Final Report, QA-2146:

Identifying possible alternative rodenticide baits to replace strychnine baits for pocket gophers in California

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Rodents cause substantial damage to crops in California and rodenticides have been major tools for reducing that damage. While strychnine has been heavily relied upon to control pocket gophers in California, its future availability is in question because of increased import costs. We conducted efficacy trials with captive, wild-caught Botta's pocket gophers to identify potential alternative rodenticides to strychnine. The rodenticide baits tested included three categories: acute rodenticides, first generation anticoagulant rodenticides, and combination rodenticides (containing an acute toxicant and an anticoagulant). There was a wide range of efficacies (0-100%) with these rodenticides. The first generation anticoagulants performed poorly, while a distinct regional variation in efficacy occurred with the strychnine and zinc phosphide baits. The combination baits performed the best overall, averaging 90% efficacy. We also reported on the average bait consumption and day-to-death for the various rodenticides tested. We discussed the potential advantages of combination baits and especially the potential for lower concentrations of active ingredients. Finally, we recommend that a field trial be conducted to determine the efficacy of the combination baits to control pocket gophers.

Introduction

There are numerous species of pocket gophers in North America with most species belonging to the genera *Geomys* and *Thomomys* (Nowak 1991). Pocket gophers cause various types of damage to agricultural and rangeland resources and to reforestation (Witmer and Engeman 2007). Pocket gophers (*Thomomys* spp.) are generally considered one of the most damaging wildlife pests in California (Marsh 1992, Clark 1994). A recent study estimated average losses ranging from 5.3–8.8% across a variety of crops in CA (Baldwin et al. 2013), with one study showing a loss of 36.5% of annual production in alfalfa in fields with high density gopher populations (Smallwood and Geng 1997). The most widespread pocket gopher in California is the Botta's pocket gopher (*Thomomys bottae*; Case and Jasch 1994).

Primary control options for pocket gophers include trapping, burrow fumigation with aluminum phosphide, and baiting with rodenticides (Baldwin 2012, Baldwin 2014, Baroch and Poche 1985, Evans et al. 1990, Case and Jasch 1994, Witmer and Engeman 2007). Both trapping and burrow fumigation can be highly effective at controlling pocket gophers (Lewis and O'Brien 1990, Proulx 1997, Baker 2004), but are typically more time consuming and costly than baiting (Marsh 1992, Engeman and Witmer 2000). As such, baiting is often preferred by many growers, Pest Control Advisors, and Pest Control Operators. Three baits are used to control pocket gophers strychnine, zinc phosphide and first generation anticoagulants.

Strychnine is an acute toxicant that is widely used for controlling pocket gophers (Marsh 1992). It is considered the most effective control material (Case and Jasch 1994). Historically, strychnine has been the preferred bait for controlling gophers given its acute toxicity and more palatable flavor than zinc phosphide. However, in some areas, gophers have developed a behavioral resistance to strychnine baits (Marsh 1992). More importantly though, there is now a current shortage of strychnine baits in the U.S. due to burgeoning strychnine costs (B. Hazen, Wilco Distributors, Inc., *pers. comm.*). In fact, Wilco Distributors, Inc., who has been the primary importer of strychnine for pest control purposes into the U.S., recently stopped the importation of strychnine and halted all production of strychnine baits. Other companies produce strychnine products (e.g., RCO Pest Control Products), but most had obtained their strychnine from Wilco Distributors, Inc. Unless a new source of strychnine is obtained in the near future, most or all strychnine applications will cease once current supplies of strychnine baits are exhausted. As such, the identification of an equally or more effective bait is needed to provide individuals with a viable alternative for controlling high density gopher populations where other control options are cost prohibitive.

Zinc phosphide is an alternative acute toxicant and has been used for pocket gopher control (e.g., Tickes et al. 1982, Proulx 1998). Unfortunately, zinc phosphide has typically performed as well as strychnine in field trials (e.g., Barnes et al. 1982, Proulx 1998; but see Tickes et al. 1982), perhaps due to potential taste aversion (Engeman and Witmer 2000). However, new formulations (e.g., ZP® Rodent Bait Ag, Bell Laboratories, Inc.) are currently available that may increase effectiveness potentially making the use of zinc phosphide a viable option for controlling gophers.

Anticoagulant baits (chlorophacinone and diphacinone) are also available for controlling pocket gophers. Anticoagulant baits are less toxic than strychnine and zinc phosphide, thereby reducing potential mortality from incidental ingestion of these baits by non-target species. Additionally, an antidote (Vitamin K) is readily available for anticoagulants which reduces the risk associated with primary exposure. These baits require multiple feedings over 3–5 days to control gophers. Therefore, greater amounts of bait are required with anticoagulants. As such, these baits have not always tested well (e.g., Tickes et al. 1982, Stewart et al. 2000). However, new products that utilize milo (Gopher Getter Type 2 Ag Bait, Wilco Distributors, Inc.; 0.005% diphacinone) and wheat (Rozol® Pocket Gopher Bait, Liphatech, Inc.; 0.005% chlorophacinone) grains are currently available that warrant lab testing. These baits are widely used although there is no efficacy data associated with these materials. This information is needed to determine if these baits can be an effective tool for pocket gopher management in California.

Researchers in North America and New Zealand are investigating new "combination" rodenticides. These rodenticides have two active ingredients, combining an anticoagulant and an acute active ingredient (e.g., cholecalciferol). While we are calling cholecalciferol an acute toxicant, we note that some consider it to be a "sub-acute" toxicant (Buckle and Eason 2015). In New Zealand, Eason et al. (2010a) found that one having the two active ingredients, cholecalciferol and coumatetralyl, produced promising results with rats and mice. Interestingly, they were able to obtain high efficacy with lower concentrations of the active ingredients than the concentrations used when either active ingredient is used alone as a commercial rodenticide bait. Hence, there may be some synergistic effect. This is noteworthy because if lower concentrations can be used to effectively control rodent populations, there could be a lower risk of harm to non-target animals through secondary consumption. More recently, Witmer et al. (2014) and Baldwin et al. (IN PRESS) found that a cholecalciferol plus diphacinone pelleted bait was very effective with California voles in cage and field efficacy trials, respectively. However, the same pelleted bait was not very effective with house mice (Witmer and Moulton IN PRESS).

The objective of this study was to identify effective new formulations of rodenticides for the control of pocket gophers in California. These rodenticides contained combinations of active ingredients or new formulations of existing active ingredients. We determined the efficacy of the new rodenticides on wild-caught Botta's pocket gophers in two-choice trials in a controlled (animal room) setting. We hypothesized that some of the test baits would exhibit a high efficacy ($\geq$ 80% mortality) when presented to the pocket gophers.

Methods

Pocket gophers (henceforth, gophers) for this study were Botta's pocket gophers (*Thomomys bottae*) live-trapped in California and transported to the USDA National Wildlife Research Center (NWRC), Fort Collins, Colorado. The gophers came from two regions of California: the southern group was from the San Diego County area, and the northern group was from the Davis Sonoma County area. Gophers were kept in individual numbered plastic, shoebox cages in an animal room at NWRC under the NWRC IACUC-approved study protocol QA-2146.. They were fed a maintenance diet of rodent chow pellets and carrot chunks, and received water *ad libitum.* They were provided with bedding and a den tube, and material to chew on (e.g., wood blocks). There was a two week quarantine and acclimation period before the trials began. There were 4 rounds of trials with various treatment groups of 5 animals each. Animals were randomly assigned to treatment groups for the two-choice trials. The 12 rodenticide baits used in the trials are listed in Table 1. Additionally, there was also be a control group of 5 gophers maintained on the maintenance diet. An effort was made to include both males and females in each group, but the ratio varied depending on availability. Experimental rodenticide baits were generally tested on both gopher groups from the southern region and from the northern region.

The weight, sex, cage number, and treatment of each gopher was be recorded before the initiation of a trial. Rodents were fed the maintenance diet before the start of the trial. On Day 1 of the trial, a bowl of pre-weighed rodenticide bait was added to the appropriate cages. All animals continued to receive the maintenance diet. For the next ten days, maintenance diet materials were added daily to the cages, whereas rodenticide baits were added as needed. All gophers continued to receive water *ad libitum* throughout the trials. At the end of the 10-day rodenticide exposure period, gophers were placed in clean cages and put back on the maintenance diet only for a 14-day post-exposure period. The uneaten rodenticide baits in the dirty cages was collected and weighed to determine the amount consumed both by surviving and by dying gophers.

Gophers were examined twice daily by the study staff and their condition and any mortalities were recorded. Dead gophers were placed in individual, labeled zip-lock bags and refrigerated for later necropsy. When necropsied, those provided with anticoagulants were examined for signs of anticoagulant poisoning as described by Stone et al. (1999). All surviving gophers were ultimately euthanized and incinerated at the end of the study.

Gophers were randomly assigned to the treatment and control groups. The percent mortality of treatment groups and the control group was compared with a Fischer's Exact Test. The days-to-death and food consumption by groups was compared with analysis of variance tests.

Results

Efficacy and Days-to-Death

The efficacy of the rodenticides used in the trials varied widely from 0% to 100% (Table 1). We subdivided the 12 rodenticides into 3 categories: first generation anticoagulants, acute toxicants, and combinations (containing both an anticoagulant and an acute toxicant). These categories varied significantly in efficacy (F = 11.61, P = 0.003), with the combination group having the highest average efficacy (93%; Figure 1).

In addition to the variation in efficacy across rodenticide type, there was also a substantial regional difference in the efficacy level of some of the rodenticides (Table 1). This was especially evident with both strychnine baits and one of the zinc phosphide baits (Figure 2). The efficacy was significantly lower (F = 84.5, P = 0.001) for gophers from the southern region versus those from the northern region.

The days-to-death for gophers that died during the trials varied by rodenticide category. Gophers in the acute rodenticide trials had a significantly shorter (F = 10.01, P = 0.007) days-to-death (Figure 3). The combination toxicants were intermediate and the first generation anticoagulants had the longest days-to-death.

Bait Consumption

The average amount of bait consumed in the 10-day exposure period by gophers that died during the trials varied by rodenticide category (Figure 4). Significantly more ($F = 78.3$, $P = 0.000$) first generation anticoagulant bait was consumed than the acute toxicant baits and the combination baits which were consumed in similar amounts. The pattern closely resembles the pattern for the days-to-death when one compares Figure 3 with Figure 4.

The average amount of bait consumed in the 10-day exposure period did not vary significantly (all $P \geq 0.486$) between gophers that survived versus those that died for three of the types of rodenticide baits: first generation anticoagulants, cholecalciferol, and zinc phosphide baits. Bait consumption was significantly different ($F = 90.6$, $P = 0.011$) for surviving and dying gophers exposed to the strychnine baits. For this group, gophers that died consumed only an average of 2.5 g over the 10-day exposure period, while those that survived consumed an average of 14.6 g over the 10-day exposure period.

Discussion

Rodents cause substantial damage to crops in California (Gebhardt et al. 2011) and rodenticides have been major tools for reducing that damage (Witmer and Eisemann 2007). While strychnine has been heavily relied upon to control pocket gophers in California (Marsh 1992, Salmon et al. 2000), its future availability is in question because of increased import costs. Additionally, there are other issues with strychnine rodenticides and other rodenticides used to control pocket gophers and other rodent species in North America. Salmon and Lawrence (2006) reported that there seems to be resistance to first generation anticoagulants occurring in voles (*Microtus* spp.). This perhaps derives from over reliance on these materials to control rodent populations. There also is varying efficacies for anticoagulant baits, zinc phosphide baits, and strychnine baits across a wide array of rodent species (Salmon et al. 2000, Stewart et al. 2000, Bourne et al. 2002, O'Brien 2002, Balliette et al. 2006, Schmit 2008, Proulx et al. 2010, Pitt et al. 2011, Witmer and Moulton IN PRESS). Numerous types of commercial rodenticide baits may no longer be available for use in the future because of newly-imposed US Environmental Protection Agency mitigation measure (e.g., Hornbaker and Baldwin 2010). There are also increasing concerns about impacts to non-target animals from both acute rodenticides (mainly primary hazards) and anticoagulant rodenticides (mainly secondary hazards; e.g., McMillin 2012, Crowell et al. 2013, Stansley et al. 2014). Finally, there is an increasing concern about the humaneness of some rodenticides (mainly with anticoagulants; e.g., Lapidge et al. 2009). Hence, various researchers in the US and elsewhere are investigating alternative formulations and/or active ingredients (Eason et al. 2010a, 2010b, Blackie et al. 2013, Morgan et al. 2013, Witmer et al. IN PRESS).

Many of the rodenticide issues presented in the previous paragraph were found to be true in the current study with pocket gophers. For example, the first generation anticoagulants were not very effective and had a lengthy days-to-death (often considered inhumane). The low efficacy has been attributed to overuse and the development of resistance in many rodent populations (e.g., Salmon and Lawrence 2006); this is why the second generation anticoagulants were developed (Witmer and Eisemann 2007), but the use of these materials are not permitted in agricultural fields in the US. Additionally, gophers will often not eat much anticoagulant bait when other more preferred foods are available in the environment. Hence, the advantage of a more toxic bait that only requires a small amount to be consumed which could result in higher efficacy levels being achieved.

We also found a regional difference in the efficacy of strychnine baits and one of the zinc phosphide baits with much lower efficacy in the southern region pocket gophers versus the northern region pocket gophers. This may have resulted from overuse of these types of baits in the southern region. This can result over time from bait shyness (i.e., consuming a sub-lethal dose and then not feeding on that bait again in the future), a decreasing palatability issue, or an increased tolerance to the active ingredient (Marsh 1992).

The most efficacious rodenticide baits tested in this study were those containing an acute ingredient and a first generation anticoagulant; what we call a "combination" bait. The first, and perhaps only, use of this type of rodenticide was with one developed and registered for use in Europe. It was called "Racumin" and contained cholecalciferol and the first generation anticoagulant coumatetralyl (Pospischil and Schnorbach 1994). Our test combination baits also contained cholecalciferol, but had either the first generation anticoagulant diphacinone or the second generation anticoagulant brodifacoum. It is thought that the anticoagulant acts as a synergist thereby enhancing cholecalciferol toxicity by blocking vitamin-dependent proteins that are involved in calcium regulation. Interestingly, both the bait containing diphacinone alone and the bait containing cholecalciferol alone had much lower efficacies. This may have resulted, in part, from the lower concentration of cholecalciferol in our combination bait (0.03%) than in the cholecalciferol-alone bait (0.075%). Cholecalciferol is known to pose some palatability issues (Prescott et al. 1992, Twigg and Kay 1992). Unfortunately, high concentrations ($\geq$ 0.1%) are often needed for adequate efficacy with pocket gophers (e.g., Tobin et al. 1993, Witmer et al. 1995). The lower concentrations of one or both active ingredients may be an additional benefit from combination baits, potentially because of lower costs, less toxicant being put into the environment, and reduced costs of manufacture. Future studies should evaluate the potential to also reduce the concentration of the anticoagulant in the combination bait. Finally, with regard to the humaneness issue, we note that the average days-to-death of the combination bait, while still higher than that of the acute baits, was somewhat lower than that of the first generation baits. We recommend that a field efficacy study of the combination bait be conducted in agricultural fields infested with pocket gophers.

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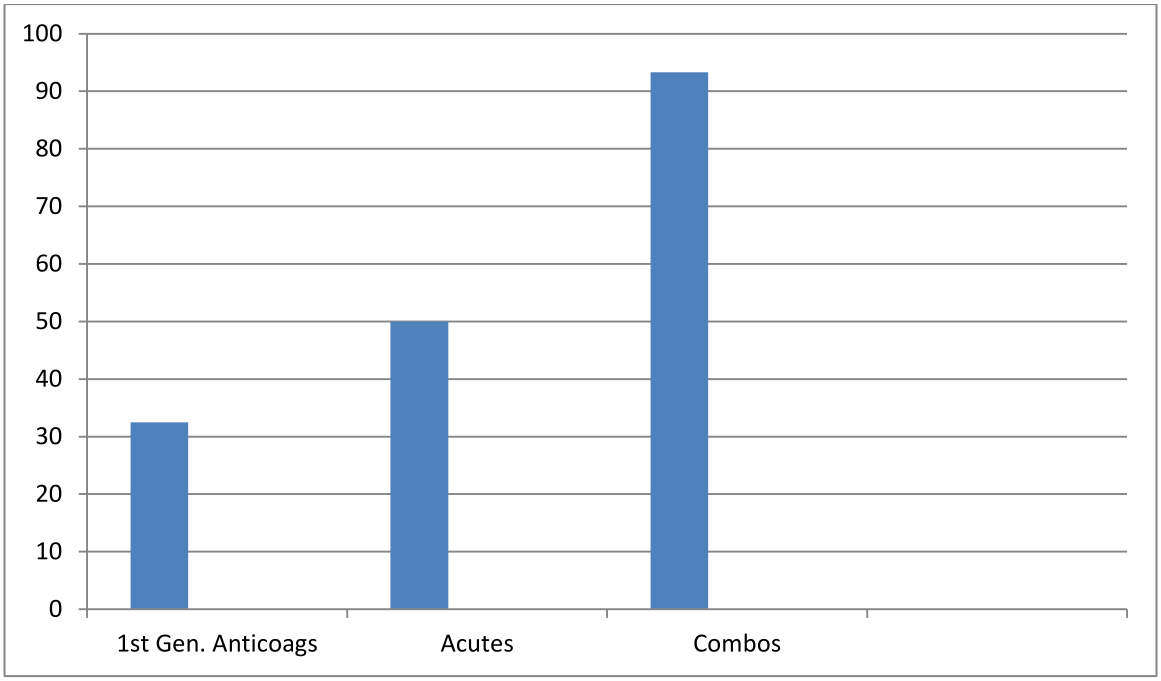
Table 1. Rodenticide treatments, percent efficacy by region, average bait consumption by surviving and non-surviving gophers, and average days-to-death of non-surviving gophers.

Rodenticide Type	**% Efficacy, Southern Region (No. dead/no. in group)**	**% Efficacy, Northern Region (No. dead/no. in group)**	**Ave. Bait Consumption g (S.D.), Survivors**	**Ave. Bait Consumption g (S.D.), Non-survivors**	**Ave. Days-to-Death (S.D.) for Non-survivors**
0.01% chlorophacinone, coated grain	40% (2/5)	60% (3/5)	24.9 (6.2)	24.3 (7.1)	9.6 (4.6)
0.005% chlorophacinone, pellet	40% (2/5)	60% (3/5)	27.3 (11.8)	20.3 (16.9)	6.2 (3.0)
0.005% diphacinone, pellet	0% (0/5)	N/A (= not applicable)	15.6 (7.9)	N/A	N/A
0.005% diphacinone, pellet	40% (2/5)	20% (1/5)	2.7 (1.5)	5.4 (6.1)	15.3 (3.5)
0.03% cholecalciferol + 0.0025% brodifacoum, pellet	100% (5/5)	N/A	N/A	5.1 (1.1)	10.8 (4.0)
0.015% cholecalciferol + 0.0025% brodifacoum, pellet	100% (5/5)	100% (5/5)	N/A	7.0 (8.0)	6.4 (2.8)
0.03% cholecalciferol + 0.005% diphacinone, pellet	60% (3/5)	100% (5/5)	7.2 (3.4)	6.5 (2.7)	5.3 (3.6)
0.5% strychnine, coated grain	0% (0/5)	100% (5/5)	15.8 (3.4)	2.7 (4.6)	1.0 (1.2)
0.5% strychnine, coated grain	20% (1/5)	100% (5/5)	13.3 (9.8)	2.3 (0.7)	1.0 (0.6)
2.0% zinc phosphide, pellet	60% (3/5)	40% (2/5)	1.0 (0.3)	0.8 (0.4)	0.8 (0.4)
2.0% zinc phosphide, pellet	0% (0/5)	80% (4/5)	0.5 (0.8)	1.3 (0.8)	1.5 (0.6)
0.075% cholecalciferol, pellet	40% (2/5)	N/A	4.9 (4.7)	5.8 (5.7)	3.5 (0.7)

Figure 1. The average percent efficacy of the three categories[a] of rodenticides used in the trials.



[a]Categories = 1st generation anticoagulants, acute toxicants, and combination anticoagulant and acute toxicant.

Figure 2. Regional difference in percent efficacy for two strychnine baits and one zinc phosphide bait used in the trials.

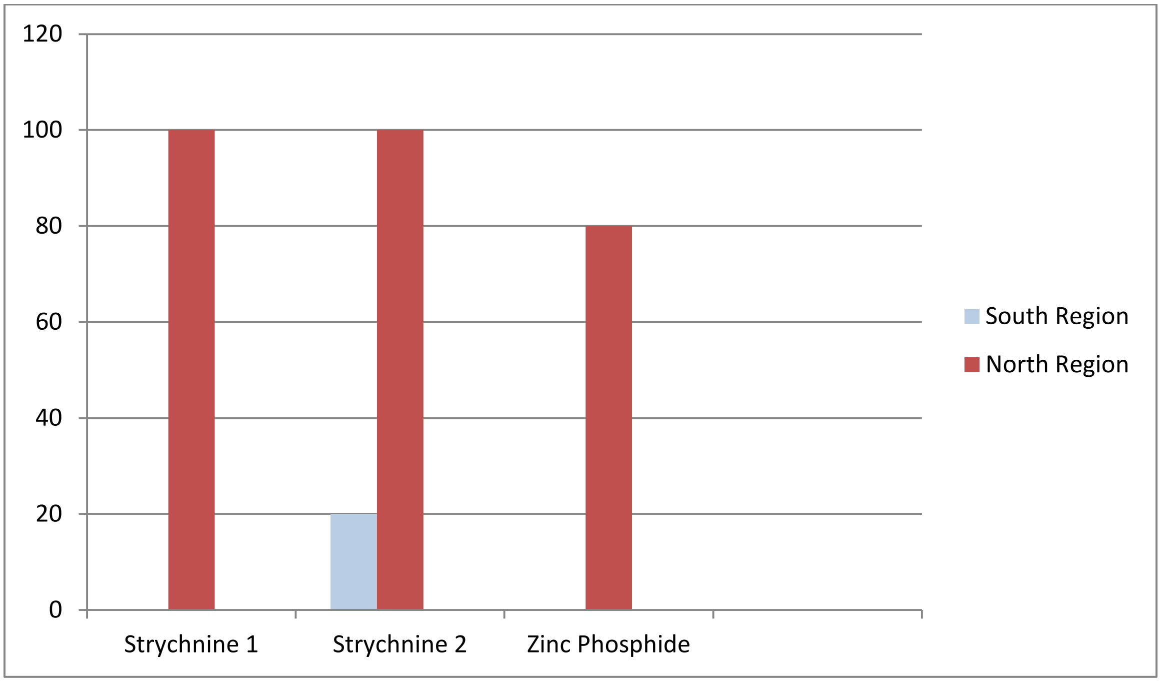
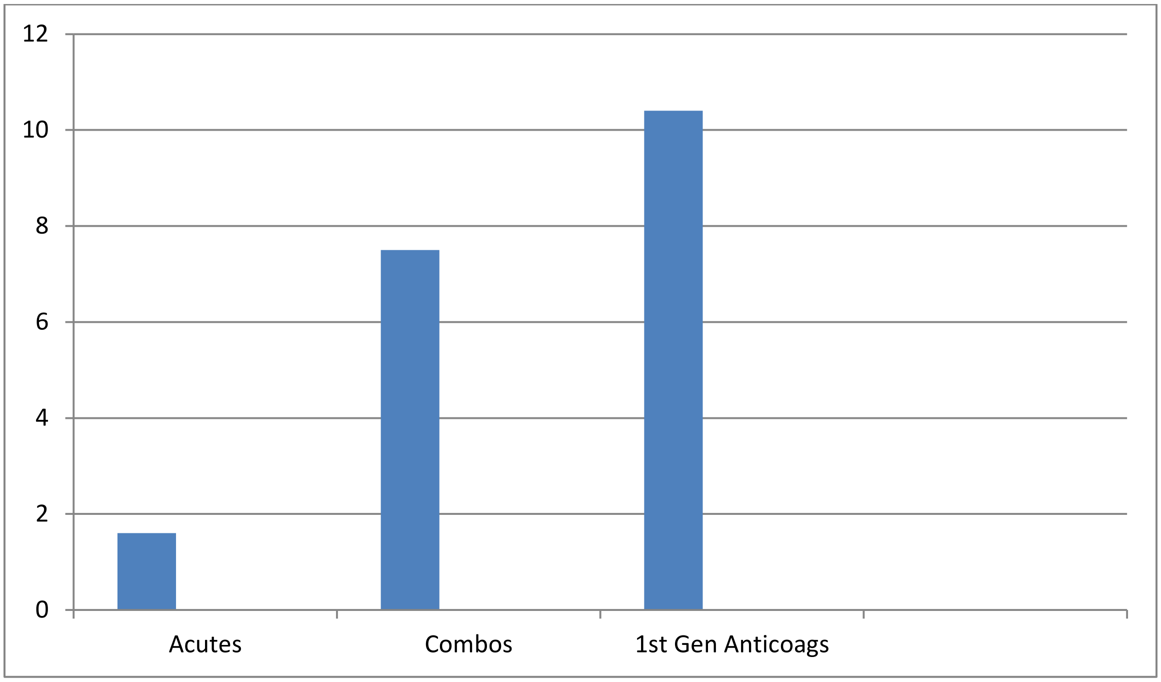
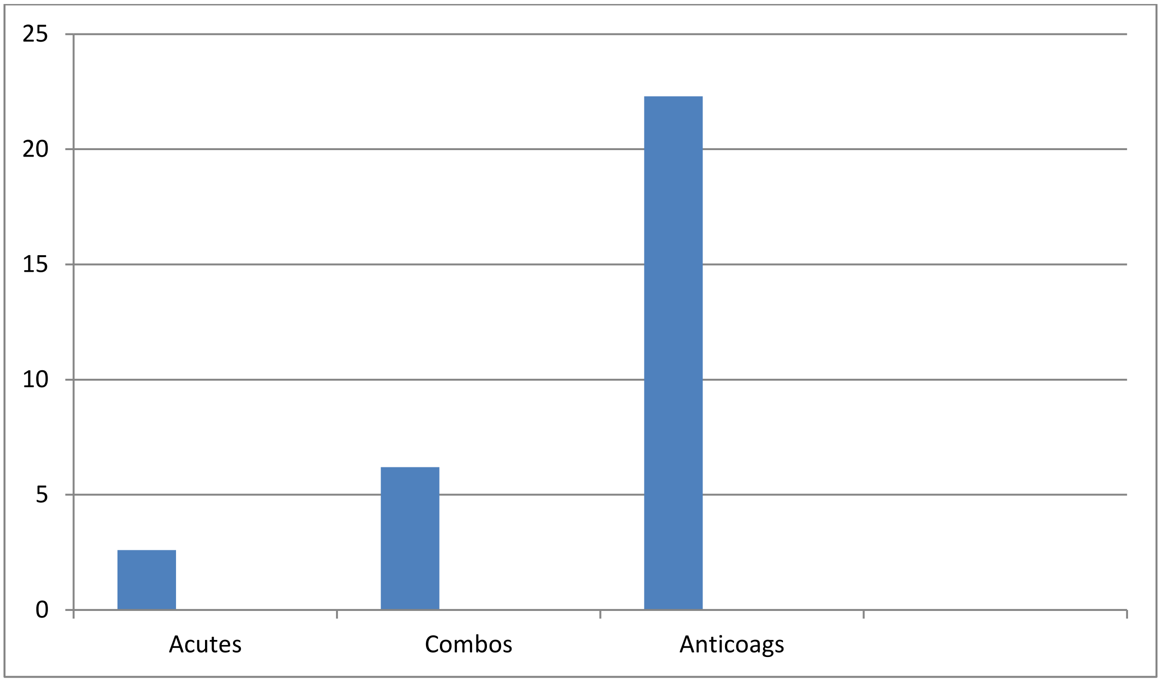


Figure 3. Average days-to-death of gophers that died during the rodenticide trials by rodenticide category[a].



[a]Categories = acute toxicants, combination anticoagulant and acute toxicant, and 1st generation anticoagulants.

Figure 4. Average bait consumption (g per 10-day exposure period) by gophers that died during the trials by rodenticide category[a].



[a]Categories = acute toxicants, combination anticoagulant and acute toxicant, and 1st generation anticoagulants.