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Short communication

Potential non-target risks from strychnine-containing rodent carcasses

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Abstract

Underground strychnine baiting is a common technique used to suppress pocket gopher (*Thomomys* sp.) populations until seedlings are established. Non-target risks from underground baiting can still occur if strychnine-baited animals die aboveground. Accordingly, the fate of strychnine-baited carcasses of four small mammal species, *Thomomys*, *Mus*, *Microtus*, and *Peromyscus*, were documented during four trials on the Rogue River National Forest. We found no difference among species and type of damage, either insect or predator, during the four trials. However, survival differed between species in two trials where fewer *Thomomys* carcasses survived until completion of the study. We also examined the risk to tertiary non-targets from insects collected at the sites. Strychnine concentration among insect groups from treated carcasses differed with Diptera larvae and ants consistently containing higher concentrations. Even with high strychnine concentrations (0.2756 μg/g), risk assessments showed negligible tertiary risks from consuming strychnine-laced insects.

Keywords: Insect; Non-target; Pocket gopher; Scavenging; Strychnine; Tertiary risk; *Thomomys*

1. Introduction

Named for their external, fur-lined cheek pouches, pocket gophers (*Thomomys* spp.) are pest species which can cause damage to both agriculture and timber crops year-round. Pocket gophers occupy a wide variety of habitats, although early successional forests are preferred, and are adaptable to conditions of disturbance caused by agriculture and logging activities (Marsh and Steele, 1992). In newly planted units, pocket gophers prune roots of seedlings and girdle or clip seedling stems (Capp, 1976; Crouch, 1986; Marsh and Steele, 1992). Therefore, efforts to establish tree seedlings on sites with high populations of pocket gopher can be futile unless protective measures are implemented.

Management practices implemented to reduce pocket gopher damage include silvicultural practices, such as planting immediately after harvesting, selective cutting, or minimizing disturbance of a site after logging (Crouch, 1986; Marsh and Steele, 1992); trapping (Crouch and Frank, 1979); fumigation (Sullius and Sullivan, 1993); habitat manipulation such as herbicide treatments (Hansen and Ward, 1966); physical exclusion devices (Hooven, 1971); or repellents (Sullivan, 1987; Sullivan et al., 1990). Most of these methods are expensive, slow and difficult to implement, and are

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often ineffective at reducing damage (Marsh and Steele, 1992). Accordingly, strychnine baiting is widely used to reduce pocket gopher populations in areas of reforestation (Chase et al., 1982; Marsh and Steele, 1992).

Although strychnine baits are placed underground in gopher burrow systems to maximize efficacy and reduce the risks to non-target species, some hazards to non-targets still remain (El Hani et al., 2002). Primary exposure to the bait may occur from species that use pocket gopher burrows, although exposure will vary by species, season, and habitat type (Fagerstone et al., 1980). Another risk associated with the use of underground strychnine bait is that pocket gophers, or other small mammals using pocket gopher burrows, may consume the bait and die aboveground. These carcasses are then available to a wide variety of avian and mammalian scavengers as well as decomposers. Strychnine is a fast-acting toxin that is not readily assimilated into tissue or bone (Savarie, 1991). Although some residues may be found in the body, the majority of strychnine residues in carcasses are usually found in the gastrointestinal tract (GI) and in bait stored in cheek pouches (Hegdal and Gatz, 1976; Anthony et al., 1984). The duration of the risk posed by poisoned carcasses depends on carcass scavenging rates and factors which impact decay rates including temperature, humidity, and insect activity (Sullivan, 1988; Tobin and Dolbeer, 1990). Thus, the potential effect of strychnine baiting on non-targets will vary among sites (Fagerstone et al., 1980). Tertiary risks may also occur from insects feeding on the strychnine-baited carcasses. Some insects appear to be relatively unaffected by strychnine, whereas strychnine administered orally to ants (0.1–0.5 mg/kg) results in impaired motor coordination but no mortality (Kostowski et al., 1965). Therefore, insects that feed on poisoned carcasses may retain strychnine concentrations and could pose a risk to insectivore species.

In this study, we evaluated the fate of aboveground small mammal carcasses at the Rogue River National Forest, Oregon, during the late summer—early fall when strychnine baiting normally occurs. In addition, we conducted chemical assays on insects that consumed strychnine-poisoned pocket gopher carcasses to determine potential hazards to insectivores.

2. Methods

2.1. Carcass fate

This study was conducted at four sites on the Rogue River National Forest in Oregon. Sites were representative of recent reforestation areas that are normally targeted for pocket gopher population reduction. The fate of aboveground carcasses was assessed on three dates in 1998; 24–28 August (trial 1), 15–19 September (trial 2), and 29 September–3 October (trial 3). Yellow jackets or vespid wasps (*Vespula* sp.) and hornets (*Dolichovespula maculate*) were rare in 1998 and previous studies suggest that they can have an impact on carcass decay rates; therefore, an additional test was conducted on 1–5 September 1999 (trial 4) in an effort to determine decay rates with a higher density of yellow jackets.

Pocket gopher carcasses (untreated) used in 1998 were obtained from trapping for damage management on the Rogue River National Forest. Gopher carcasses used in 1999 were obtained from a site in Olympia, Washington. In addition to pocket gophers, we examined the carcass fate of untreated house mice (*Mus musculus*), deer mice (*Peromyscus maniculatus*), and voles (*Microtus ochrogaster*) obtained from the Olympia Field Station, Washington. Three individuals of each available species were randomly placed at each of the four sites and spaced $\geqslant 50$ m apart. *Microtus* were not tested in trial 1 nor *Mus* in trial 4. Each carcass was secured in place by inserting the bottom of a wire flag through the hip area and into the ground. Carcass status and the presence of scavengers was recorded and photographed every 2 h for the first 10 h. Subsequently, the records and photographs were collected in the morning and evening each day for 4 days. Carcass damage was classified as being: (1) no damage; (2) slight tissue damage (ears, mouth, tail, legs); (3) minor damage—most ($>75\%$) of digestive tract and cheek pouches (for pocket gopher) still in tact; (4) moderate damage—medium holes, carcass still recognizable, 25–75% of digestive tract or cheek pouches remain; (5) heavy damage—heavy damage to carcass, but some portion of digestive tract or cheek pouches remain; (6) heavy damage—large holes, all of digestive tract and cheek pouches gone; (7) severe damage—only bits of skin and bone remain; (8) carcass gone from insect or decay; (9) damaged by scavengers; or (10) consumed by scavenger. Carcasses were considered damaged by scavengers when a large portion of the body (often the front half) was taken during one interval, when the remaining portion of the carcass was severely damaged, when portions of tissue were found on the flagging (the carcass was pulled off the stake) or when the flag was pulled out of the ground. Based on other research conducted to assess weasel caching behavior, we feel that the rate of carcass consumption by predators was similar between baited and non-baited carcasses.

The portion of carcasses posing a risk to non-target scavengers and insectivores was evaluated by comparing animals with categories 3–8 damage scores (insect damage) to animals in categories 9 and 10 (scavenger damage). Damage in category 2 was often hard to assign to predation or insect damage categories. We used a three-dimensional contingency table to test carcasses disappearance from scavengers versus insects for four species and four trials. In addition, a Kaplan–Meier survival analysis was performed for each trial to compare survivability distribution functions among species using the Wilcoxon test of equality (SAS® Version 8.0, SAS institute Inc., Cary, N.C.).

2.2. Insect strychnine residue analysis

We collected insects to determine strychnine concentrations from the same sites that were used in the carcass fate study from 24 to 28 August 1999. Five strychnine-baited and five unbaited pocket gopher carcasses were placed within insect traps. Strychnine-baited carcasses were recovered from animals that were baited with strychnine-treated oats and subsequently died. Traps were placed in the clear cuts at 0900 h and retrieved at approximately 1600 h each day. At the end of the day, insects within traps were removed, stored in clear plastic bags, and packed in ice. At the end of the study, any larvae in the remaining portions of the carcasses were removed and frozen. Insects were sorted by plots, treatment (strychnine baited or control), day of collection, and taxonomic order. Strychnine was extracted from composite insect samples following methodology from Stahl et al. (2004). To determine if differences in strychnine levels occurred among plot, treatment, and species, we used a multiple ANOVA with a least significant difference test for multiple comparisons to test means between species. Differences in strychnine levels between control plots and treatment plots were examined using a *t*-test ($P<0.05$).

For the tertiary risk characterization, the most sensitive bird (house sparrow—*Passer domesticus*), rodent (house mouse—*Mus musculus*), and reptile (bullfrog—*Rana catesbeiana*) species were selected. We used the 95th percentile of the strychnine residues (0.2756 μg/g) obtained from the insect strychnine residue analyses to estimate strychnine ingestion. The 95th percentile is a conservative number used in risk calculations since it is unreasonable to assume that predators will obtain 100% of the toxicant and that using an average number will not adequately protect all species. To calculate worse case scenario, we assumed that the species' diet for a single day consisted entirely of insects with strychnine concentrations of 0.2756 μg/g. For both terrestrial species, the acceptable risk quotients, based on amount of toxicant consumed per daily dietary requirement, determined by EPA are <0.1 (Sample and Sutter, 1997), and for aquatic species, 0.05 (Urban et al., 1998).

3. Results

3.1. Carcass fate

Microtus were not tested in trial 1 nor *Mus* in trial 4, which therefore violated the assumptions of the Chi-square because of zero data. We, therefore, used data from trials 2 and 3 when all species were available to test for differences between scavenging damage and insect damage. We found no difference in the number of carcasses scavenged versus damaged by insects ($\chi^2 = 6.17$, df = 10, $P = 0.8$). Trials were mutually independent of species and type of damage. Survivability differed between species in trial 1 ($\chi^2 = 6.63$, df = 2, $P = 0.03$) and trial 3 ($\chi^2 = 8.18$, df = 2, $P = 0.04$) but not in the other two trials. In both trials 1 and 2, fewer *Thomomys* carcasses remained at the end of the study than the other species.

3.2. Insect strychnine residue analysis

We divided insects into seven general categories: Diptera adults (flies), Diptera larva, Hymenoptera–Formicidae (ants), Hymenoptera–Vespoidae (hornets and yellow jackets), Hymenoptera–other, Coleoptera (beetles), and other species. Insects included in the "other" category included Lepidoptera ($n = 4$), Hemiptera ($n = 1$), and Orthoptera ($n = 1$). We detected a difference in strychnine concentrations between treatments ($F_{58,84} = 5.03$, $P<0.0001$) with plot and species contributing to the model. Treatment effects and all interactions with treatments were also significant, but this can be explained by the absence of strychnine, except for one instance, in insects from control plots. In one control sample, a moth was found to have detectable strychnine concentrations (0.501 μg/g). We are unsure if this anomaly is due to methodology, lab error, or the possibility that the moth fed on other strychnine-carcasses prior to capture (Stahl et al., 2004). Insects from control carcasses contained less strychnine residues (0.008 ± 0.007 μg/g SE) than insects from strychnine-treated carcasses (0.053 ± 0.014 μg/g SE; $t = -2.72$, $P = 0.007$). Strychnine concentration among insect groups from the treated plots differed ($F_{6,84} = 12.36$, $P<0.0001$). Diptera larvae contained higher concentrations of strychnine (0.37 ± 0.12 μg/g SE) than the other six groups. In addition, Formicidae (ants) also had greater concentrations of strychnine (0.19 ± 0.05 μg/g SE) than Vespidae (0.03 ± 0.02 μg/g SE), adult Diptera (0.14 ± 0.07 μg/g SE), and Coleoptera. The interaction between species and plots ($F_{23,84} = 2.84$, $P = 0.0003$) in the model was significant. We therefore used a least-means squared multiple comparison with a Bonferroni adjustment (Rice, 1989) to test for differences in strychnine concentrations in this species by plot interaction. Strychnine concentrations in Diptera larvae were higher in plot 4 than the other plots as well as between other insect species within plot 4. Concentrations in ants was similar between most of the plots except between plots 1 (0.115 μg/g) and 5 (0.012 μg/g). Although strychnine residues were detected in some insect species, risk quotients for all three species

Table 1
Strychnine risk assessment for three sensitive species based on strychnine-collected insects from the Rogue River national Forest, Oregon

Common name (species)	Ingestion rate (g food/g bodyweight/day)	Strychnine ingestion (μg strychnine/g bodyweight day)	LD_{50} (mg/kg)	Risk quotient
House sparrow *(Passer domesticus)*	0.975[a]	0.2689	4.2[d]	0.064
House mouse (*Mus musculus*)	0.150[b]	0.0413	2.0[e]	0.021
Bullfrog (*Rana catesbeiana*)	0.070[c]	0.019	2.2[f]	0.009

[a]House sparrow ingestion rate extrapolated from passerine insectivore marsh wren (*Cistothorus palustris)*, US EPA, 1993.
[b]Johnston et al., 1999.
[c]Culley, 1992.
[d,f]Hudson et al., 1984.
[e]Lewis, 1996.

(bird, amphibian, mammal) tested fell below the EPA established threshold determined to pose a risk (Table 1).

4. Discussion

Pocket gophers very rarely die above ground (Barnes et al., 1985; Evans et al., 1990; El Hani et al., 2002); however, other primary exposed non-target small mammals may die above ground, thereby increasing the likelihood of secondary hazards. Previous studies have documented non-target kills by pocket gopher strychnine baiting (Fagerstone et al., 1980; El Hani et al., 2002). Carcass searches conducted during field tests of underground strychnine baiting to control pocket gophers have revealed strychnine-containing carcasses from a variety of species including field mice, golden-mantled ground squirrel (*Spermophilis tridecimlineatus*), yellow pine chipmunk (*Tamis amoenus*), and western harvest mice (*Reithrodontomys megalotis*) (Fagerstone et al., 1980; Anthony et al., 1984; Evans et al., 1990). Fagerstone et al. (1980) documented 0.29 ppm of strychnine in the body tissue of chipmunks and 0.1 ppm in the GI during a test of underground baiting for pocket gophers. In addition, strychnine residues were detected in two deer mice. One contained 2.6 ppm strychnine in the tissue and 36 ppm in the GI and the other contained 5.4 and 18 ppm, respectively. Small mammal populations were not adversely affected (Fagerstone et al., 1980); however, carcasses may remain available for secondary and tertiary consumers.

Scavenging can play an important role in carcass disappearance (Sullivan, 1988; Tobin and Dolbeer, 1990; Linz et al., 1991). However, the risk to scavengers is dependent upon several factors: (1) availability of carcasses; (2) carcass longevity; (3) type of rodenticide used; (4) ability of scavenger to locate carcasses before degradation; (5) the rate of rodenticide degradation; and (6) ability of the scavenger to detoxify the rodenticide and their sensitivity to the toxin (adapted from Sullivan, 1988). Scavengers, both terrestrial and aerial, accounted for a large proportion of carcass disappearance in this study. Survivability differed between species, with the largest species, *Thomomys*, being removed more in half the trials. Larger carcasses are often easier to detect than smaller carcasses (Witmer et al., 1995), and scavengers usually will choose items with larger proportional intake compared to effort or risk. Although secondary risks have been shown to be minimal (Hegdal and Gatz, 1976; Anthony et al., 1984; Barnes et al., 1985), scavengers that cache large quantities of carcasses, especially if strychnine bait is present in the cheek pouch, may increase their exposure and risk.

Although scavenging played a large role in carcass disappearance, the possibility of secondary hazards first depends on the rate of disappearance of the carcasses by decomposers. Longevity for Columbian ground squirrel (*Spermophilus columbianus*) carcasses in Montana ranged from 1 to 8 days due to insect activity (Sullivan, 1988). Tobin and Dolbeer (1990) and Witmer et al. (1995) also documented the large role that insects played in degrading carcasses. Weather has a profound effect on insect activity, and hence carcass disappearance rate. Rapid decomposition by insects may reduce secondary hazards; however, no studies have documented the risks to insectivores.

Strychnine was neither an attractant nor repellent to insects in that similar numbers of insects were collected at both control and treated carcasses. Although strychnine levels in several insect species, especially Diptera larvae and ants, were easily detectable, and some concentrations high, our risk assessment did not suggest a significant risk to tertiary consumers. Even if their entire food intake for a day consisted of strychnine-laced insects, all three species assessed in the analysis were within acceptable levels of risk. For example, even if frogs consumed Diptera adults or flies with strychnine residues of 0.2756 μg/g (95th percentile from analysis) as their entire diet for one day, the risk quotient falls (0.009) well below the acceptable risk level (0.05). Therefore, we concluded that insect-mediated tertiary risks associated with underground strychnine baiting are negligible.

Strychnine baiting can be relatively effective at reducing pocket gopher populations even over large areas (Marsh and Steele, 1992). In addition, compared to other lethal and non-lethal methods currently available, baiting is the least cost-prohibitive. However, the potential for non-target problems associated with using an acute toxicant is a concern to most forest managers. Although pocket gophers die below ground, other primary non-targets may die above ground thus exposing scavengers to the toxicant. In this experiment, the rate of carcass disappearance by scavengers or by decomposers was similar, and scavengers were not "cuing" in on a readily available resources. In addition, our findings were consistent with other studies that documented the rapid degradation of carcasses from insect activity (Sullivan, 1988; Witmer et al., 1995). Risk quotients were well below the acceptable risk associated with insects feeding on carcasses. It appears from this study that scavenging risk and tertiary risks posed by pocket gopher carcasses are negligible as long as proper application and label directions are followed.

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