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RABBIT *(ORYCTOLAGUS CUNICULUS)* CONTROL WITH A SINGLE APPLICATON OF 50 PPM BRODIFACOUM CEREAL BAITS

Summary: The relationships between an index of rabbit density (number spotlighted), bait application rate and control effectiveness of a single application of a highly acceptable cereal bait (1250 baits/kg), containing 50 ppm brodifacoum, were investigated. The impact of this control on non-target species was also evaluated.

Bait application rates >500 baits per spotlighted rabbit killed 97-100%, while rates averaging <300 baits/rabbit killed <65%. Provided application rates did not exceed about 800 baits/rabbit, 80% were consumed by day 3 to 4, so few remained to pose risks to domestic livestock. Most rabbits died between the fourth and eighth day with the majority of deaths occurring in burrows or under scrub, thus reducing access to avian predators.

The large number of baits eaten resulted in brodifacoum residues in the rabbits (mean 4.4 mg/kg in livers). This contributed to the few observed non-target deaths of avian and mammalian rabbit predators. However there appeared to be no long-term impact on rabbit predator-prey relationships in the study area as a result of a single application of brodifacoum baits.

Keywords: Rabbit control, Oryctrolagus cuniculus, brodifacoum, anticoagulant, bait application, secondary hazards.

Introduction

Rabbit management in New Zealand depends on shooting from vehicles or poisoning with 1080 (sodium monofluoroacetate), applied mainly to carrot, oat or manufactured cereal baits. Shooting is costly and not very effective, while 1080 baiting poses some farm management problems, namely the need to exclude stock from treated areas for extended periods, and secondary poisoning risks to dogs. In addition, 1080 control necessitates pre-feeding with non-toxic bait, to reduce the risk of poison-induced bait aversion and ensure high acceptance of toxic baits.

Since the development of anticoagulants for rodent control in the late 1940's (O'Connors, 1948) these compounds have repeatedly been shown to achieve higher levels of rodent control than can be achieved with acute poisons (e.g. Rennison *et al.*, 1968; Rennison and Dubock, 1978). As a result anticoagulants are the predominant compounds for controlling commensal rodents.

The anticoagulant brodifacoum was developed by Hadler and Shad bolt (1975). Redfern *et al*. (1976) subsequently determined that it killed warfarin-resistant Norway rats after a single feeding. This "single feed" potency obviates the normal anticoagulant requirement for ingestion over several days. Thus the risk of bait spoilage is reduced, potentially enhancing control effectiveness.

Godfrey *et al*. (1981a) established that the acute and chronic (5 days) LD50 of brodifacoum for the feral rabbit is approximately 0.20 mg/kg. This is lower than the chronic (7 days) LD50 for pindone, 0.52 mg/kg (Oliver and Wheeler, 1978), but similar to the chronic (6-14 days) LD50 for diphacinone, 0.25 mg/kg (Oliver and Wheeler, 1978; Correll *et al.,* 1952). Neither of these latter compounds are effective acute poisons.

There are only limited data on the field control effectiveness of brodifacoum, or other anticoagulants, for lagomorph control. Crosbie *et al*. (1986) established that brodifacoum (100 ppm) and 1080 (200 ppm) jam baits were equally as effective (> 85% killed) for rabbit control, while small-scale field tests with 50 ppm and 25 ppm carrot baits produced "acceptable" kills (Godfrey, pers. comm.). Pindone oats (350 and 470 ppm) at rates of 15.9 - 18.5 kg/km of bait line have achieved acceptable rabbit kills (90-100%) in Western Australia (Oliver *et al.,* 1982; Robinson and Wheeler, 1983). Diphacinone cereal baits (50 ppm) applied at 1.4 kg/ha successfully controlled jackrabbit *(Lepus californ;cus)* populations in California (Johnston, 1978).

None of these studies have examined the control potential of single applications of acute anticoagulants, nor the effects of poison concentration and amount of bait applied per target animal on control effectiveness. Subsequent risks to non-target species, via direct or indirect poisoning under field conditions, have also been inadequately studied in relation to lagomorph control. A single application of

bait, at a rate and toxicity that will give high percentage kills but leaves few baits uneaten, is potentially the most cost effective strategy for anticoagulant rabbit control on New Zealand grazing land. The objective of these trials was to determine:
(i) the relationships between an index of rabbit density, bait application rates and kill effectiveness of a single application of a highly acceptable cereal bait containing 50 ppm brodifacoum;
(ii) the amounts of bait uneaten and the levels of brodifacoum in the carcasses of poisoned rabbits, i.e. non-target risks.

Methods

Design

The overall trial methodology consisted of: pre- and post-poisoning assessment of relative rabbit numbers by spotlight counting; a single application of a cereal-based bait impregnated with 50 ppm brodifacoum; assessment of the rate of bait consumption; determination of the amount of brodifacoum in the carcasses of poisoned rabbits plus any non-target species killed; and monitoring the recovery of the populations over the subsequent two years. The rate of leaching of the poison from baits was examined at one site.

Sites

All sites were in Canterbury Province, South Island, New Zealand.

Trial 1: Scargill, North Canterbury. (Lat. 42∞57'S. Long. 172∞58'E.).

The area consisted of 43 hectares of newly-sown (ryegrass, clover and turnips), rolling hill lands of predominantly Holden and Tipapa soils, interspersed with rock (greywacke) outcrops incorporating tussock *(Poa laevis)* and scrub patches *(Discaria toumatou* and *Coprosma sp.)*. Surrounding hills were predominantly undeveloped tussock and scrub-covered grazing land. Rainfall in the area averages 750 mm per annum. Over the two months (Jan/Feb 1982) prior to the trial period rainfall totalled 71.4 mm, resulting in good pasture establishment. The trial commenced in March 1982.

Trial 2: Barrhill, Mid Canterbury. (Lat. 43 ∞37'S. Long. 171∞47'E.).

The trial area (1060 hectares) consisted of: arable plains (Barrhill soils); river terraces (Waimakariri shallow soils) with developed pastures and fodder crops; riverbed islands covered with lupins *(Lupinus arboreus)* and some grasses; open river shingle beds; and a steep river scarp predominantly covered with broom *(Cytisus scoparius)* and gorse *(Ulex europaeus)* (Fig. 1). The arable plain was separated from the river flats by the scarp. The study concentrated on the arable plains margin and developed river flats which covered an area of approximately 174 hectares.

Figure 1: *Vertical aerial view of part of the Barrhill trial showing, from bottom to top, arable plains, river scarp, developed and undeveloped river flats plus river streams. (Also see Fig.* 3).

Annual rainfall averages 970 mm, and falls in the months prior to and during the trial (April/May/June) averaged 53.7 mm/month. This trial commenced in June 1982.

Trial 3: Lake Heron Basin, Mid-Canterbury. (Lat. 43∞29'S. Long. 171∞12'E.).

This site, of 700 hectares, consisted of relatively uniform rolling tussock-covered alpine grassland. Soils in the area are predominantly Tekapo and Pukakil Acheron, while precipitation (including snowfall) averages 1200 mm per annum.

Trial sites were surveyed by ground methods and aerial photography. Rabbits had not been poisoned for several years at any sites.

Rabbit population assessment

Routes along which rabbits were surveyed, were established within all sites except the nil treatment areas at Barrhill and Lake Heron. Counts were done using various forms of spotlighting, during the first two-three hours of darkness under favourable weather conditions.

At Scargill, counts were done from a stationary vehicle at a series of points, and at the same time by walking a part of the study site inaccessible to vehicles. The nil treatment area was counted from a moving vehicle (Fig. 2).

At Barrhill, moving vehicle and walking counts were used, while at Lake Heron all counts were from a moving vehicle. The routes were divided into a varying number of subsectors depending on features such as ridges, fences and tree lines. The subsectors represented treatment units (Fig. 3).

The search range of the different spotlighting techniques varied as a result of observer, light wattage, nature of terrain and vegetative cover. Therefore the area spotlighted on each route and defined subsector was calculated for all sites. Rabbit predators, feral cats *(Felis catus),* and ferrets *(Mustela*

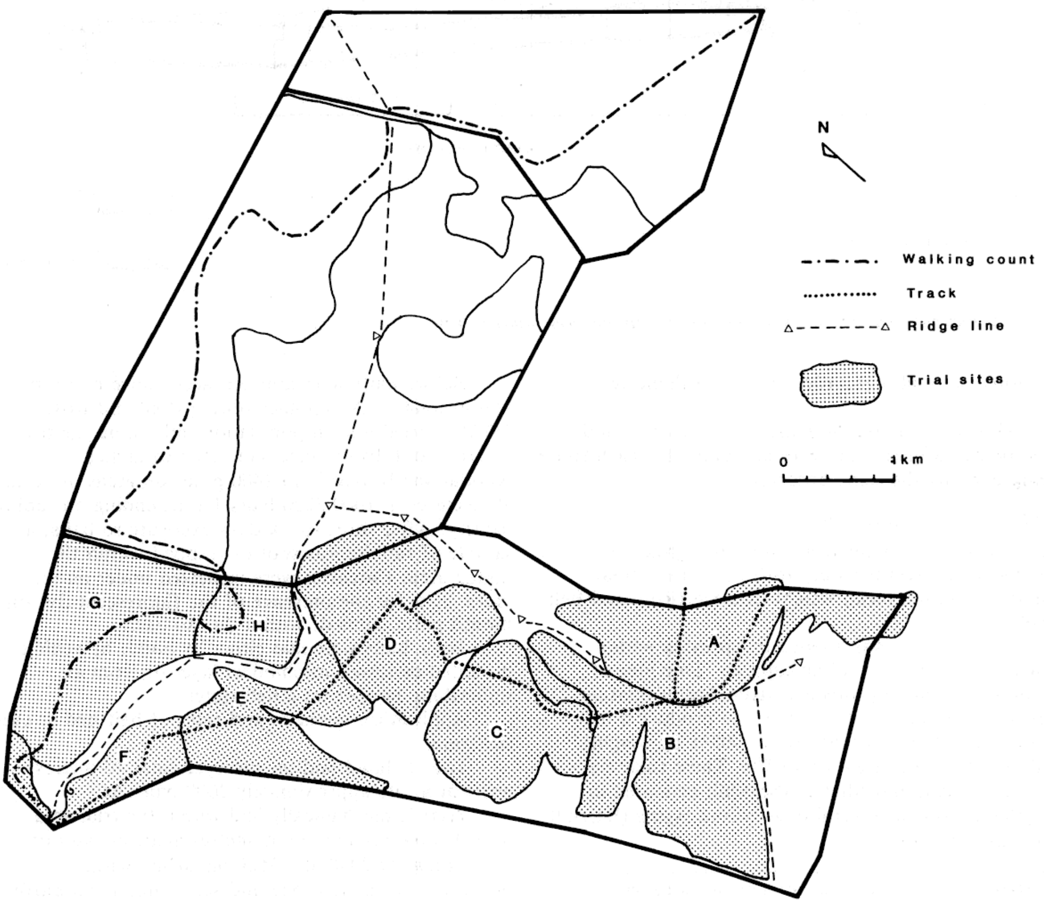

Figure 2: *The Scargill trial area showing location of count routes and trial site spotlightable areas.*

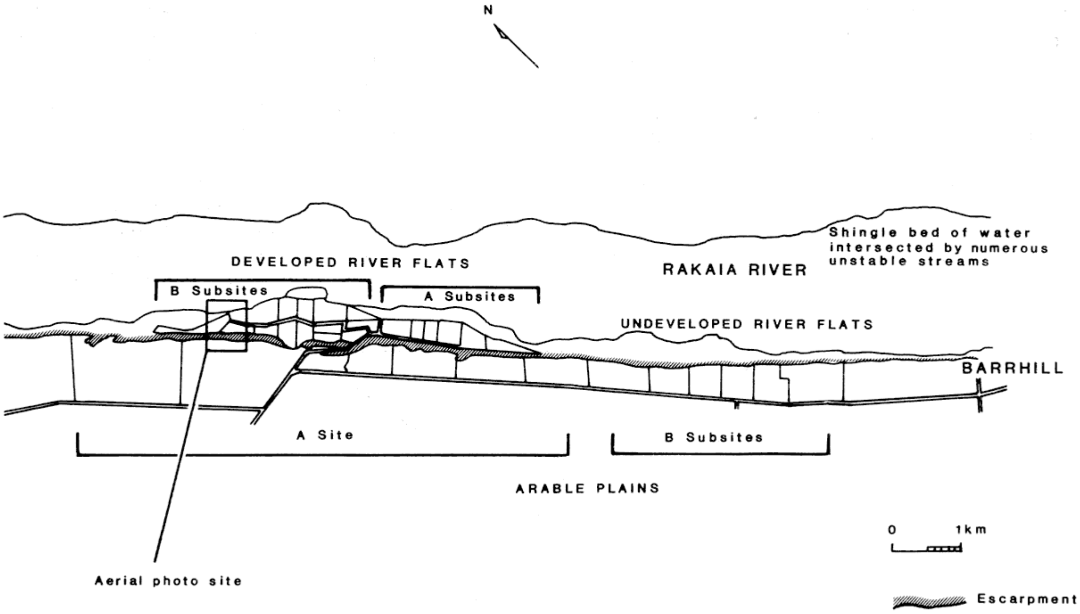

Figure 3: *Barrhill trial area showing the relationship between study subsites.*

putorius) were also recorded, while spotlighting rabbits.

This methodology was used for both pre- and post-poison assessments, with all counts for each route being done by the same observer.

Baits and bait application

All trials used a commercial rabbit bait (Mapua*). It is a low-density, relatively dry (6% moisture) cereal-based bait with a mean weight of 0.8 g (Ross and Bell, 1979).

Brodifacoum was applied by spraying within concrete mixers of 15-45 kg capacity. One litre of brodifacoum/monopropylene glycol/water mixture was used for each 10 kg of baits, to produce a bait containing 50 ppm brodifacoum .005% by weight) with a moisture content of 14.5%. These toxic baits were either laid immediately (Scargill) or stored in polythene bags for several days before laying (Barrhill and Lake Heron).

Before baits were applied, acceptance by rabbits was evaluated. Acceptance testing (Bell and Ross, 1983), carried out on populations adjoining the trial site to avoid disturbance, consisted of laying Rhodamine B dyed baits (400 ppm) on areas of 10 to 80 hectares at 1000-3200 baits/ha depending on rabbit density. After three to six days exposure to baits, a sample of rabbits was shot or trapped within the baited area. Carcasses were inspected under an ultra-violet light for the presence of the fluorescent dye on mouth parts, anus or within the stomach.

Toxic baits were laid either by hand, by vehicle-mounted or towed mechanical layer or from an underslung hopper on a helicopter.

Application methods and rates of bait laid at each site were:

Trial 1: hand laid on surveyed lines 40 metres apart at a rate approximately 2000 baits/ha.

Trial 2: mechanically laid within the trial area into shallow furrows 30-50 metres apart at rates of approximately 2000 and 3500 baits/ha; aerial broadcast on the riverbed and scarp area (trial buffer lones) at an average rate of 3500 baits/ha. Calibration

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.*êMapuaê is the trade name for a cereal based bait produced by Mintec N.Z. Ltd.

of the helicopter bait laying equipment under flying conditions was carried out prior to trial applications, as were bait handling and flow characteristics (Le. bait breakage) of mechanical layers.

Trial 3: mechanically laid on approximately 300 metres of furrow per hectare at an average rate of 1500 baits/ha.

The three standard rates of bait applied per hectare (1500, 2000, 3500) were laid over the various rabbit densities at each trial site in order to create a range of bait application rates/rabbit. That is, variations in the number of baits available to rabbits at subsites was generated by applying baits uniformly to varying rabbit densities.

Immediately after bait laying at all locations, 10-15 plots were established on bait lines within most treatments to estimate bait consumption. The number of baits on 10 metres of furrow (a plot) were counted daily for three to five days.

During the Lake Heron trial, samples of toxic baits were collected at various intervals to enable brodifacoum leaching to be assessed in relation to weather.

At the completion of all trials, residual rabbit populations and nil treatment areas were poisoned as required by landholders. This necessitated a second application of brodifacoum on the Scargill trial site, and 1080 cereal bait poisoning on the Scargill nil treatment area.

Brodifacoum levels in rabbit and non-target animals killed

Poisoned rabbits were searched for at all sites. Intact carcasses were autopsied and haemorrhage sites recorded. Liver, omental fat and muscle samples were assayed for brodifacoum residues. Non-target animals found dead within the trial areas, or adjacent to them, were also assayed for brodifacoum residues.

Post-poison population dynamics

During the first year after poisoning, samples of rabbits were shot from one site (Barrhill, arable plains) to determine the age structure of the recovering population.

Results

Control effectiveness

Maximum pre-treatment rabbit densities ranged from 3.2/ha to 13.1/ha at Scargill, 1.7/ha to 7.4/ha (10-60/spotlight km) at Barrhill, but only 2.5 per spotlight km at Lake Heron (Table 1). At all sites there was considerable variation in number counted per night, despite carrying out most counts during what were favourable weather conditions for observing rabbits.

The most relevant density index at Scargill and Barrhill sites was the number of rabbits spotlighted/ha, because the sites consisted of open

Table 1: *Rabbit densities pre and post poison.*

Trial sites	Area (ha)	Area Spotlighted (ha)	Length of Spotlight Route (km)	Pre Poison Mean Count (n)	Pre Poison SE	Rabbits per ha (highest count)	Rabbits per km (highest count)	Post Poison No. Rabbits Counted Days After Poison Laid 5	7	11	14	40	41	42	Control Effectiveness % Kill (40-42 days)
Barrhill															
Developed river flats															
- A Subsites (4)	35.0	23.2	3.6	43.0 (6)	8.3	3.2	26.6	13	3	2	1	1	0	0	99.2
- B Subsites (7)	47.1	44.7	6.7	248.5 (6)	29.4	7.8	53.3	107	26	10	2	4	1	0	99.3
Partly developed river flats (3)	21.8	9.6	2.2	42.8 (6)	2.7	5.1	22.7	14	7	1	1	1	1	0	98.4
Arable Plains															
- A Site	56.0	56.0	8.0	66.2 (6)	9.4	-	-	10	5	7	1	3	0	1	98.0
- B Subsites (2)	-	-	6.5	75.8 (4)	9.0	-	-	11	7	1	-	0	0	-	100.0
Undeveloped river bed (1)	-	-	4.0	36.0 (4)	9.4	-	-	12	7	6	-	1	1	-	98.1
									Post Poison						% Kill
Scargill									Mean Count (n)				SE		
Trial Subsites (8)	12.5	12.5	-	88.9 (7)	9.1	11.4	-		34.5 (4)				3.9		61.2
Other treated areas	18.6	-	-	33.7 (7)	4.8	-	-		5.8 (4)				1.8		82.8
Nil treatment	-	-	3.2	57.9 (7)	13.9	-	-		79.0 (4)				12.7		n.s.
Lake Heron	700	-	18.5	30.8 (4)	8.0	-	-		0.5 (2)				-		98.4

Table 2: *Bait application and consumption rates*

Trial sites	Total Area (ha)	Baits Laid /ha	Metres of Furrow/ha	No. Baits/ Spotlighted Rabbit (mean of counts)	No. of Sites	Bait Consumption						mg of Brodifacoum Potentially Eaten/ Spotlighted Rabbit by Day 5 (LD90's)	
						Total Baits Laid on Sites	% Consumed by day 1	2	3	4	5		
Barrhill													
Developed river flats													
- A 1 + 2	10.2	2451	441	2026	15	609	9	19	-	60	65		
- A 4	5.4	2430	426	992	10	383	6	17	-	83	86		
- A 5 + 6	11.6	2155	406	1418	15	465	18	57	-	83	86		
- A 9	7.8	2644	447	1120	15	577	15	44	-	95	99		
Total/Weighted Mean	35.0	2393	428	1463	55	2034	13	37	-	70	77	45	75
- Ba 1 + 2	5.8	3611	462	872	10	489	11	26	52	-	71		
- B 3	6.0	3229	325	639	11	583	7	40	57	-	84		
- B 4	4.9	3751	428	645	12	627	13	34	55	-	91		
- B 6	7.3	4965	484	606	15	800	28	73	96	-	99		
- B 7	8.3	2410	372	530	15	599	18	86	95	-	99		
- B 8	6.8	3602	418	728	12	626	14	50	96	-	97		
- B 9 + 10	8.0	4297	494	963	15	77	18	59	80	-	87		
Total/Weighted Mean	47.1	3690	428	711	90	4501	16	56	78	-	90	26	43
Arable flats	56.0	2879	367	2440	110	4534	7	22	37	-	64	62	104
Scargill													
- A	1.9	2000		259	30	1015	8	49	89	-	-		
- B	2.1	2000		372	22	974	7	59	94	-	-		
- C	1.4	2000		459	12	455	8	57	92	-	-		
- D	1.9	2000		333	15	517	3	17	63	-	-		
- F	0.9	2000		137	12	326	14	52	99	-	-		
- G	2.2	2000		219	22	684	9	65	96	-	-		
- H	0.7	2000		467	8	240	4	24	70	-	-		
Total/Weighted Mean	12.5	2000		313	138	4802	7	46	84	-	-	11	18
Lake Heron	700	1500	299	-	60	1655	3	5	12	20	28	-	

pasture delimited by scrub margins. Thus the areas counted were rabbit feeding sites so numbers seen probably represented 60-90% of the total population (Gibb *et al.,* 1978). These rabbit densities were not constant along transects because the spotlight range, at any point on the count route, was determined by distance to the scrub margin. This varied considerably (Fig. 1).

In contrast, the counts on the nil treatment area at Scargill and treatment area at Lake Heron were in open tussock rangeland so the area spotlighted was a relatively constant function of distance. However, the proportion of the total population sighted was probably lower than at Scargill and Barrhill sites because rabbit feeding' areas were more diffuse.

At Barrhill and Lake Heron over 96% of the rabbits spotlighted were killed (Table 1). This level of control resulted in limited data on the minimum number of baits required to control known rabbit populations. At Scargill control success was lower, reflecting bait availability (Table 1).

The rate of population decline following poisoning was monitored at Barrhill from the fifth day after bait-laying. All sub-populations were declining rapidly by day 5 or 7, and by day 14 the final percentage kill had been reached (Table 1).

Bait application rates and consumption patterns

Cereal baits were highly acceptable to rabbits at all sites. At Scargill 97% (n = 29) accepted rhodamine dyed baits, at Barrhill 99% (n = 86) and at Lake Heron 100% (n = 24).

The 2000 baits/ha application rate was achieved at the Scargill site. At Barrhill an average of 2393 baits/ha were laid at A sub-sites, 3690/ha at B sub-sites, and 2879/ha on the arable plain. On all buffer areas around the trial sub-sites at Barrhill 3500 baits/ha were laid. At Lake Heron 1500 baits/ha were laid (Table 2).

The number of baits laid per spotlighted rabbit was derived for all sub-sites, except those at Lake Heron. At Scargill and Barrhill, the number of baits per rabbit (mean of all counts), within 20 sub-sites, ranged from 137 to 2440 (Table 2). The percentage of baits eaten by the third or fourth day (i.e. before the poison induced anorexia) was also established. At Barrhill A and B sites an average of 1463 and 711 baits were available per spotlighted rabbit. Seventy and 78% respectively were eaten by the third or fourth day. On the arable plains at Barrhill over 2400 baits per rabbit resulted in only 37% being eaten by day three. At Scargill, an average of <313 baits per rabbit resulted in 84% being eaten by day three (Table 2).

The relationship between the percentage of rabbits killed and the number of baits laid per spotlighted rabbit is shown in Fig. 4. At all sites where over 500 baits/rabbit were laid, 97-100% were killed. At lower application rates marked variation was evident but the kill success declined. 94% of the variance in percent kill was accounted for by the piecewise-linear relationship $Y = 0.22X$; $Y \quad 100$, with the ascending portion fitted by linear regression through the origin for X values < 500 and Y taken as 100% for the remainder (Fig. 4).

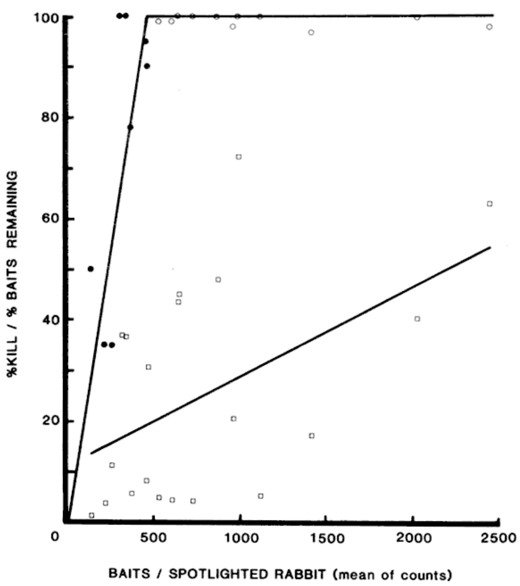

Figure 4: *The relationships between the number of baits laid per spotlighted rabbit, the percentage of rabbits killed and the baits remaining. Open circles indicate percentage killed; solid ones were used to calculate the relationship (Y = O.22X, Y 100). Squares represent baits remaining.*

There was also a significant linear relationship between the percentage of baits remaining and number laid per spotlighted rabbit (Fig. 4): $Y = 11.3 + 0.02X$; $r = 0.49$, $p < 0.03$.

The amount of brodifacoum potentially consumed per spotlighted rabbit ranged from 11.0 mg at a Scargill sub-site to 63.0 at a Barrhill sub-site. These quantities represent 18 and 104 rabbit LD90s respectively (Godfrey *et al.,* 1981) (Table 2).

The rate of loss of brodifacoum from cereal baits is reported in another paper (Rammell *et al.,* 1984).

Characteristics of rabbit mortalities and residues

The first deaths occurred 4 days after bait laying but most rabbits died between the fifth and eighth day. Occasional deaths occurred up to 28 days. Despite the relatively high numbers at some sites, dead rabbits were difficult to locate. No complete carcasses were found at Scargill, only 112 after very extensive searching at BarrhiU and 13 at Lake Heron. Most died within burrows or scrub areas. A few died in the open and were scavenged by hawks *(Circus approximans)* or other predators.

Haemorrhage characteristics and brodifacoum residue levels in poisoned rabbits have been reported (Rammen *et al.,* 1984). Mean residue levels (mg/kg) in livers, muscle and fat were 4.4 (n = 43), 0.26 (n = 27) and 0.86 (n = 22) respectively. There was considerable variation in levels in the three tissues as wen as between rabbits. This caused marked differences in the total amount of brodifacoum residue in rabbit carcasses (Table 3).

Table 3: *Estimated brodifacoum residues of rabbits poisoned with 50 ppm brodifacoum baits. The total residues in a rabbit are based on a mean liver weight of 55.0 g and body weights consisting of 20% fat and 60% tissue (including gut and reproductive organs)*

	n	Mean Wt (Range) (g)	Mean Residues (Range) (mg/kg)
Males	6	1883 (1675 - 2050)	0.81 (0.13 - 1.64)
Females	14	1878 (1425 - 2175)	1.04 (0.14 - 1.64)

All rabbit populations were representative of the habitats and time of year, in relation to sex ratios, age structures and breeding condition (pers. obs.). At BarrhiU the sex ratio of poisoned rabbits was 51% male, 49% female and 20% of the females were pregnant. The age distribution was 69% 7-12 months, 17% 12-22 months and 14% over 22 months.

Non-target deaths

Non-target deaths occurred at BarrhiU and Lake Heron, but none were located at Scargill. One or two specimens of five bird species, paradise duck *(Tadorna variegata),* black-backed gun *(Larus dominicus),* harrier *(Circus approximans),* magpie *(Gymnorhina tibicen)* and chaffinch *(Fringilla coelebs)* were found, plus two cats *(Felis catus),* one hare *(Lepus capensis)* and four sheep *(Ovis aries).* The cats, gun, and hawk probably died from eating rabbit carcasses, the other birds and the sheep from eating baits. Residue levels are reported elsewhere (Rammell *et al.,* 1984).

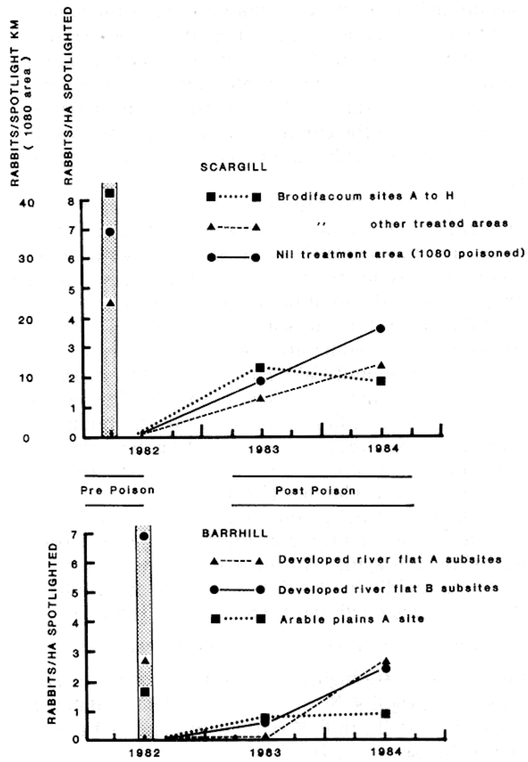

Figure 5: *The recovery rate of rabbit populations following poisoning with brodifacoum and compound 1080. This figure is based on the highest of 3 or 4 counts at each count period.*

Rabbit population recovery

The post-poison recovery of rabbit populations at Scargill and Barrhill was surveyed in mid to late winter for the first two post-poison years. The trial and nil treatment areas at the Scargill site were poisoned after completion of the trial, so population recovery at all sites was from low initial numbers. All sub-populations increased over the years but only one (Barrhill-site A) returned to its pre-poison level. All others, including the nil treatment area at Scargill, only returned to approximately half former levels (Fig.

Table 4: *Predator sightings while spotlight counting at all trial sites .[1]Highest count;§Cats only; *Cats plus one ferret in June and July at Barrhill.*

	Pre poison 1982			Post poison 1982			1983 (June)			1984 (July)		
	Rabbits[1] sighted	Predator§ sightings over 6 nights	Mean sightings per night	Rabbits[1] sighted	Predator* sightings over 2 nights	Mean sightings per night	Rabbits[1] sighted	Predator* sightings over 2 nights	Mean sightings per night	Rabbits[1] sighted	Predator* sightings over 2 nights	Mean sightings per night
				(26-30 days after bait laid)								
Scargill (Marchi April 1982) Brodifacoum area	127	6	1.0	23	3	0.8	49	0	0	62	3	1.0
Nil treatment area (1080 laid after 1982 post-brodifacoum poison counts)	111	7	1.2	98	0	0	30	0	0	58	I	0.3
				(40-42 days after bait laid) sightings over 3 nights			sightings over 4 nights					
Barrhill (June 1982) Sites A, B & Arable Plains A	594	9	1.5	9	4	1.3	104	3	0.8	309	8	2.7
				(35-42 days after bait laid) sightings over 2 nights								
Lake Heron (August/September 1982)	46	9	1.5	I	0	0						

5). At all sub-sites increases were associated with areas where there was good scrub cover. At one (Barrhill, arable plain), which consisted of an interface between a scrub covered scarp and developed pasture, the first year's increase in numbers was largely due to reproduction within the area because a shot sample (n = 106) of rabbits revealed very few (6.5%) over 12 months of age. The age-distribution of this population differed significantly from that which was poisoned (X^2 <0.005).

The number of predator sightings pre- and post-poison are shown in Table 4.

Discussion

Control Effectiveness

These trials confirm indications from laboratory studies (Godfrey *et al.,* 1981) that brodifacoum could be an effective rabbit poison. The kills of 97-100%, where adequate bait was laid, were similar to what has been achieved with 100 ppm jam baits (Crosbie *et al.,* 1986). However, in this case rabbits were pre-fed (conditioned) with non-toxic baits which negated one of the potential advantages of anticoagulants - acceptance of toxic baits over several days because manifestation of poison effects is slow.

These results are also similar to what has been achieved with 50 ppm cereal-based brodifacoum baits in rodent control. This includes 87-99% control of warfarin resistant *Rattus norvegicus* in poultry houses, (Apperson *et al.,* 1981) and 93-100% control of voles *Microtus pennsylvanicus* and *M. pinetorum* in apple orchards (Byers, 1979 and 1981).

As rabbits readily accepted the Mapua baits over 2-3 days, high mortality was expected where bait was adequate, provided brodifacoum at 50 ppm did not cause bait aversion. *Rattus argentiventer* has exhibited aversion to 20 and 50 ppm brodifacoum baits, but not 5 and 10 ppm (Buckle *et al.,* 1982). The high percentage kills in the current study indicate that rabbits accepted 50 ppm baits as readily as non-toxic ones, while 100 ppm jam baits were accepted in the earlier trial albeit after pre-feeding. There would therefore appear to be no overt aversion to 50 ppm brodifacoum in cereal baits. All rabbit populations were declining rapidly by day 5. However the decline was in terms of spotlighted rabbits and may not have truly reflected the actual death rate. Robinson and Wheeler (1983) found that the number of rabbits spotlighted in a pindone poisoned population indicated a decline earlier than revealed by radio tracking. They suggested that rabbits within a day or two of death did not emerge and thus were not spotlighted. Such a bias has probably resulted in an over-estimation of the percentage kill on a day to day basis from day 5-14 in the current trial, but it would be unlikely to affect the final kill estimations (Table 2).

The rate of population decline observed at Barrhill indicates that most rabbits probably ate a lethal dose in the first three to four nights; the highest sub-population at Barrhill had declined 67% by night five. This suggests that most rabbits will be killed after only two to four nights exposure to unweathered baits, assuming that most eat baits after only one to two nights exposure to them.

Bait application rates, consumption rates and brodifacoum residue relationships

A major objective of these trials was to determine the amount of bait needed, in relation to a measure of rabbit densities, to kill a high percentage and yet have little bait remaining. These aspects are of major importance to pastoral rabbit management for two reasons. Firstly, the amount of toxic bait left after rabbits are killed, in association with weather, influences when domestic livestock can be returned to the area. Secondly, the amount of bait eaten, in conjunction with poison concentration, will determine residue levels and thus risks to rabbit predators.

It is clear that where there are <300 baits/spotlighted rabbit the percentage killed is significantly lower than when 500 or more baits are available per rabbit (Fig. 4). It therefore appears that even though only 12-23 of the 0.8 g 50 ppm baits are needed to kill the average 1.8 kg rabbit, at least 300-400 baits per spotlighted rabbit need to be laid to ensure there are sufficient to allow all rabbits access to at least one lethal dose. It must be stressed that this is 300-400 per spotlighted rabbit and not per rabbit present per hectare. The number of baits available per rabbit in the whole population could be up to 50% lower depending on the proportion of the population spotlighted.

At all main sites where <350 baits per spotlighted rabbit were laid >97% of the rabbits were killed (Tables I and 2). Where there were 350-800 baits per rabbit, less than 20% of baits remained at most sites by day three or four. Application rates over 800 per rabbit clearly exceeded requirements, with up to 70% remaining by day four (Table 2, Figure 4).

Baiting rates that greatly exceed a given population's consumption capacity over 3 to 4 days negate one of the major potential advantages of anticoagulants - the removal of most toxic baits by the target animals. This potential advantage contrasts markedly with compound 1080-based baiting which normally results in over 70% of toxic baits remaining after most rabbits have been killed.

The considerable variability in the relationship between baits laid, percentage killed, and particularly percent of baits remaining, is partly a product of the unquantified relationship between the rabbit indices used and absolute rabbit numbers. However, factors such as the availability and types of alternative foods will also be important. Despite these limitations it is evident that 350-800 baits/spotlighted rabbit result in most being killed. Given this wide range of effective baiting rates we consider spotlight counting to be a suitable method of estimating relative population densities and hence bait application rates.

At baiting rates of 350-800 per rabbit there is sufficient bait for all rabbits, but a high percentage is eaten before death and considerably more poison than needed to kill is ingested than is necessary to kill. This is because feeding does not cease for at least 3 days even after ingesting a lethal dose (Godfrey and Lyman, 1980).

Residue levels in poisoned rabbits also indicated that excessive brodifacoum was ingested. More than one lethal dose was contained within the liver, fat and muscle of most rabbits (Table 3). However, total body residues based on these three tissues could be underestimated because residues in the alimentary tract were not included. At high dose rates, anticoagulants are increasingly excreted in the faeces of rats because it appears tissue absorption may be a saturable process (Yu *et al.,* 1982). In rabbits, coprophagy may also result in higher levels of brodifacoum in the alimentary tract, over longer periods, than has been observed for rodents. The bait consumption rate and number eaten before death, plus residue levels in poisoned rabbits, indicates that the brodifacoum concentration in baits (50 ppm) could be reduced substantially.

This conclusion is supported by a vole *(Microtus pinetorum* and *M. pennsylvanicus)* study which indicated that control was effective when bait concentrations were reduced by 80% (50 ppm to 10 ppm), bait application rates halved (45.9 kg/ha to 22.9 kg/ha) and the amount of bodifacoum per hectare reduced by 90% (2295 mg/ha to 229 mg/ha) (Merson *et al.,* 1984). Whole carcass residues were directly related to brodifacoum application rates, being similarly reduced by 90% (4.07 ppm to 0.35 ppm). Another study (Byers and Merson, 1982) indicated that good vole control was possible with rates as low as 56 mg/ha. In the current study, rates ranged from 60-200 mg/ha dependent on the number of baits laid in relation to rabbit density. Provided bait numbers are adequate it appears these rates of active ingredient per ha could be reduced. Although rabbits can ingest a lethal dose of brodifacoum in one night it is evident from these field trials, and previous laboratory studies, that feeding will continue for an additional one to two nights. This delayed effect of brodifacoum, which in common with all anticoagulants obviates the need for pre-baiting, means the evolution of a brodifacoum baiting strategy should be towards more, possibly smaller, low-toxicity baits rather than the reverse.

The relationships between the amount of anticoagulant per hectare and per target animal, residues, and non-target risks have not been previously investigated for lagomorphs. Crosbie *et a1.,* (1986) laid two applications of 100 ppm brodifacoum jam baits in a dense rabbit population, resulting in 1300 mg of brodifacoum/ha. In Western Australia pindone has been laid at rates of 5950 to 15,800 mg/km (Oliver *et a1.,* 1982) while diphacinone in bait boxes has been used at 68 mg/ha on jackrabbits in California (Johnston, 1978). All these studies effectively involved saturation baiting and, as no carcass residue studies were carried out, the potential for secondary poisoning was not assessed.

Target and non-target mortalities and risks

The death of most rabbits within burrows or under scrub cover should reduce the risk of secondary poisoning to aerial predators. Only two harriers and two gulls were known to have been poisoned. However, mammalian predators or scavengers such as cats and ferrets can clearly find dead or dying rabbits regardless of location. The two cats and a ferret known to have been killed by brodifacoum during this study (Rammell *et a1.,* 1984) had probably fed on dead or dying rabbits for several weeks. During the trial period at Barrhill and Lake Heron sites the weather was very cold with frosts at night. Rabbit carcasses were therefore slow to decompose. The first cat death occurred 30 days after poison application, indicating that there may have been an extended period of feeding.

The death of four sheep that were accidentally left on the Lake Heron trial area was due to direct consumption of baits. The significant feature of these deaths is that they indicate the sheep LD50 may be lower under arduous field conditions than those derived from laboratory studies. The LD50 for sheep is approximately 11 mg/kg, although deaths have occurred at rates as low as 3.13 mg/kg (Godfrey *et. a1.,* 1985). For the sheep killed at Lake Heron to have ingested only the LD50 level would have necessitated consumption of 10,000 baits (for each 40 kg sheep) or all bait laid on 6.5 hectares. Even at the lowest levels at which deaths have been recorded (3.13 mg/kg), 3130 baits had to be eaten. This number (the total off 2 ha) would have been difficult for the sheep to locate.

The risks to domestic livestock can usually be avoided by removal from treatment areas and a suitable post-poison withholding period. However, carcass contamination by consumption of sublethal quantities of residual baits could still occur. These risks can be substantially reduced by the matching of bait application rates to rabbit densities as discussed above, plus rapid leaching of poison from baits and general bait disintegration. The bait formulation used in these trials was designed to withstand 100 mm of rain before disintegration. Leaching studies (Rammell *et a1.,* 1984) indicate that, prior to collapse, brodifacoum is steadily removed with 80% being lost after 94 mm rain in five falls over 66 days and 60% of this in the first 20 days. Disintegration of baits removes virtually all risk to livestock, so baits with a much shorter field life would be of obvious value as an adjunct to bait application rates that ensure most baits are eaten before death.

The risk of accidentally poisoning domestic dogs during rabbit control operations with brodifacoum, appears to be considerably less than when 1080 is used. The LD50 of dogs to brodifacoum is much higher than to 1080 (Godfrey *et a1.,* 1981b) and an antidote (Vitamin K1) that can be administered, even after poison symptoms appear, is available (Godfrey, pers. comm.). No dogs were poisoned during these trials although one was observed to eat baits.

The secondary poisoning hazards posed by anticoagulant control of commensal or agricultural rodents have been reviewed by Kaukeinen (1982). In comparison with many other pesticides, anticoagulants have caused very few non-target problems. However, globally there has been only limited use of second generation* anticoagulants for agricultural rodent control. Thus there has been little opportunity to assess risks. Laboratory studies on first generation + anticoagulants by Mendenhall and Pank (1980), and Townsend *et a1.,* (1981) indicated there was potential risk to avian predators such as the tawny owl *(Strix aluco)*. This potential does not appear to have been widely realised under field conditions. Twenty years' use of first generation anticoagulants for ground

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.*Anticoagulants that are effective acute and chronic poisons; the LD50's for single and multiple doses are usually similar.

+ Anticoagulants that are usually only effective as chronic poisons; the LD50's for multiple doses are very much lower than for single ones.

squirrel control in California has produced few reports of secondary poisoning (Clark, 1978) while an intensive study of the risks to barn owls *(Tyto alba)* of brodifacoum commensal rodent control around farm buildings, revealed no owl mortality due to the compound (Hegdal and Blaskiewicz, 1984). Another study, evaluating the avian predator risks of brodifacoum vole control in orchards, indicated that species such as the screech owl *(Otus asio),* which feed extensively on voles, could be killed during orchard control operations (Merson *et al.,* 1984). It is therefore evident that anticoagulants can cause some wildlife deaths. In New Zealand, harriers, cats and ferrets would appear to be at greatest risk when rabbits are poisoned with brodifacoum. The relevance of such mortality mostly relates to the part these species play in the natural regulation of rabbit populations. Cats are considered to play an important role in the regulation of rabbits in many situations (Gibb *et al.,* 1978) and therefore long-term reduction of this species is undesirable. Spotlight indices of cats and ferrets at the Scargill and Barrhill sites, despite the low numbers, do not indicate any short or long term changes in numbers that could be directly attributed to brodifacoum secondary poisoning. The number of cats sighted per night declined at all sites (including the nil treatment area at Scargill) in the 30 to 42 days post poison (Table 4). However, with the exception of the nil treatment area, rabbit numbers also declined dramatically, so there were fewer rabbits to hunt. During 1983 and 1984 cat numbers were probably strongly influenced by rabbit densities, since rabbits are known to be an important component of cat diets even in areas where they are relatively sparse (Fitzgerald and Karl, 1979).

Population Recovery - Post Poison

The post poison resurgence of a rabbit population is largely influenced by the reproductive rate of survivors, the rate of immigration into the poisoned area and the impact of natural mortality factors such as predation. Monitoring of rabbit numbers at Scargill and Barrhill sites was aimed at providing a broad indication of the rate at which brodifacoum poisoned populations recovered and, fortuitously, the opportunity to contrast with the effect of 1080 (Fig. 5). If rabbit predators had been decimated rather than simply forced to migrate due to loss of rabbits as prey, it could have been anticipated that populations would have responded much more rapidly than they did. In other studies where predators have been effectively removed, or excluded from an area, rabbit numbers have increased rapidly reaching high densities within 2 years of predator removal (Gibb *et al.,* 1978, Newsome, 1983). Only one sub-site, in the current study, had returned to its pre-poison level 2 years after poisoning and this "result" was almost certainly affected by scrub clearance in the study area. Population recovery at all other sites (brodifacoum and 1080) was similar and not markedly different from that observed in other comparable areas poisoned with 1080 as part of normal rabbit management.

It would therefore appear, based on known predator mortalities after poisoning, cat sightings and the rate of rabbit population recovery, that the overall predator/prey balance in the study areas was not seriously affected by the brodifacoum poisoning. However this conclusion is based on a single application at three sites. More frequent use of 50 ppm baits could have an effect on predator populations.

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