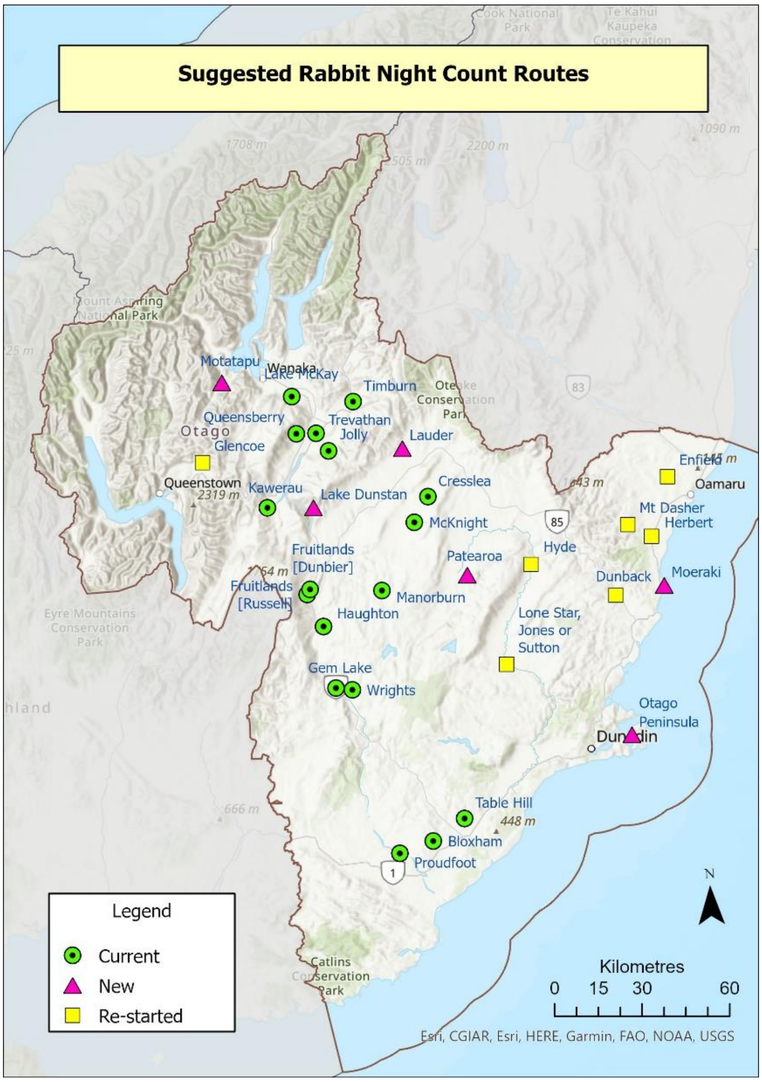

Figure 4: Location of suggested spotlight routes in Otago.

6. New technologies

6.1 Camera traps

Latham et al. (2012) have described a method using fixed cameras to assess changes in rabbit numbers caused by aerial 1080 poison operations in Otago – such operations are now rare. However, the method may be useful to assess annual trends in areas where spotlight routes are difficult to establish (see below). The cameras took a photo when triggered by an infrared device when operating at night. This study recommended using at least six cameras and suggested they be deployed for at least five days, in this case before and after the control operation, to obtain adequate power to detect changes. Three indices were used to assess rabbit abundance – number of photos with rabbits per camera, number of rabbit images per camera and number of rabbits per photo. The latter index takes the most time to analyse.

Such a method could also be used to assess annual trends in populations but is likely to detect only large changes in abundance at a site between years. The system would be useful in areas where the standard spotlight routes are difficult to establish, e.g., areas with many smaller properties such as life-style blocks and in peri-urban areas. However, ORC would need to conduct some trials to set the specific protocols – ideally first in areas with current spotlight routes to cross reference results between the two indices.

6.2 Thermal detection systems

There are several tools that could be used to detect and count rabbits along the routes. The simplest would simply use thermal cameras to count the rabbits instead of the current white-light spotlight. Simultaneous counts of rabbits and other small mammals were made from a thermal device (FLIR Scout III 640; the highest resolution camera available in Australia for under A$10,000) and a 100-Watt spotlight in and arid habitat in Australia. The thermal cameras increased the counts of rabbits by 23% (i.e., the sum of the counts by both methods) but did not increase the swath width covered. The authors suggested the lower detection probability from spotlighting was due to the observers missing animals that had no eye-shine (McGregor et al. 2021). Both counts are indices and there seems little to favour the use of one over the other.

The future, however, does hold options for more efficient survey methods using drones. Most trials reported have attempted to count large mammals (dugongs and elephants) in the daytime – so not much relevance to rabbits in New Zealand. So far as I know there has been only one trial reporting on the use of thermal cameras mounted on drones to monitor small mammals at night in New Zealand. Warburton & Gormley (2021) used DJI Matrice Quadricopters with FLIR Tau 2 640 × 412-pixel resolution and 19 mm lens video cameras flown at c.60 m altitude to measure the percent kill of Bennett's wallabies after a 1080 poison operation in the Makenzie Basin. The devices also detected rabbits (B. Warburton, pers. comm.). The results were interesting, but the authors noted they were not confident in identifying the species when reviewing the videos, suggesting higher resolution cameras may be needed. The current costs for drones were about three times those if the cameras were mounted on a small helicopter.

The Department of Conservation has been testing drones with thermal cameras and artificial intelligence systems to analyse the data on rabbits in the Mackenzie Basin. No results have been published. Normal cameras (rather than thermal) might be suitable for flights at dawn and dusk but getting the timing right to account for variable diurnal behaviour of rabbits might require research.

7. Recommendations

- ORC should conduct spotlight counts on a single night on its routes to assess major changes in rabbit densities. If care is taken to select nights with similar weather (no rain, no high winds, maybe least moonlight) as far as possible, the variability between years and sites will be minimised. In practice the rule should be not to conduct counts on the 'worst' nights.
- To achieve a consistent result, ORC should consider using a single contractor to measure its spotlight routes. A tender process that first required evidence of capacity to cover all routes before the price is considered is good practice in major projects. The alternative is to use ORC staff but with training to ensure a standardised method and reporting system.
- The frequency of surveys on routes with low counts should be increased to once every two years initially, or once every three years if numbers remain low, and only increase to annual counts if numbers show a large increase.
- The resources saved by the above reductions in effort could be used to increase the number of spotlight routes to include more lower-prone sites (see section 5).
- In general, the 16 current routes should be continued at annual or biennial frequencies and some pragmatic rules to extend the coverage are suggested in section 5.
- At places where spotlight routes are difficult to establish, trials to test camera trap indices could be established. Peri-urban or life-style blocks are candidate areas. Some of these trials might also be conducted at current spotlight routes (high and low-density sites) to cross-reference the two indices.
- ORC need to collect, curate and store the information on its spotlight routes and the data collected in a central system. Route names, locations and lengths and the spotlight/vehicle systems used need to be consistent.
- A formal protocol for all to follow, i.e., expanding on the NPCA best practice, and training on best practice and record-keeping if several staff (or contractors) are employed to conduct the surveys needs to be in place.
- The data recorded on field sheets, paper copies and electronic databases needs to be capable of cross-validation when required.
- Added value can be achieved by consistently recording other mammal pests seen along the routes.
- The use of aerial survey methods, e.g., using drones, requires considerable research before it can be used as an operational option.

Part B. Serology and trends in immunity to rabbit haemorrhagic disease

1. Objective

To assess the merits of rabbit virology sampling programme as part of a proactive biosecurity strategy.

2. Purpose of autopsy and serology data

The other main rabbit monitoring programme has been to sample rabbits for the presence of antibodies to rabbit haemorrhagic disease to measure the persistence and efficacy of the virus as a biocontrol agent (e.g., Parkes et al. 2002). To interpret the results, the age and sex of the rabbits (at a minimum) must also be collected and matched with the serological data.

This monitoring programme began in 1997 across most regions in eastern New Zealand under the past commitment of regional councils to the original application to import the virus led by ORC. Landcare Research also conducted a few autopsy/serology projects as part of its research programme in Otago and North Canterbury. In recent years only Otago (Table 5, Figure 5) and other eastern councils have continued to sample and test the antibody state of rabbits – up to 2021 in Otago, up to 2019 in Hawke's Bay, up to 2018 in Canterbury and up to 2017 in Marlborough. It is not clear why councils stopped testing but in any event the testing agency (AgResearch) has run out of the reagents required for the ELISA tests and does not seem to be easily able to import new supplies to test for both RHDV1 and RHDV2 variants of the virus.

ORC has autopsied and tested the age-related antibody status of rabbits at about 31 sites since 1997, albeit with much of the data lost (Table 5). Eleven sites (Kawarau/Bannockburn, Dunback, Fruitlands, Bendigo, Merino Downs, Lindis Crossing, Manorburn/Galloway, Gorge Creek, Cresslea, Ardgour and Hillend) have been sampled annually up to about 2001 and thereafter biennially with the last being in 2021. Sampling at the other 20 sites has been more infrequent.

Table 5. Serology sampling in Otago. For the proportions that tested seropositive see section 3. Note: it would be useful if ORC can find the missing serology data and autopsy data.

Year	No. sites sampled	No. samples with any seropositive rabbits	No. rabbits tested	Notes
1997	6	5	321	Most ORC data has no matching serology
1998	10	10	272	Most ORC data has no matching serology
1999	9	9	221	Most ORC data has no matching serology
2000	26	25	692	
2001	21	20	644	Some ORC data has no matching serology
2002	6	6	144	
2003	11	11	307	
2004				None sampled

2005	9	9	257	
2006				None sampled
2007	6	6	159	Some ORC serology data missing
2008				None sampled
2009	9	9	261	
2010				None sampled
2011	10	10	252	
2012				None sampled
2013	13	12	367	
2014				None sampled
2015	11	11	342	
2016	2	2	61	
2017	17	16	464	
2018	13	13	392	Serology data but no autopsy data
2019				
2020				
2021	11	10	314	

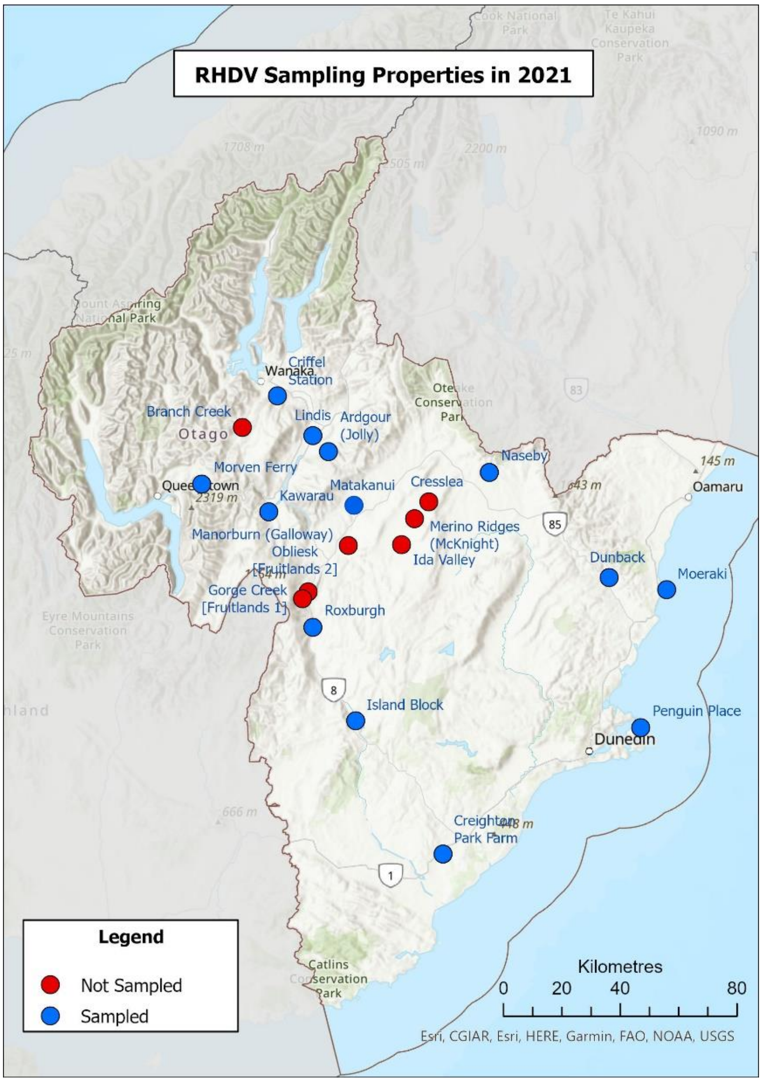

Figure 5. Location of recent ORC sites where rabbits were autopsied and blood sera tested for antibodies to RHDV

3. Background to serology

The antibody and immune status of rabbits sampled (i.e., shot and blood sera tested for antibodies to RHDV1) falls into one of four categories:

- Seropositive (i.e., with antibodies in their blood) indicating they had been challenged with the virus and survived to be shot sometime later. Note: very young rabbits may be seropositive but with maternal antibodies from their mother – thus the ideal sampling season of autumn when there are very few rabbits younger than 9 weeks present.
- Viremic (i.e., with active virus in the blood). This shows as very high reading in the test but there are very few such rabbits sampled as most will die in a few hours.
- Seronegative and susceptible (i.e., with no antibodies in their blood) indicating either the rabbit was never challenged with the virus or see below. Note: very young rabbits are resistant to RHDV and do not seroconvert when challenged orally.
- Seronegative but immune (i.e., with no current antibodies in their blood). Rabbits that survive infection and seroconvert lose their antibodies after several months (Parkes et al. 2002). These animals remain immunised and survive any future challenge.

Thus, sampling during or soon after epidemics give the best indication of the immune status of rabbits that survive the epidemic – generally this period is in autumn. That is, testing in autumn picks up the seropositive animals and minimises the seronegative but immune class.

The rule of thumb as to what is seropositive is the ELISA test gave a percent inhibition of over 50% at the 1:40 dilution (Zheng & Parkes 2011). Therefore, testing at greater dilutions is not essential. Very few rabbits achieved this level before RHDV arrived in spring 1997 (O'Keefe et al. 1998) and the few that did test positive were thought to be evidence of a pre-existing benign calicivirus – since confirmed.

On this point, New Zealand now has four rabbit caliciviruses – the pre-existing benign RCV, the Czech strains of RCDV1 and their descendants released from Australia in 1997, a new version of this strain RHDVa-K5 imported and released in 2018, and a novel calicivirus (Hall et al. 2021) that kills both rabbits and hares RHDV2 that appeared in New Zealand 2018 and may be becoming the dominant strain at least judging by preliminary PCR tests on blowfly carriers of the virus Landcare Research, unpubl. data).

ELISA tests on sera can apparently, by using different reagents imported from Italy, distinguish between the pre-existing benign virus, the RHDV1 strains that have evolved from the 1997 release including the RHDV1-K5 version, and the novel RHDV2 (S. Gupta, pers. comm.). I note the RHDV2 strain in New Zealand is slightly different from similar strains in Australia so the ability of ELISA tests developed in Italy to detect antibodies to the New Zealand strain would need to be confirmed, as would any cross-reactivity in the test results between the various strains.

The seropositive cases in the 2021 Otago sample are indicative that the rabbits had been exposed to RHDV1 or perhaps the RHDV1-K5 virus and survived, but this provides no information on the effect of the new RHDV2 virus – except that the lower proportions of young surviving after challenge, i.e., with antibodies to RHDV1 (Figures 6, 7) implies RHDV2 may have killed some of these young that have evolved resistance to RHDV1.

The first problem is that importing new reagents from Italy is expensive, partly because of the need to keep the reagents on dry ice, a more recent imposition by the airlines. This and the current 'market' for their use in New Zealand being limited increases the cost especially if reagents to test for antibodies to all strains are required, i.e., the current cost of $30/rabbit is likely to increase. The second problem is that understanding the evolving immunity of rabbits via testing for antibodies in surviving animals needs to distinguish between what type of calicivirus was involved. This question seems to require a research project before any operational monitoring is justified as it remains unclear whether RHDV2 overcomes rabbits that have evolved resistance to RHDV1 (as evidenced in Figure 6), or have caught RHDV1 and survived with immunity.

4. Some key results from the ORC serology

There is strong evidence that rabbits were evolving resistance to RHDV1. The proportion of young of the year (i.e., born between May and January (Figure 1) that were shot and tested in February – May, i.e., after evidence of active RHDV epidemics), that were seropositive was increasing up to 2018 (Figure 6). A regression model of the data up to 2018 suggested the annual increase was about 1.55% for all New Zealand (Parkes et al. unpubl. data). While there are gaps in the annual data for Otago (Figure 7), the pattern appears similar.

This increase appears to have halted and declined after 2018 but this is indicated by only two samples from Hawke's Bay (in Figure 6 for 2019) and for Otago (Figures 6 & 7). Nevertheless, the result is interesting as it was after 2018 that the new calicivirus RHDV2 appeared in New Zealand and it is known to be particularly lethal to rabbits (Hall et al. 2021).

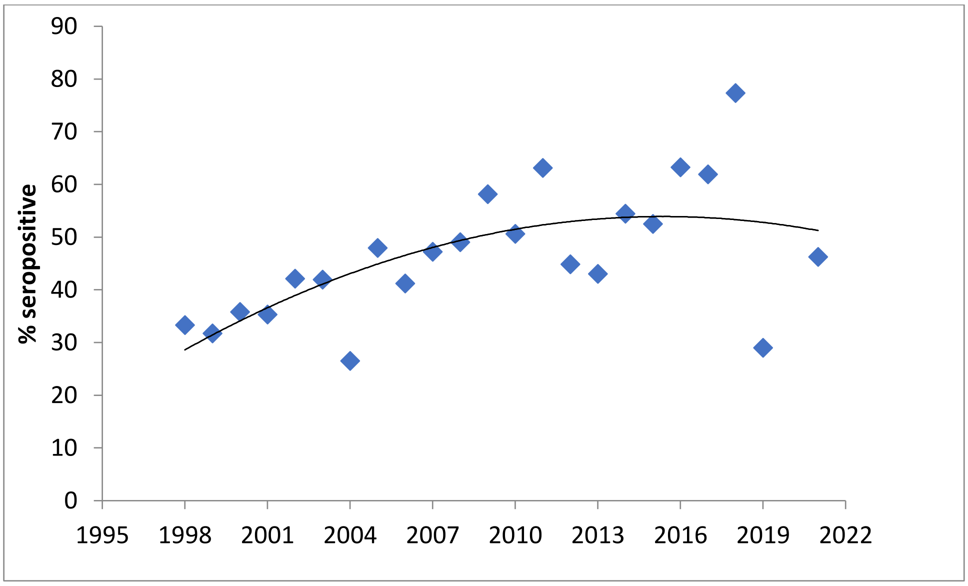

Figure 6: Percent of juvenile rabbits with antibodies to RHDV1, 1998-2021 for all regions in New Zealand

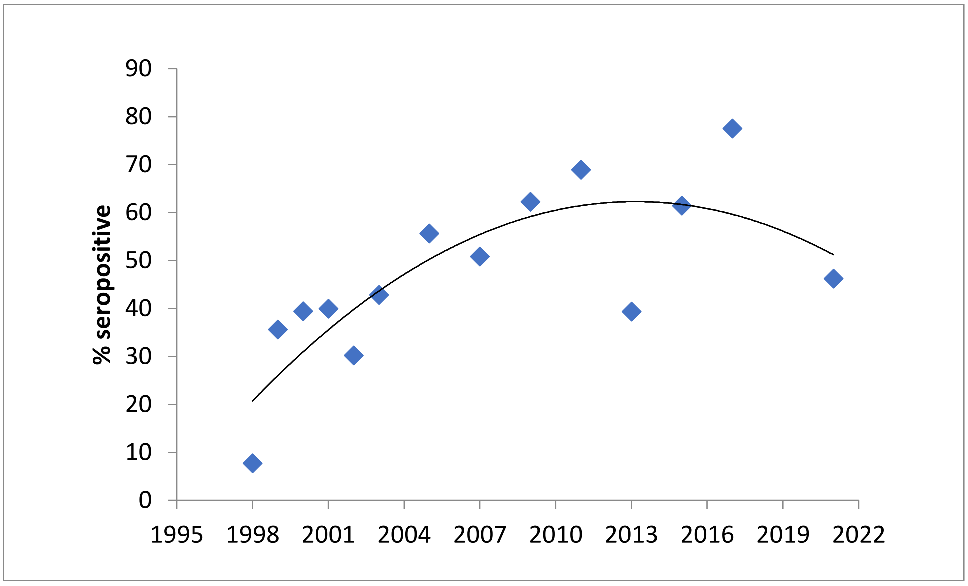

Figure 7: Percent of juvenile rabbits with antibodies to RHDV1 for Otago

A high and increasing proportion of adult rabbits in annual samples that are seropositive is expected (Figure 8). This is simply a reflection of the increasing immunisation of the juveniles during their first epidemic (Figure 6), and an accumulation of older rabbits that pass through with challenge and survive many (annual) epidemics. This figure sends no signal about the evolution of rabbits or the virus.

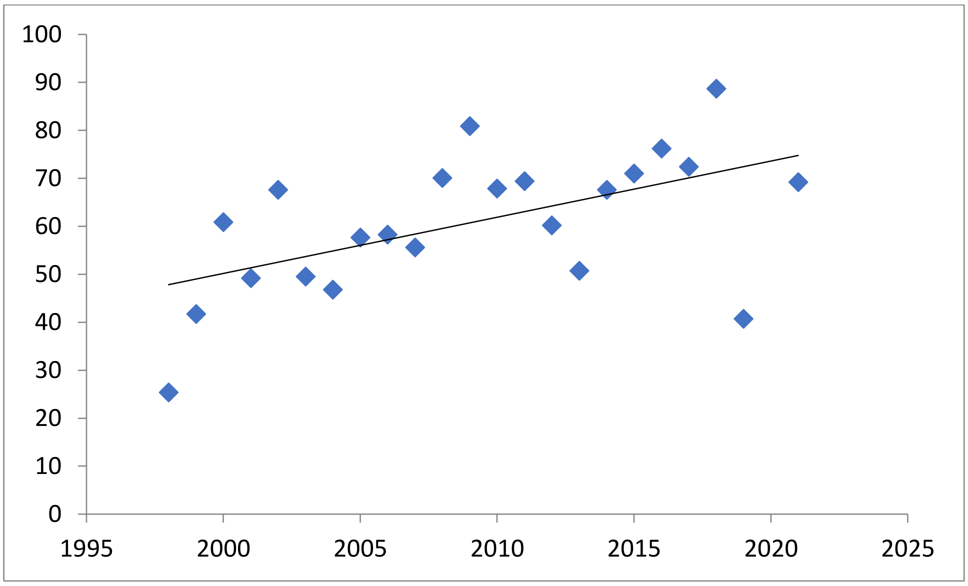

Figure 8: Percent of adult rabbits with antibodies to RHDV1 for all New Zealand regions

5. Recommendations

- Serological testing for RHDV1 antibodies in wild rabbits does not by itself provide information on the efficacy of the biocontrol. Tests for antibodies to both RHDV1 and RHDV2 will be required to interpret the causes of rabbit abundance that relate to the virus.

- A national perspective would be of most value and require cooperation between regional councils and Crown Research Institutes. ORC should initiate a discussion between councils to advance this national approach.
- Sampling is best done in autumn and testing of young rabbits (born since the previous winter) gives the most useful results.
- Given a regional (and cross-council) analysis gives the best results, it is not necessary to obtain large samples from each site – or test them all in the year sampled.
- Irrespective of future serological monitoring, one way to assess the spread of the strains of calicivirus is by looking for the virus itself. PCR tests on dead rabbits or of blowflies is the method being researched to do this (see Landcare Research's current research programme).
- Councils and/or AgResearch should keep past sera samples, particularly those since 2018, to act as baselines if a research project is begun.
- As with spotlight route data, ORC needs to curate and hold its serological data in a central system. It would be worth tracing the lost data and recording results in a consistent way.

Main Conclusions

Spotlight counts provide an objective measure of the abundance of rabbits over time at each site sampled, and with some caution of the annual trends in abundance at a regional level.

Interpreting changes in such indices (cause and effect) is more difficult. Several factors may drive changes in rabbit abundance (the extent of local conventional control, the efficacy of the biocontrol viruses, land-use changes and potentially in the longer-term climate changes). From a practical point of view, only the extent/intensity of conventional control can be managed if spotlight indices show unacceptable population sizes.

The intrinsic rate of increase of rabbits has been estimated at between 1.21 and 2.77 (quoted in Hone 1999), i.e., up to a 16-fold annual increase. Parkes et al. (2008) observed rates of increase in the Mackenzie Basin before RHDV and with no subsidies for landowner control of 0.56 (a finite rate of 1.75 per year). Once RHDV1 arrived, this rate declined to 0.06 (a finite rate of 1.06 per year). The implication is that conventional control does slow the growth of rabbit populations and RHDV1 on top of conventional control has kept many rabbit populations in check (see Figure 3).

Of these potential causes of change in rabbit abundance it appears RHDV1 has been the most important. However, with evolving rabbits and new strains of the virus the importance of the biocontrol might change. Therefore, continuing with serological monitoring (for both RHDV1 and RHDV2) will be desirable to allow future interpretation of measures of rabbit abundance. This is best done at a national scale with all major eastern Regional Councils and in collaboration with research and testing agencies such as Landcare Research and AgResearch. The research process required is:

- Confirm that cELISAs can distinguish between RHDV1 strains and the New Zealand version of RHDV2.
- Confirm that AgResearch can import the necessary reagents to do these tests, and what they will cost.
- Agree on a sampling strategy (autopsy and sera collection) between regional councils to get some national coverage.
- Explore how to integrate the current measures of spread of RHDV2 (from dead rabbits and blowfly PCR tests) done by councils and Landcare Research with the expanded serology.

Some other potential causes of changes in rabbit abundance might be explored by surveying the extent and nature of landowners' conventional control at the spotlight route properties, and noting major land-use changes as they occur along each route.

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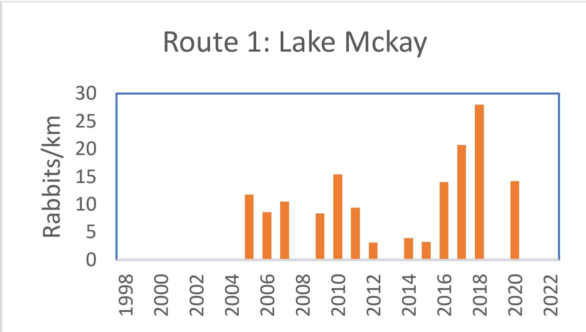
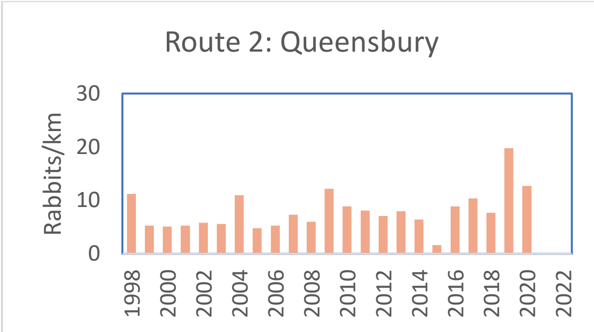
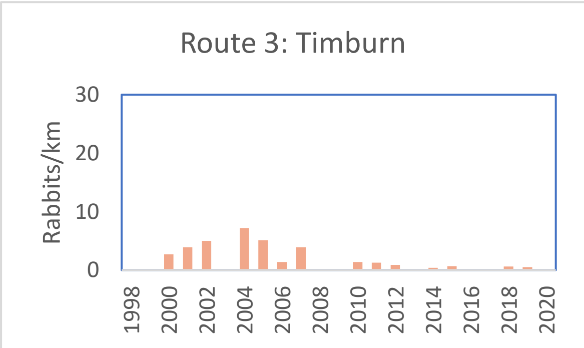
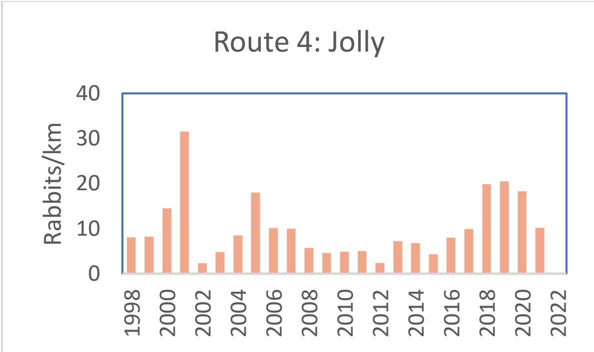
Appendices

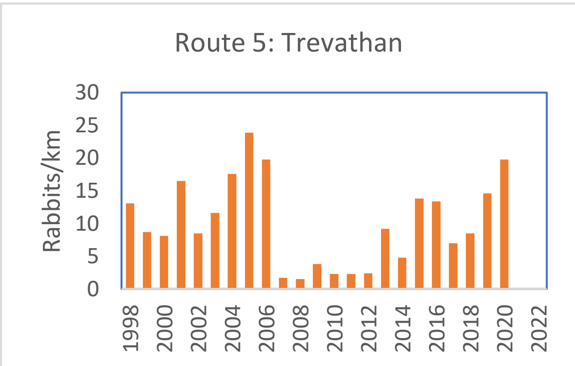
Appendix 1: Rabbit spotlight abundance indices in 17 routes monitored by ORC since 1998. The names are as per Figure 2.

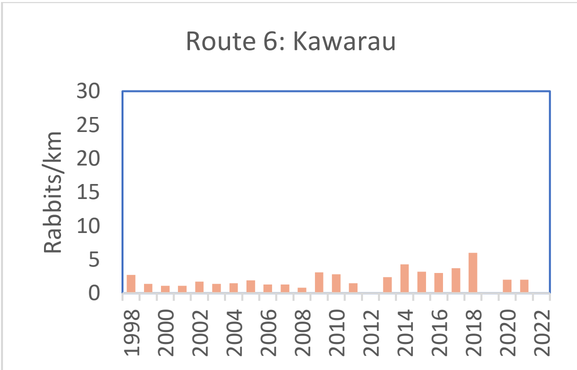


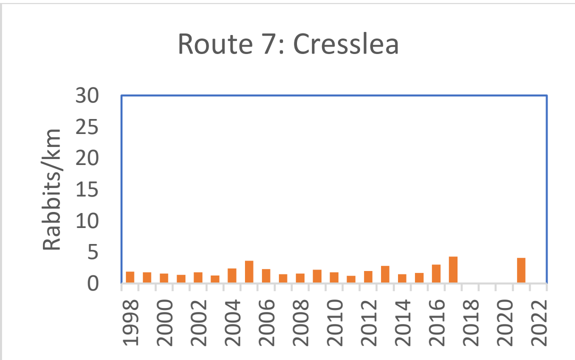


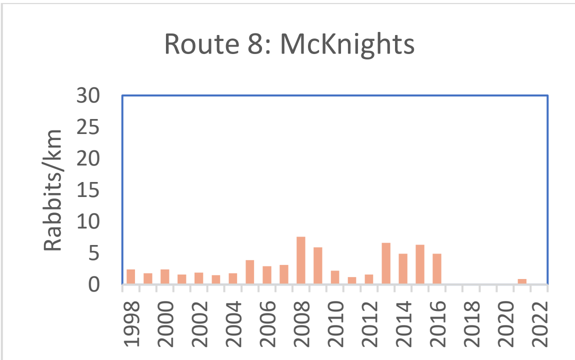


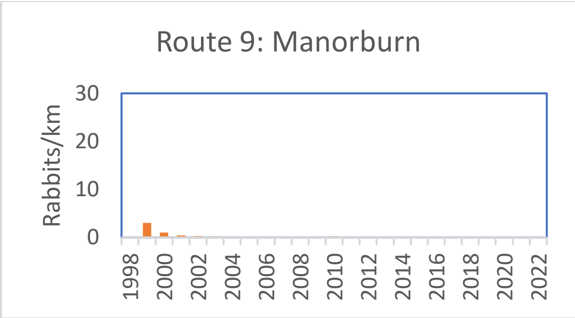


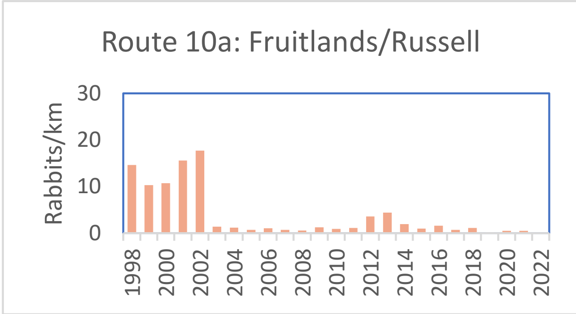


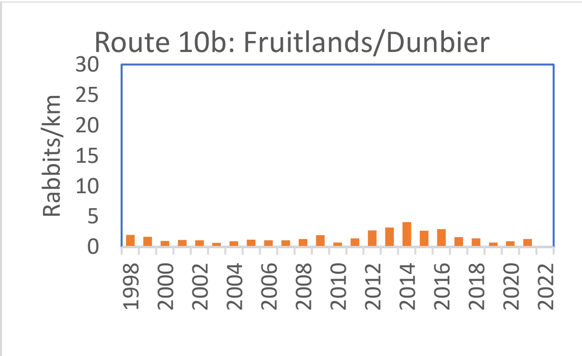


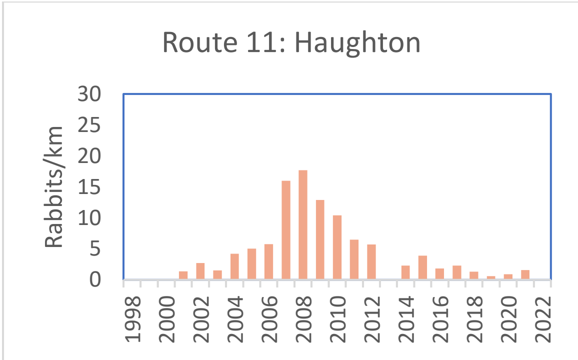


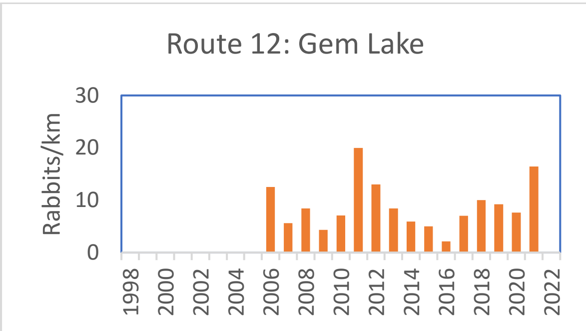


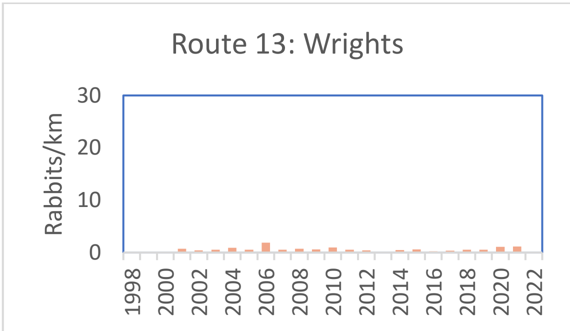

Route 9: Manorburn
Rabbits/km
30
20
10
0
1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022

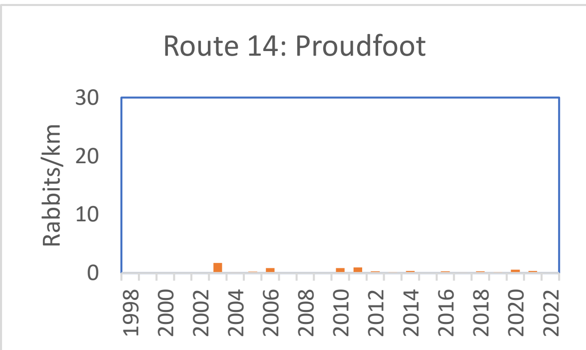

Route 10a: Fruitlands/Russell
Rabbits/km
30
20
10
0
1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022

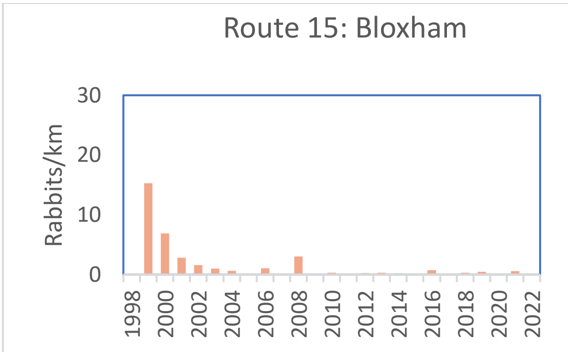

Route 10b: Fruitlands/Dunbier
Rabbits/km
30
25
20
15
10
5
0
1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022

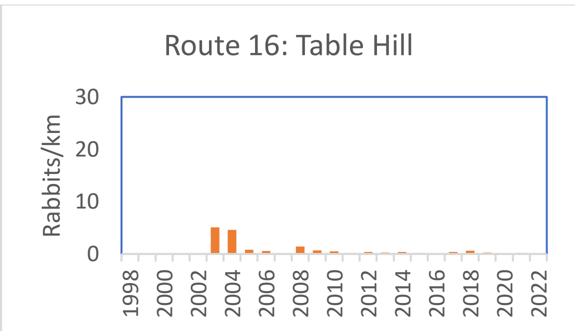

Route 11: Haughton
Rabbits/km
30
25
20
15
10
5
0
1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022

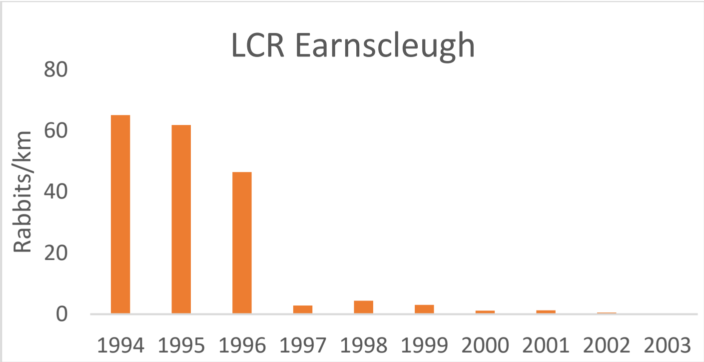

Route 12: Gem Lake
Rabbits/km
30
20
10
0
1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022


Route 13: Wrights
Rabbits/km
30
20
10
0
1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022

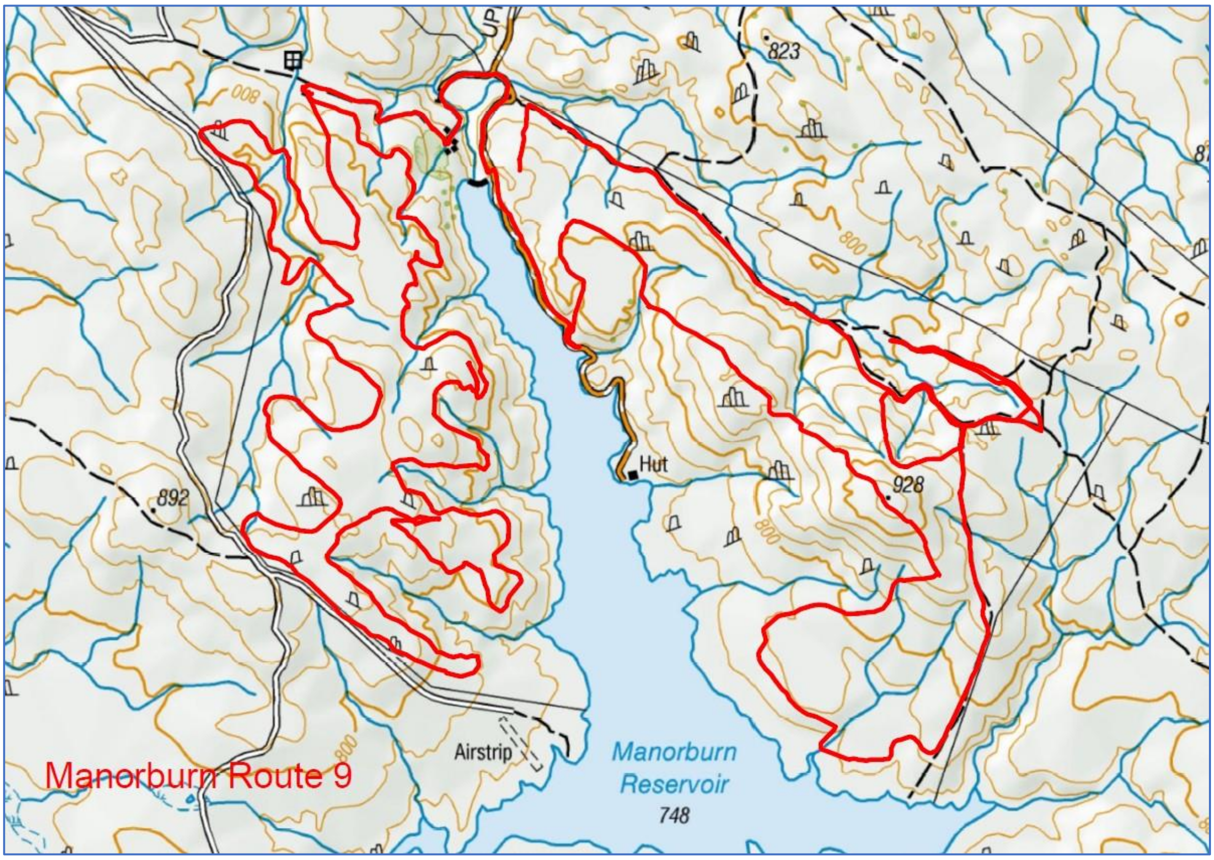

Route 14: Proudfoot
Rabbits/km
30
20
10
0
1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022


Route 15: Bloxham
Rabbits/km
30
20
10
0
1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022


Route 16: Table Hill
Rabbits/km
30
20
10
0
1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022



Appendix 2: An example of a mapped route



Appendix 3: Rabbit prone land classes