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DENSITY OF RABBITS (*ORYCTOLAGUS CUNICULUS* L.) IN THE MACKENZIE BASIN, SOUTH ISLAND, NEW ZEALAND

Summary: The density of rabbits (*Oryctolagus cuniculus*) in the modified tussock grasslands of the Mackenzie Basin, South Island, New Zealand, in August-September 1991 was determined within 26 1-ha quadrats spread over 1000 ha. The area was poisoned with 1080-carrot baits and dead and live rabbits counted. The overall kill rate was 93%. Wide variability in rabbit densities amongst the quadrats was correlated with burrow density, but vegetation was not a significant predictor of rabbit numbers. High density quadrats were not all spatially clumped together. Variation amongst quadrats of 0-43% of rabbits dying underground shows that searching burrows as well as the surface will provide the most accurate rabbit densities. Poisoning efficacy was ≥90% in 77% of the quadrats, but two low-density quadrats recorded kill rates <70%. Nine per cent of carcasses had been partly eaten by predators, suggesting a potential for the predators to be killed during rabbit control operations via secondary poisoning. The average density of 19 rabbits per ha confirms the classification of this area as a moderate to high rabbit-prone zone, with the rabbit population imposing grazing pressure equivalent to at least 1-2 sheep per ha at the beginning of spring. Sustainable agriculture cannot be attained in these semi-arid regions of New Zealand without cheap, widespread and effective rabbit control.

Keywords: Rabbit; *Oryctolagus cuniculus*; abundance; density; poisoning; burrows; Mackenzie Basin

Introduction

Previous authors have referred to "high" rabbit (*Oryctolagus cuniculus* L.) densities in Central Otago and the Mackenzie Basin causing serious problems for pastoral agriculture (e.g., Kerr *et al.*, 1987; Fraser, 1988; Gibb and Williams, 1994), but there have been few studies to determine the actual rabbit densities in these rabbit-prone areas. While there are indices of rabbit abundance available for various parts of New Zealand (e.g., Gibb, Ward and Ward, 1969; Williams *et al.*, 1986; Gibb and Williams, 1990; 1994), there are no published accounts of absolute rabbit densities in the South Island.

We need to calibrate indices of rabbit abundance against absolute numbers to make rabbit control more cost-effective. Indices on their own cannot tell us the minimum number of poison baits needed to reduce a rabbit population to a certain degree. The efficacy of standard rabbit poisoning operations is usually determined by comparing an index of rabbit density before and after the operation, such as spotlight counts of rabbits along fixed transects (Oliver, Wheeler and Gooding, 1982; Williams *et al.*, 1986). Estimates of the actual numbers of rabbits killed and how these vary amongst patches of relatively high and low abundance are not usually assessed. Understanding this spatial variability is potentially important in predicting the spatial variation in impacts of standard control operations and sources of subsequent resurgence in rabbit abundance.

An understanding of absolute rabbit abundance will give us a greater insight into rabbit-predator interactions. This is needed for determining whether the interaction between rabbit and predator numbers is an important predictor of the prevalence of bovine tuberculosis (Ragg, Waldrup and Moller, 1994). Measures of absolute abundance of rabbits will provide baselines for the study of the impact of Rabbit Calicivirus Disease (RCD) on the predator-prey relationships between introduced predators, rabbits and alternative prey species (Moller, Norbury and King, 1996; Norbury and Murphy, 1996).

Accurate measurements of absolute rabbit density can be used also to assess the reliability of indices of abundance. This study was conducted in conjunction with spotlight counts of rabbits along transect lines (Fletcher *et al.*, 1995). Spotlight counts gave an imprecise estimate of relative density

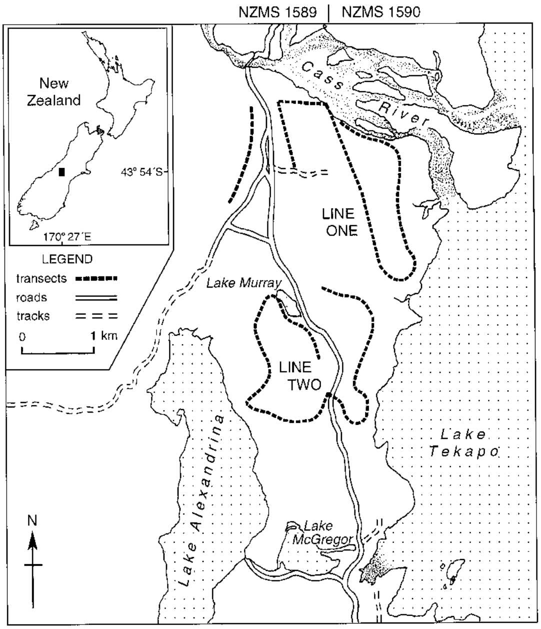

Figure 1: *Study site in the Mackenzie Basin, showing the two transect lines (LINE 1 and LINE 2). LINE 1 continues on the western side of the road.*

at this site. The reliability of faecal-pellet counts and indices of abundance based on signs of rabbit activity could also be assessed by calibration with absolute abundance. This has seldom been attempted (Frampton and Warburton, 1994). For meaningful results, an accurate measure of absolute rabbit abundance is essential.

Here we use a poisoning-counting technique to determine the density of rabbits in one area in the Mackenzie Basin. We describe the variability in density estimates and control efficacy amongst quadrats and investigate possible predictors of this variance.

Methods

The study took place in August-September 1991 on pastoral farmland between the Cass River delta and Lake Alexandrina in the Mackenzie Basin (Fig. 1). Vegetation consisted primarily of a fescue-tussock grassland community (Connor, 1964), hawkweed (*Hieracium praealtum* Gochnat) and matagouri shrubs (*Discaria toumatou* Raoul), on a 'Tekapo' soil type (Robertshaw, 1992). No rabbit poisoning had occurred on the area in the three years prior to this study. After 11 nights of spotlight counts (see Fletcher *et al.*, 1995 for details), non-toxic pre-feed carrot baits were laid and left for one week. Poison baits (carrots loaded with 0.02% wt/wt 1080), were laid on 7 September as part of a wider control operation for the Canterbury Regional Council.

Rabbit carcasses were collected between 11 and 20 days later from 26 1-ha quadrats. These were spread over approximately 1000 ha, 13 quadrats along each of two transect lines, covering 17 km in total (Fig. 1). Initially one quadrat was placed every 1 km, then additional quadrats were marked (no more than three per km) to ensure that there were adequate numbers of each class of vegetation. Carcasses were recorded as being on or near the surface or having been dug up from burrows, and whether or not they had been scavenged. All burrows found were dug up and searched for carcasses on all quadrats. A count of live rabbits flushed from the quadrats was recorded while each quadrat was being searched for poisoned rabbits. The density of rabbits on each quadrat was calculated as the total number of carcasses found plus the number of live rabbits flushed from the quadrat when it was searched following the poisoning. Each quadrat was classified by sight to provide relative scores on the density of burrows (low, medium or high).

Vegetation surveys conducted after the post-poison counts gave a precise estimate of plant cover. The percentage cover of various vegetation compositions was recorded in 1-m radius plots (20 plots per 1-ha quadrat) and grouped into three classes for statistical analysis. The percentage of matagouri cover was also calculated for each quadrat.

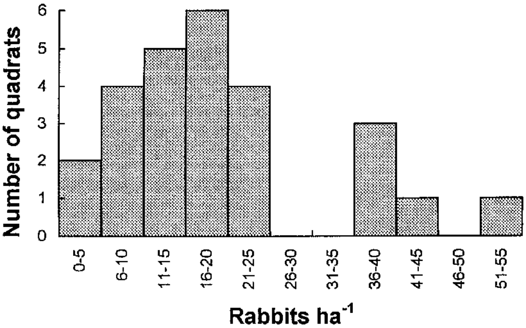

Figure 2: *Frequency distribution of number of rabbits (dead and alive) counted in each 1-ha quadrat (n=26).*

Table 1: *Variation in rabbit density ha^{-1} amongst the 26 1-ha quadrats, and survival rates of rabbits following poisoning by 1080, related to rabbit density, burrow density and vegetation composition within each quadrat. Adjacent quadrats are numbered consecutively.*

Rabbit density	Quadrat	Burrow density	Vegetation composition[1]	% Surviving	95% Confidence limits Lower	Upper
2	14	Low	Tussock	50	1	99
2	24	Low	Tussock	0	0	84
6	12	Low	Ground	33	4	78
6	22	Low	Tussock	0	0	46
7	13	Low	Ground	0	0	41
8	15	Medium	Pasture	0	0	37
11	2	Low	Ground	0	0	28
11	4	Low	Ground	0	0	28
11	6	Low	Tussock	0	0	28
14	3	Low	Ground	0	0	23
14	5	Medium	Tussock	7	0	34
16	11	Low	Pasture	6	0	30
17	26	Medium	Tussock	6	0	29
18	1	Low	Ground	6	0	27
18	7	Medium	Ground	6	0	27
18	17	High	Pasture	11	1	35
19	8	Medium	Tussock	11	1	33
22	9	Low	Tussock	9	1	29
22	20	High	Ground	9	1	29
24	21	High	Ground	17	5	37
25	16	High	Ground	16	5	36
39	10	Medium	Tussock	3	0	13
40	19	Medium	Ground	3	0	13
40	18	High	Ground	8	2	20
42	23	High	Ground	7	2	19
52	25	High	Pasture	2	0	10

[1] *Vegetation composition: Ground=bare ground and cushion plants covering >80%, Pasture=Bare ground and cushion plants covering 15-80% and pasture grasses covering>15%, Tussock=Bare ground and cushion plants covering≤5% and tussock grasses covering>5%*

Factorial analysis of variance on log-transformed data was used to determine the effects of vegetation composition, % matagouri cover and burrow density on rabbit densities. Depressions and hills were also recorded but these factors were too confounded with each other and with vegetation composition to allow analysis of their effects upon rabbit densities. Logistic regression was used to determine the effects of vegetation composition, % matagouri cover, burrow density and rabbit density on percentage survival and percentage of rabbits found underground. Binomial confidence intervals were calculated following Owen (1962).

Results

The mean number of total rabbits found per 1-ha quadrat was 19.4 (± 5.1 95% confidence interval) and ranged from 2 to 52. The frequency distribution of densities is skewed, with a few quadrats with extremely high rabbit densities (Fig. 2). There was no clear geographical pattern defining quadrats with high and low rabbit densities. While some adjacent quadrats had similar rabbit densities, some of the highest density quadrats were adjacent to those with the lowest rabbit densities (Table 1). Rabbit density was not related to vegetation composition of the quadrats (Fig. 3a). Rabbit density did not increase with increasing % matagouri cover, which reached a maximum of only 7%. Rabbit density was positively correlated with burrow density ($F_{2,23}$=9.3, P=0.001) (Fig. 3b).

No more than four rabbits were flushed from any quadrat after the poison operation. The overall percentage of rabbits surviving the poisoning was 7% (Binomial 95% confidence interval=5%-9%, n=504 rabbits), with a kill rate of >90% in 20 of the 26 quadrats. Survival exceeded 20% on only two quadrats (Fig. 4). Both these quadrats had very low numbers of rabbits (6 and 2) and wide confidence intervals for percentage survival (Table 1). They did not contribute strongly to the % survival analyses. Survival rates did not vary significantly with vegetation composition or % matagouri, but increased with burrow density (χ^2=7.4, d.f.=2, P=0.025). After allowing for burrow density, survival rates were lower at high rabbit densities (χ^2=6.3, d.f.=1, P=0.012). This was most noticeable at high burrow density (Fig. 5).

The percentage of rabbits dying below ground was 18% overall (S.E.=2%, n=504) and ranged from 0% to 43% in individual quadrats. There was no detectable effect of vegetation composition, rabbit density or burrow density on the percentage of rabbits dying below ground. Of the total of 91 rabbits found below ground, 13.2% could not be seen from the surface before digging began. This represents 2.4% of the total 504 rabbits counted. Of the 471 dead rabbits collected, 9.1% had been scavenged. Similar proportions of above and below ground rabbits had been scavenged (9.4% and 7.7%, respectively).

Discussion

Rabbit density varied greatly in the 1-ha quadrats. Larger quadrats would be needed to give an accurate estimate of rabbit density in any region without excessive sampling. J.D. Robertshaw and R.G. Mills (*unpubl. data*; Landcare Research, Alexandra, N.Z.) found even greater levels of variation in their study using 0.5-ha quadrats. The considerable localised spatial variation in rabbit abundance underscores the need for spotlight counts to be repeated on exactly the same transects to estimate changes in rabbit abundance in a given area (Fletcher *et al.*, 1995).

There was no pattern of high or low rabbit densities with different types of vegetation cover. The higher proportion of rabbits under shrubs compared with in open ground reported in Chile (Simonetti, 1989) was not confirmed in our study. Because rabbit density was correlated with burrow density, care must be taken not to be influenced by the distribution of burrows when siting quadrats for estimating absolute abundance or line transects for rabbit spotlight counts. The variability in the percentage of rabbits dying underground means that accuracy will be lost if counts do not include these underground carcases. An alternative to digging up all burrows would be to determine a correction factor. This would require repeating the present study in different habitats and seasons to ensure that the derived correction was more widely applicable. Excavating all the burrows is therefore the only practicable alternative.

The poison operation was efficient enough (93% kill) to provide confidence in our estimates of rabbits per quadrat. The kill rate may have been slightly over-estimated if some of the rabbits had died from other causes (e.g., inclement weather) prior to the poison operation; but, equally, we may have missed carcasses occasionally. The poisoning method used here is probably a very much more accurate method of estimating absolute abundance than alternatives such as mark and recapture methods (Boulanger and Krebs, 1994). The latter are also vastly more time consuming.

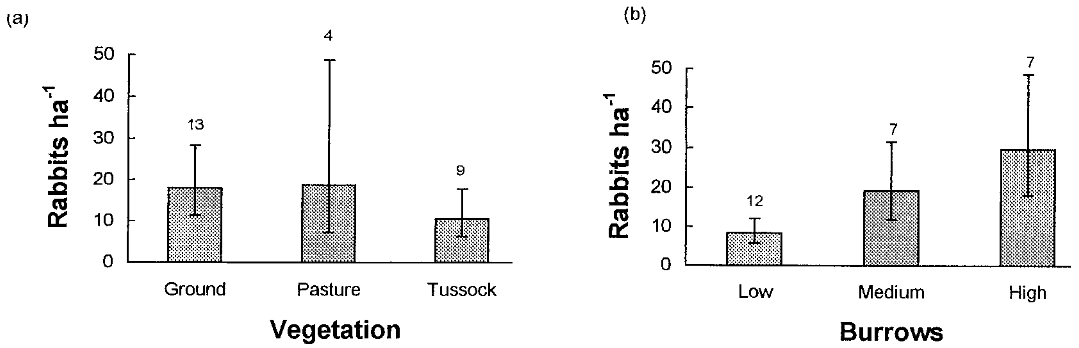

Figure 3: *Mean (±95% CI) number of rabbits per 1-ha quadrat for (a) each vegetation class: Ground=bare ground and cushion plants covering >80%, Pasture=Bare ground and cushion plants covering 15-80% and pasture grasses covering>15%, Tussock=Bare ground and cushion plants covering≤5% and tussock grasses covering>5%; and (b) each burrow density: Low, Medium or High. Sample sizes are given above each bar.*

Twenty of our 26 quadrats (77%) had kills of ≥90%, but kill rates in the other quadrats were as low as 50%. Pockets of the rabbit population may be left which would allow a rapid bounce-back in the population to damaging levels. However, efficacy was highest in patches of high rabbit abundance. If these areas are the most favourable for rabbits and therefore the likely sources of resurgence of the population, then conventional poisoning is probably more effective at delaying resurgence than is indicated by the average reduction in rabbit abundance. The decrease in % survival with increasing rabbit density but also decreasing burrow density may be related to food availability and rabbit movements. Overpopulated areas may have had better bait acceptance if food was limiting. Surviving rabbits may have moved from low to high burrow density areas, if these are preferred areas, after the residents had died (Fraser, 1985). The complex relationship between rabbit density, burrow density and % survival makes it difficult to predict what areas will have high and low poisoning efficacy. The spatial patchiness of rabbit abundance and poisoning efficacy deserve more study so that the key areas from which rabbit outbreaks recur can be targeted better in future.

The frequency of scavenged carcasses (9%) suggests that predators may suffer secondary poisoning following a rabbit control operation. A feral cat was found dead on one of the quadrats after the poisoning operation. A study in Central Otago and the Mackenzie Basin found that 8% of ferrets but 0% of cats received lethal doses of 1080 after a rabbit poisoning operation (G. Norbury, *pers. comm.*; Landcare Research, Alexandra, N.Z.). Given the potential of predators to prevent the resurgence of rabbit populations (Gibb, Ward and Ward, 1978), secondary poisoning of predators is a potentially important factor affecting rabbit population dynamics.

The average density of 19 rabbits ha^{-1} reported here is much higher than the 0.3 ha^{-1} seen in

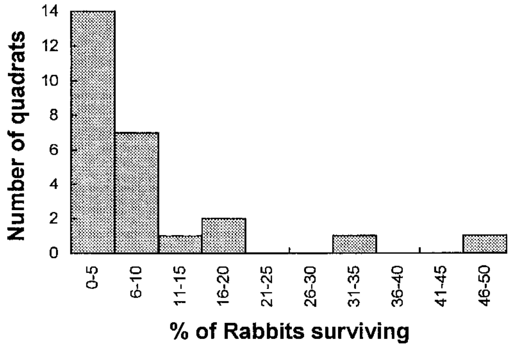

Figure 4: *Frequency distribution of the percentage of rabbits surviving the poison operation in each 1-ha quadrat (n=26).*

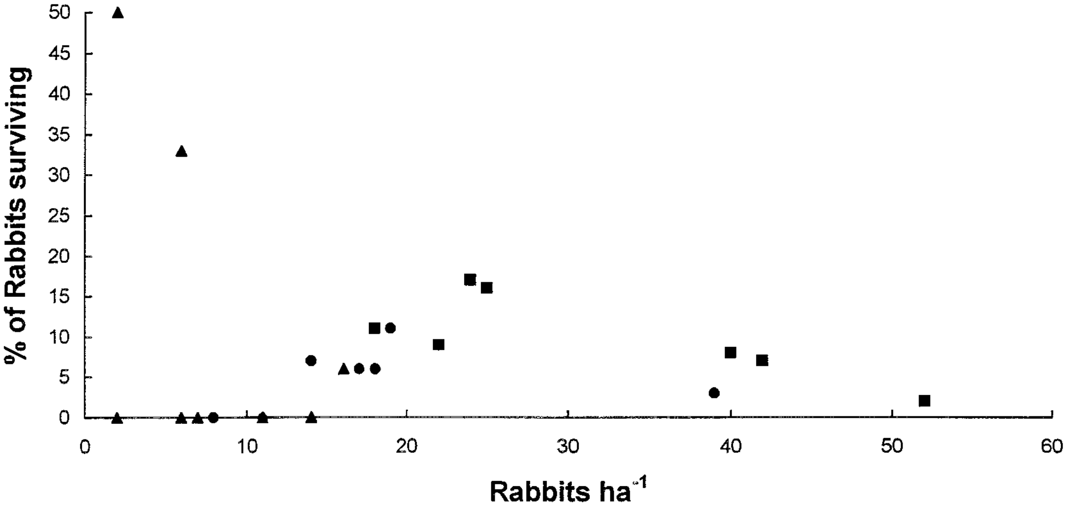

Figure 5: *Relationship between rabbit density and the percentage of rabbits surviving the poison operation in quadrats with Low (▲), Medium(●) and High (■) burrow densities.*

Wairarapa in spring (Gibb *et al.,* 1969). That region was considered to support only a sparse rabbit population. Our figure corresponds more closely to the 20.5 ha^{-1} and 25.2 ha^{-1} recorded by J.D. Robertshaw and R.G. Mills (*unpubl. data*) in September 1991 in two other sites in the Mackenzie Basin. It falls within the the 10-35 rabbits ha^{-1} range recorded by mark and recapture for a 4-ha site in Central Otago (Fraser, 1985). The winter had been severe in the Mackenzie Basin in 1991, leading to high rabbit mortality. Robertshaw and Mills calculated that there had been a 40% reduction in the rabbit population at their study site prior to poisoning. The rabbit densities reported in our study may thus be lower than usual. The timing of our study at the end of winter also means that our rabbit density estimate does not include the spring influx of young rabbits into the adult population (Robertshaw, 1992), so we expect our estimate of 19 rabbits ha^{-1} to be at a seasonal low. Rabbit populations usually double between late winter and peak numbers in autumn (Gibb and Williams, 1990), so our study suggests that average abundance of *c*. 40 ha^{-1} would be expected in autumn without poisoning intervention. Even in late winter some localised patches are experiencing intense grazing pressure from over 50 rabbits ha^{-1}.

The average spotlight count for our study area was 124 ±45 rabbits km^{-1} (±SD) (D.J. Fletcher, H. Moller and B.K. Clapperton, *unpubl. data*), which is higher than the average counts that have been recorded for other areas in New Zealand (Gibb and Williams, 1990). It is considerably higher than the threshold (40 km^{-1}) normally considered to indicate extreme rabbit-prone land (Allen *et al*., 1995). Our count is also higher than the average count of 76 ±25 recorded by Norbury and McGlinchy (1996) on 17 transects in the semi-arid regions of Canterbury and Otago selected non-randomly to exceed the 40 km^{-1} threshold.

Our rabbit counts averaged two to four times the spring and summer densities of rabbits at which protection from rabbits produced a six-fold increase in pasture yield (Norbury and Norbury, 1996). If estimates of between 10 and 16 rabbits consuming the equivalent of one sheep (Myers *et al*., 1994) are applicable in New Zealand tussock grassland, then rabbits are imposing grazing pressure equivalent to 1-2 sheep ha^{-1} at the very least, and maybe up to 4 sheep ha^{-1} at times. This is about 1.2-4.7 times the grazing pressure imposed by farm stock units in the Mackenzie Basin in 1976-78 (0.85 stock units ha^{-1}) (RCD Applicant Group, 1996). These crude comparisons highlight the impact of rabbits on the sustainability of agriculture in the semi-arid regions of the South Island if rabbits are not controlled. They tell us nothing about the long-term degradation of the soil and water, and vegetation from this high level of rabbit grazing, so the overall impact of rabbits on the production values may be much greater than is suggested here. Since our estimates of grazing pressure by rabbits were obtained at a time of relatively low rabbit density, our calculations suggest that the prospects for sustainable agriculture in the semi-arid areas are bleak unless cheap, widespread and effective rabbit control can be obtained.

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