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# Population Reduction of Richardson's Ground Squirrels Using a Brodifacoum Bait

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ABSTRACT: On 6 study plots (3 treated and 3 control of 2.47. acres--1 ha), we evaluated the efficacy of a 50 ppm brodifacoum grain bait on Richardson's ground squirrels (spermophilus richardsonii Efficacy was measured by 3 methods: (1) radio-telemetry - 22 ground squirrels were live trapped on each treated plot and equipped with radio transmitters, (2) mark-recapture - by mark-recapture sampling methods and the computer program entitled CAPTURE, and (3) Tanaka's formula - by using only marked survivors retrapped posttreatment. Treatment began the day following the pretreatment trapping period by systematically baiting each burrow entrance with approximately 16-19 g of bait. Overall efficacy of brodifacoum when measured by radio-telemetry was 98.1$, by mark-recapture 96.8% (SE x,1.5%) and by T-naka's formula 99.1% (SE t 1.5%). Ground squirrels dying above ground varied between 18 and 64 among the 3 treated plots. The percentage of marked ground squirrels recovered dead above ground on the treated plots averaged 14.6% (range 6.8-24.5x). Non-target mortality on the treated plots included 3 vesper sparrows (Pooecetes gramineus and a white-tailed jackrabbit (L-enns t-ownsendi). Brodifacoum residues were 0.76 ppm for 1 vesper sparrow and at the level of detection (0.50 ppm) for the remaining vesper sparrows and the jackrabbit. The 50 ppm brodifacoum treatment tested on Richardson's ground squirrels showed greater efficacy with less variability than zinc phosphide in previous studies on the same species.

Most anticoagulant baits require multiple feedings by the target species before acquiring a lethal dose. Thus, their use has been primarily for control of commensal rodents whereas single dose (acute) toxicants have been relied upon for control of rangeland rodents. A newly developed anticoagulant rodenticide, brodifacoum, may effectively control both classes of rodents, because it acts as an acute toxicant, i.e., a single dose may be lethal (Dubock and Kaukeinen 1978).

Richardson's ground squirrels were selected as the target species for evaluating the single dose effect of brodifacoum. The LD50 of brodifacoum to this species is 0.13 mg/kg: 95% CL = 0.062 -0.188 mg/kg (Baril and Pallister 198 1

A 50 ppm brodifacoum-pelleted bait fed over a 3-day period killed all 10 test animals. This report describes a field test which determined ground squirrel mortality following 1 application of a 50 ppm brodifacoum grain bait.

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## PROCEDURE

We selected a study site at about 5000 feet (1.52 km) elevation in the Smith River Valley near White Sulphur Springs, Meagher County, Montana. Three treated and 3 control plots, each measuring 2.47 acres (1 ha), were established. Two of the 3 treated plots were in sagebrush-rangeland pastures and the third in an abandoned sanfoil pasture. One control plot was sited in each of 3 habitats: sage brush-rangeland pasture, abandoned sanfoil pasture, and a winter feed lot for cattle. To minimize posttreatment reinvasion by ground squirrels, a buffer strip of 820 feet (250 m) surrounded each treated plot, increasing the size of each plot, including buffer, to 104.4 acres (42.3 ha).

### Radio-Telemetry

Radio-telemetry was used as an estimator of efficacy. On days 4 and 5 pretreatment, we equipped 66 ground squirrels (22 on each treated plot) with 164 MHz radio transmitters. Each radioed ground squirrel was eartagged, weighed, sexed, and released at point of capture. The position of each radioed ground squirrel was determined once daily and marked with a flag. Ground squirrels not moving posttreatment were assumed dead. Status was confirmed by excavating burrow systems and recovering radioed ground squirrels.

The following formula estimated efficacy:

$$\text{Efficacy No.} = \frac{\text{No. ground squirrels with functional radios on treatment day} - \text{No. of radio-equipped ground squirrels alive Posttreatment on treatment day}}{\text{No. ground squirrels with functional radios on treatment day}} \times 100$$

### Mark-recapture

We estimated pre- and posttreatment ground squirrel populations on all study plots by mark-recapture sampling methods. An 11 by 11 trap grid was staked at 32.8 feet (10 m) intervals, and 1 Tomahawk1 live trap (model 202) was placed at each intersection (121 traps per plot). Two days before the pre- and posttreatment trapping periods, we baited the traps with wheat and wired them open, allowing the squirrels free access. Pre-and posttreatment trapping periods were 5 days each (21-25 June and 8-1 4 July 1981 ), with 12 days between periods. Posttreatment trapping was staggered with 1 treated and 1 control plot started each day over a 3-day period. Each trapped ground squirrel was aged (juvenile or adult), sexed, tagged (Monel #1 fingerling) in each ear, and marked with a leather polish dye in a specified location to prevent duplicate handling on any 1 day. Traps were checked each morning and evening, and closed at midday to prevent heat stress in the target population.

1Reference to trade names does not imply government endorsement.

Population Reduction

We estimated pre- and posttreatment populations for each plot, excluding the buffer zone, using techniques described by Otis et al. (1978). We selected their jackknife estimator, (model Mh), because previous analysis of similar ground squirrel trapping data showed this model to be appropriate (Matschke et al. 1982). Population estimates were obtained with the computer program CAPTURE (White et al. 1978). An analysis of variance, involving a two-way layout with repeated measures, tested treatment by time interaction, i.e., whether changes in pre- and posttreatment population sizes on treated plots were related to **treatment rather** than natural changes during the experiment. If no pre- and posttreatment differences occurred among control plots, we estimated population reduction for each treated plot by the following formula:

$$\text{\$ Population reduction} = \frac{\text{Pretreatment population} - \text{Posttreatment population}}{\text{Pretreatment population estimate}} \text{ estimate- a timate} \quad K\ 100$$

We derived a second population reduction estimate with Tanaka's (1976) formula, using only marked survivors retrapped posttreatment.

$$\text{Population reduction} = 1 - \frac{\text{Number marked pretreatment and captured posttreatment}}{\text{Number marked pretreatment (1-(1-pM}} \quad X\ 100$$

where p estimates the average probability of capturing a ground squirrel on 1 of t pretrapping trapping occasions (provided by computer program CAPTURE).

oral a tion

A grain bait treated with 50 ppm brodifacoum (3-[3-(4'-Bromo [1,1'-biphenyl) -4-y1)-1,2,3,4-tetrahydro-l-naphthalenyl]-4-hydroxy-2H-1-benzopyran-2-one) was formulated for this study by ICI Americas, Inc., Goldboro, North Carolina. Technical brodifacoum (92.5% purity), various adhesives, and a green dye bird repellent (Pank 1976), were mixed to form a concentrate consisting of 0.25 g brodifacoum per kg of inert ingredients. The concentrate was sprayed onto slightly crimped oat groats to formulate a 0.005% (50 ppm) bait. Bait for control plots was formulated as above, excluding brodifacoum.

Treatment

Following pretreatment trapping, we randomly assigned treatments to plots and baited 1 treated and control plot and adjacent buffers daily for 3 days. Baiting began each morning at approximately 0630 on a treated plot followed by a control plot.

All burrow entrances on each plot were systematically baited (a heaping tablespoon of 16-19 g) by 6 people walking parallel back and forth across the plot and buffer. The application rate varied with the density of ground squirrels. To prevent overlapping or skips during treatment, the lead applicator placed flags to separate baited from unbaited areas.

Date of treatment and bait application rate per study plot were as follows:

| Plot No. | Date of Treatment | Lbs of Bait Applied | (lbs/ac) | kg/ha |
|---|---|---|---|---|
| 29T | 27 June 1981 | 163.0 | 1.56 | 1.75 |
| 30T | 29 June 1981 | 249.0 | 2.38 | 2.67 |
| 33T | 28 June 1981 | 175.0 | 1.12 | 1.26 |
| 28C | 27 June 1981 | 143.5 | 1.37 | 1.54 |
| 31C | 29 June 1981 | 117.4 | 1.68 | 1.88 |
| 3 2C | 28 June 1981 | 41 .3 | 0.40 | 0.45 |

]tee ther

No rain fell during the 3 baiting days, 27, 28, and 29 June, and maximum temperatures were 73, 65, and 770 F, respectively. Minimum temperatures for the same 3 days were 50, 40, and 400 F, respectively. Posttreatment, a trace of rain occurred on 1 July, then no rain fell for 5 days. On 7 and 8 July, 0.07 and 0.15 inch (0.18 and 0.38 cm) of rain fell. Maximum temperatures were in the mid-70's for 1-3 July, increased to 850 on 4 July, 930 on 5 July, then dropped to 770 on 5 July and 710 F on 6 July.

## Target and No target Mortality

We assessed mortality among target and nontarget animals for a 12-day period posttreatment. On days 2-3, we searched the trap grids on the treated plots in late afternoon after ground squirrel activity ceased for the day. On days 4-12, we systematically searched all trap grids, and as time permitted, the buffer zones. All radio-equipped ground squirrels and non-target animals found dead were frozen for future residue analysis. A sample of non-radioed ground squirrel carcasses also were collected and frozen for analysis. All carcasses not saved for residue analysis were buried on the study site.

# RESULTS

## Radio-transmitters

Efficacy of treatment estimated by radio-telemetry was 98.1$. Of 52 radio-equipped ground squirrels with functional transmitters at time of treatment, 1 survived and 51 died posttreatment. We lost contact with 13 radios before treatment and the fate of these ground squirrels remains unknown, as none were recovered dead or trapped during the posttreatment trapping period. One radio-equipped ground squirrel was killed by an avian predator posttreatment, but the carcass could not be analyzed for brodifacoum.

Of the dead 51 radioed ground squirrels, 22 (43.1$) were recovered on the surface, 19 (37.3$) in burrow systems, and 10 (19.6%) in nests. Ground squirrels

dying in the burrow systems were recovered at depths ranging from 5 to 52 inches (13 to 132 em) averaging 31.9 inches (81.0 em) (SE ± 3.1 inches, 7.9 em). Ground squirrels dying in their nests were recovered at depths from 38 to 64 inches (97 to 163 em) averaging 50.0 inches (127.0 em) (SE f 2.5 inches, 6.4 em).

Pretreatment Trapping

Ground squirrel capture rates were sufficiently high to support the use of computer program CAPTURE to calculate a population **estimate and standard error for** each plot (Table 1). During the **pretreatment trapping period, we caught, marked,** and released 796 ground squirrels (432 adults and 364 juveniles), 424 and 372 on the treated and control plots, respectively. Initial captures were highest on day 1 (359), then decreased daily until day 5 (72) (Table 2). Conversely, recaptures increased daily from day 2 (219) through day 5 (369). We captured 544 (68.3%) ground squirrels more than once and 252 (31.7%) only once.

postreatment Trapp

Only on the control plots were ground squirrel capture rates sufficiently high (327) to allow use of computer program CAPTURE to calculate a population estimate and standard error (Table 1). On treated plots, the actual number of ground squirrels trapped per plot served as the population estimate; only 18 ground squirrels (2 adults and 16 juveniles) were trapped posttreatment (Table 1). On the 3 control plots, initial captures were highest on day 1 (168) and decreased to 30 on day 5 (Table 3). Recaptures increased daily from 96 ground squirrels on day 2 to 149 ground squirrels on day 5.

Treatment by T me ' interaction

Average pre- and posttreatment population estimates show a slight decline in control plots and a steep decline in treated plots. This indicates that changes in population size on treated plots differed from those on control plots and the statistical test for significance of this interaction resulted in p = 0.029. We believe this test provides strong evidence that treatment significantly affected population levels.

ked Ground Squirrels Surviving Treatment

Only 2 (o.47%) of 424 ground squirrels marked pretreatment on the 3 treated plots were recaptured posttreatment (Table 4). Both ground squirrels (an adult female and a juvenile male) were retrapped on plot 29, both were caught on days 1 and 2 posttreatment, and 1 was retrapped on day 4 posttreatment. On the 3 control plots, 263 (63.7%) of 372 ground squirrels marked pretreatment were recaptured posttreatment.

Ef f_icacy of Treatment (Mark-Recapture

A. Mark-Recapture Formula

No significant difference existed between pre- and posttreatment population levels on the control plots (paired t2=1.26, d.f.=2, p=0.33). Therefore, estimates of efficacy on the treated plots were not adjusted for changes in population size pre- and posttreatment. Efficacy for treated plots 29, 30, and 33 was 94.1, 97.2, and 99.2%, respectively, for a mean reduction of 96.8% (SE
1.5%).

TABLE 1. Pre- and posttreatment population estimates of Richardson's ground squirrels generated by program CAPTURE (White et al. 1978).

| Treated Plots | Total N Trapped Pretreatment | Pretreatment Population Estimate (SE) | Total N Trapped Posttreatment | Posttreatment Population |
|---|---|---|---|---|
| 29 | 151 | 205 (14.3) | 12 | 12 |
| 30 | 97 | 145 (12.7) | 4 | 4 |
| 33 | 176 | 272 (19.6) | 2 | 2 |

| Control Plots | Total N Trapped pretreatment | Pretreatment Population Estimate (SE) | Total N Trapped Posttreatment | Posttreatment Population Estimate (SE) |
|---|---|---|---|---|
| 28 | 153 | 183 ( 7.3) | 127 | 144 ( 5.4) |
| 31 | 87 | 137 (13.5) | 72 | 107 (10.4) |
| 32 | 132 | 164 ( 7.5) | 128 | 173 (10.8) |

*Table 2. Initial captures and recaptures of Richardson's ground squirrels during the 5-day pretreatment trapping period*

| Treated Plots | Day 1 IC | Day 1 RC | Day 2 IC | Day 2 RC | Day 3 IC | Day 3 RC | Day 4 IC | Day 4 RC | Day 5 IC | Day 5 RC | Total IC | Total RC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 82 | 0 | 24 | 65 | 20 | 80 | 11 | 90 | 14 | 78 | 151 | 313 |
| 30 | 36 | 0 | 25 | 26 | 17 | 35 | 11 | 40 | 8 | 44 | 97 | 145 |
| 33 | 80 | 0 | 28 | 37 | 23 | 45 | 25 | 72 | 20 | 75 | 176 | 229 |
| Subtotal | 198 | 0 | 77 | 128 | 60 | 160 | 47 | 202 | 42 | 197 | 424 | 687 |
| Control Plots | Day 1 M | Day 1 IC | Day 2 IQ | Day 2 BSc | Day 3 IC | Day 3 RC | Day 4 IC | Day 4 IQ | Day 5 IC | Day 5 RC | Total IC | Total RC |
| 28 | 75 | 0 | 30 | 34 | 27 | 66 | 13 | 77 | 8 | 80 | 153 | 257 |
| 31 | 28 | 0 | 20 | 24 | 13 | 34 | 12 | 34 | 14 | 38 | 87 | 130 |
| 32 | 58 | 0 | 28 | 33 | 19 | 48 | 19 | 51 | 8 | 54 | 132 | 186 |
| Subtotal | 161 | 0 | 78 | 91 | 59 | 148 | 44 | 162 | 30 | 172 | 372 | 573 |

IC = Initial Capture
RC = Recapture

TABLE 3. *Initial captures and recaptures of Richardson's ground squirrels during the 5-day posttreatment trapping period.*

| Treated Plots | Day 2 M-1 | Day 2 U-L | Dar 3 ITS. | Dar 3 BSc | Day 4 IM | Day 4 M | Day 5 IC | Day 5 M | Total ITS- | Total RC | Total IC | Total M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 2 | 0 | 0 | 2 | 4 | 0 | 4 | 1 | 2 | 3 | 12 | 6 |
| 30 | 0 | 0 | 1 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 4 | 0 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0 |
| Subtotal | 2 | 0 | 1 | 2 | 5 | 0 | 6 | 1 | 4 | 3 | 18 | 6 |

| Control Plots | Day 1 IQ. | Day 1 8a | Day 2 IS | Day 2 M | Day I IC | Day I RC | Day 4 1. | Day 4 9- | Day 5 M | Day 5 IC | Total M | Total Jr. | Total M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | 79 | 0 | 18 | 52 | 18 | 66 | 5 | 75 | 7 | 67 | 127 | 260 | |
| 31 | 36 | 0 | 6 | 17 | 7 | 25 | 10 | 31 | 13 | 35 | 72 | 108 | |
| 32 | 53 | 0 | 30 | 27 | 23 | .33 | 12 | 43 | 10 | 47 | 128 | 150 | |
| Subtotal | 168 | 0 | 54 | 96 | 48 | 124 | 27 | 149 | 30 | 149 | 327 | 518 | |

RC = Initial Capture
RC = Recapture

TABLE 4. Date of initial recapture during posttreatment trapping period for squirrels marked pretreatment.

| Treated of | Day 1 | Day 2 | Dar 3 | Day 4 | Dar 5 | Total |
|---|---|---|---|---|---|---|
| 29 | 2 | - | _ | - | - | 2 |
| 30 | - | - | _ | - | - | 0 |
| 33 | - | - | - | - | - | a |
| Subtotal | 2 | - | - | - | - | 2 |

| Control Plot | Day 1 | Day 2 | Day 3 | Day 4 | ply 5 | Total |
|---|---|---|---|---|---|---|
| 28 | 70 | 13 | 17 | 2 | 4 | 106 |
| 31 | 28 | 5 | 5 | 3 | 4 | 45 |
| 32 | 45 | 16 | 9 | 9 | 6 | 85 |
| Subtotal | 143 | 34 | 31 | 14 | 14 | 236 |

B. Tanaka's Formula

Using ground squirrels marked pretreatment that were recaptured posttreatment, Tanaka's formula yielded an estimated efficacy estimate for treated plots 29, 30, and 33 of 97.2, 100.0, and 100.0%, respectively, for an overall mean of 99.1% (SE t 1.5%).

Bait Consumption

Consumption of bait was not uniform among the treated plots. The bait disappeared within 3 and 4 days posttreatment on plots 33 and 29, respectively but the bait remained on plot 30 until we terminated the study 20 days posttreatment. Many of these bait spots appeared untouched. Evidently, the density of ground squirrel burrows was high, but ground squirrel numbers were low.

_; round Squirrel_ Mortality

Ground squirrel mortality was first observed on day 3 and last recorded on day 14 posttreatment. However, the total number of days in which mortality occurred varied among the 3 plots. Dead ground squirrels were first observed on day 3 (plot 33), and on days 4 and 5 (plots 29 and 30), respectively. Mortality terminated on days 7 and 8 (plots 30 and 33), respectively, and on day 14 (plot 29). On plot 29, 96% of the ground squirrels found dead had died by day 7 posttreatment.

Of the total marked ground squirrels on the treated plots, 62 (14.6%) died on the surface. The number and percentage of marked ground squirrels dying above ground on the treated plots were 37 (24.5%), 13 (13.4%), and 12 (6.8%) for plots 29, 30, and 33, respectively. Plot 29 also had the highest number of untagged ground squirrels (27) dead on the surface, followed by plot 33 (10), and plot 30 (5).

Whole body residue values for the 48 radioed ground squirrels analyzed for brodifacoum ranged from 0.50 (detection limit) to 2.48 ppm The mean value was 1.40 ppm (SE t 0.08 ppm). Residue values for the 36 non-radioed ground squirrels found dead either on the treated plots or buffers ranged from 0.50 to 2.41 ppm. Mean value was 1.36 ppm (SE ± 0.10 ppm).

During 23.5 hours of carcass searching, excluding time spent radio-tracking, we located 3 dead vesper sparrows and 1 white-tailed jackrabbit. Brodifacoum residues were 0.76 ppm for 1 vesper sparrow and 0.50 ppm for each of the remaining vesper sparrows and the white-tailed jackrabbit.

DISCUSSION

Greater efficacy (96.8%) and less variation between plots (SE ±. 1.5%) was observed with brodifacoum than with acute toxicants. For example, in 3 hand-baiting studies using 2.0% zinc phosphide to control Richardson's ground squirrels, the efficacy and standard error were 59.5% ± 14.6%, 95.0% ±_ 2.7%, and 69.8% t 4.9% (Matschke et al. 1979, Matschke et al. 1982). When a 2.0% zinc phosphide grain bait was broadcasted against the same species, efficacy was 85.1% (SE :L 6.4%) (Matschke et al. 1983). In all studies, efficacy was measured by mark-recapture. The efficacy of a 0.50% strychnine bait applied by hand to control Richardson's ground squirrels measured by the closed-hole technique was

32.8% (SE ± 1 3.2%) (Hegdal and Gatz 1 977) . The efficacy of 0.1 2596 sodium monofluoroacetate (1080) bait aerially broadcast to control California ground squirrels (,-. bgtgehevi) was 71.7% (SE t 4.76$) measured by the closed-hole technique (Hegdal et al. 1978).

Hibernation behavior characterized by reduced time above ground and reduced feeding (Fagerstone 1982) may have prevented the sole surviving, radio-equipped ground squirrel from being exposed to the bait. When initially trapped, this male weighed 600 g, indicative of approaching hibernation. Posttreatment radio tracking recorded him in the same underground location, except for a single surface observation on day 7 posttreatment. We failed to catch him during the posttreatment trapping period when traps were placed at burrow entrances surrounding his location.

The 14-day interval between bait application and posttreatment trapping was sufficient to allow ground squirrels to reinvade the buffers and move onto the trapping grids. The posttreatment data suggest that all unmarked, ground squirrels on the treated plots were immigrants. Of the 16 untagged ground squirrels trapped posttreatment on the treated plots, 15 were taken near the edge of the buffer area. More juveniles (14) than adults (2), and more males (11) then females (5) were trapped, indicative of immigrant animals (Yeaton 1972, Michener and Michener 1977). Also, the first untagged ground squirrel was not trapped until day 2 of the posttreatment trapping period, then on days 3, 4, and 5 we trapped 5, 6, and 4 untagged ground squirrels, respectively. In future studies with slow-acting anticoagulant baits and mark-recapture procedures, buffer widths should be increased another 50 m.

The detection level for brodifacoum residues in ground squirrels was 0.50 ppm, a value approximately 4 times the LD50 (0.13 mg/kg) for Richardson's ground squirrels. Theoretically, ground squirrels could consume a lethal dose that would be below the level of detectability. This may have been the case with the 2 radioed ground squirrels with residue levels of 0.50 ppm. We suspect their mortality was treatment-related despite the low residue level. In a previous movement study, no transmitter-related mortality occurred among 60 radio-equipped ground squirrels for 2 months (Fagerstone 1982). To assist in interpreting treatment mortality in future studies, fluorescent dyes or marking agents should be added to the bait to determine if dead animals consumed bait.

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