ON THE MISUSE OF PESTICIDES TO CONTROL NORTHERN POCKET GOPHERS AND RICHARDSON'S GROUND SQUIRRELS IN AGRICULTURE AND THE PRESSING NEED FOR SUSTAINABLE SOLUTIONS

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Abstract : Strychnine and chlorophacinone (anticoagulant) are two major pesticides used in the control of Northern Pocket Gophers and Richardson's Ground Squirrels in western Canada. Yet, scientific research has repeatedly demonstrated that these pesticides often failed to effectively control these rodent species and also had significant impacts on wildlife communities and the well-being of farming communities. Within the historical context of recurrent rodent population outbreaks in western Canada agricultural regions, there is a pressing need to develop and implement a series of solutions including 1) species-specific Integrated Pest Management (IPM) programs consisting of proven, safe and effective chemical and mechanical methods, natural control agents, and educational presentations and brochures; 2) the recruitment of successful producers and respected community leaders to implement IPM programs that take into consideration regional constraints; and 3) the enlistment of naturalist and conservation groups, and government agencies, to develop conservation programs that meet the needs of wildlife communities (including Species-at-Risk) and producers.

Introduction

In western Canada, the Northern Pocket Gopher (*Thomomys talpoides*; also known as mole) and the Richardson's Ground Squirrel (*Urocitellus richardsonii*; also known as gopher) are fossorial rodents which cause major losses to producers due to their feeding and digging activities. Both species have been the subject of extensive control campaigns with questionable results (e.g., Isern 1988; Marsh 1992; Nietfeld and Roy 1992). Today, strychnine and chlorophacinone (anticoagulant) are being recommended for the control of these rodents (e.g., Alberta Agriculture and Rural Development 2008) but, after extensive use for decades, the populations of these rodents have always been, and continue to be, beyond control (e.g., Nietfeld and Roy 1992, Saskatchewan Agriculture 2010).

During two Research & Control Programs on Northern Pocket Gophers (1993-2005) and Richardson's Ground Squirrels (2007-2010) in western Canada, I evaluated the efficacy of strychnine and chlorophacinone, and other rodenticides, to control these fossorial rodents. On the basis of these research programs, and studies conducted in similar ecosystems in the United States, I intend to demonstrate that these rodenticides often failed to effectively control Northern Pocket Gophers and Richardson's Ground Squirrels, and also impacted significantly on wildlife communities and the well-being of farming communities. Finally, I present preliminary Integrated Pest Management (IPM) programs where chemical and mechanical methods, cultural practices, and

natural mortality factors can be used in conjunction with education programs and socio-political strategies to minimize damages caused by Northern Pocket Gophers and Richardson's Ground Squirrels.

Strychnine

Strychnine is an alkaloid which is a constituent of the seeds of the strychnine tree (*Strycnos nux-vomica*) of India and Indonesia (Brookes 1975). Strychnine was first registered in Canada in 1928 (Pest Management Regulatory Agency, PMRA, 2005) for the control of Richardson's Ground Squirrels, even though it was distributed in Saskatchewan as early as 1912 (Isern 1988). Because of its toxicity to a variety of species, its secondary persistence (Littrell 1990), and its misuse (Howell and Wishart 1969, Wobeser and Blakley 1987), strychnine became a source of concern for the public and professionals (Hegdal and Gatz 1977, Landals 1993, Owen-Carter 1993). In 1993, the Canadian Federal Government banned the popular liquid strychnine solution, and replaced it with ready-to-use (RTU) strychnine-treated oats. Farmers and politicians considered that liquid strychnine was the only effective poison to control Richardson's Ground Squirrel populations (Proulx 2010). In 2007, an Emergency Registration program of 2% liquid strychnine was granted by PMRA and became effective in 2008 (Wilk and Hartley 2008) for the control of a Richardson's Ground Squirrel population outbreak (Proulx 2010). The Emergency Registration required that 2% liquid strychnine be mixed with grain to formulate 0.4% freshly mixed (FM) baits. However, the ability of FM 0.4% strychnine-treated baits to control Richardson's Ground Squirrel populations had never been thoroughly tested in the Canadian Prairies (Proulx and Feldstein 1994, McKinnon and Mineau 2004).

Use in the Control of Northern Pocket Gophers

Control Efficacy

Underground baiting with strychnine alkaloid bait has long been used to control Nothern Pocket Gophers in agricultural fields (Tickes et al. 1982; Lewis and O'Brien 1986). In a compendium of control techniques, Goodwin Enterprises & Distributors Ltd. (Sundre, Alberta) reported excellent Northern Pocket Gopher control with grain coated with 0.25%, 0.31%, 0.5%, and 1.0% strychnine alkaloid, and claimed that strychnine was a relatively safe poison without secondary effect (Willis, undated). Strychnine baits are still being recommended today (Salmon and Baldwin 2012) and they are produced by various companies.

In Canada, using the 'open-hole' monitoring method to determine if resident Northern Pocket Gophers have died following poisoning (i.e., Northern Pocket Gophers do not leave their burrow system open; Engeman et al. 1993), Proulx (1998) found that control levels obtained by hand-baiting burrow systems with 0.4% strychnine-treated oats were less than 17% in spring and fall, and 36% in summer. Considering that poison baits must kill at least 70% of Northern Pocket Gophers in order to effectively control populations (Fagerstone et al. 1981), control levels obtained with 0.4% strychnine-treated oats were inadequate. Proulx's (1998) findings were in agreement with studies carried out on Botta's Pocket Gophers (*Thomomys bottae*) in the United States (Table 1). Lee et al. (1990) demonstrated that Botta's Pocket Gophers acquired physiological tolerance to strychnine, i.e., after they ingested a series of sub-lethal doses, they could tolerate increasingly higher doses of strychnine. The animals had or acquired a feeding strategy which enabled them to consume what normally is in excess of a lethal amount of strychnine by eating sub-lethal amounts periodically throughout a 24-hr period. Strychnine that was consumed in one feeding was excreted in urine or metabolized before another feeding (Lee et al. 1990). Finally, Proulx et al. (1995a) showed that Northern Pocket Gophers daily spent many hours maintaining their burrow system. Whether producers are baiting burrow systems by hand, with a mechanical applicator, or with a

burrow builder, Northern Pocket Gophers recognize areas of their burrow system that have been modified, even slightly, by the introduction of the poison bait. Then they often mix or cover the poison bait with soil, or use bait and soil to plug the disturbed portion of the tunnel (Proulx 1998).

Non-target and Secondary Poisoning

Since Northern Pocket Gopher burrow systems are inhabited by several small mammal species (Vaughan 1961; Whittaker et al. 1991), many of them are poisoned (Proulx, personal observations) and may be eaten by scavengers and predators (see the Richardson's Ground Squirrel section below).

Table 1. Control efficiency of strychnine to control Northern Pocket Gophers.

Species	***Bait***	***Control efficiency (%)***	***Reference***
Northern Pocket Gopher	0.4% strychnine-treated oats	<17 in spring and fall 36 in summer	Proulx 1998
Botta's Pocket Gopher	0.35% strychnine-treated milo	≤10	Tickes et al. 1982
	0.5% strychnine-treated oats	≤10	
Botta's Pocket Gopher	0.3% strychnine-treated wheat or wheat-barley-raisin mix	13	Tickes 1983
	0.35% strychnine-treated wheat, or milo, or peanut-flavored milo	≤12	
	0.5% strychnine-treated oats or tablets	≤18	
	1.8% strychnine-treated milo	25	

Value as a Rodenticide

Northern Pocket Gophers are mainly herbivores and do not favor seeds and grains used in the production of poison baits (Proulx 2002a). Therefore, strychnine baits are not in sync with Northern Pocket Gophers' feeding ecology. These baits will, however, be eaten by non-target species such as mice and voles, which will be eaten by carnivores and scavengers. Strychnine baits used for the control of Northern Pocket Gophers therefore has an impact on the whole community food web.

Forty years ago, in their 1973 review of Northern Pocket Gopher biology and management, Turner et al. (1973) stated that this rodenticide was no longer acceptable for use against Northern Pocket Gophers and recommended that more effective and safer compounds be sought. My findings in Canada (Proulx 1998) supported their conclusion that strychnine is not a valuable rodenticide for the control of Northern Pocket Gophers.

Use in the Control of Richardson's Ground Squirrels

Control Efficacy

During the 2007 drought in southwestern Saskatchewan, Proulx and Walsh (2007) controlled less than 40% of Richardson's Ground Squirrels with FM 0.4% strychnine-treated oat baits made from a 5-year-old concentrate. The low performance of baits in 2007 was possibly due to the staleness of strychnine that had been produced in 2002. Also, in 2008, using a freshly produced strychnine concentrate, Proulx et al. (2010a) controlled more than 70% of ground squirrels (Table 2). However, in 2009 and 2010, when green vegetation became more abundant, FM 0.4% strychnine-treated oats failed to control more than 70% of Richardson's Ground Squirrels (Table 2; Proulx et al. 2010b; Proulx 2011a). When the strychnine concentrate was not fresh, or when ground squirrels had access to abundant vegetation, strychnine was not effective to control ground squirrels. In spite of many attempts to improve the efficacy of the rodenticide by using different baits (Proulx et al. 2010a), various additives (Proulx 2011a), and different bait station models (Proulx 2011a), FM 0.4% strychnine-treated baits usually failed to control at least 70% of ground squirrels.

Proulx and Walsh (2007) and Proulx et al. (2009, 2010b) demonstrated that RTU 0.4% strychnine-treated oats were ineffective to control Richardson's Ground Squirrels. In most cases, control was less than 55% (Table 2).

Table 2. Control efficiency of strychnine to control Richardson's Ground Squirrels (FM: freshly mixed; RTU: ready-to-use).

Bait	***Control efficiency (%)***	***Reference***
FM Strychnine		
FM Nu-Gro 0.4% strychnine-treated oats made with 5-year old 2% liquid concentrate (2007 study)	38.1(spring)	Proulx et al. 2010a
FM Nu-Gro 0.4% strychnine-treated oats made with newly produced 2% liquid concentrate (2008 study)	73.1-95.4% (spring) 75.4 (summer)	
FM Nu-Gro 0.4% strychnine-treated canary seeds made with newly produced 2% liquid concentrate (2008 study)	63.9-84.5(spring) 83.4-92.2 (summer)	
FM Nu-Gro 0.4% strychnine-treated oats made with newly produced 2% liquid concentrate (2009 study)	69.6-85.8 (spring) 58.3-62.1 (summer)	Proulx et al. 2010b
FM Maxim 0.4% strychnine-treated oats made with newly produced 2% liquid concentrate (2009 study)	57.5 (spring) 51.3-58.3 (summer)	
FM Nu-Gro 0.4% strychnine-treated alfalfa pellets made with newly produced 2% liquid concentrate (2009 study)	60.7-66.3 (spring) 40.4-55.7 (summer)	
FM Nu-Gro 0.4% strychnine-treated oats made with newly produced 2% liquid concentrate (2010 study)	66.1-54.7 (spring)	Proulx 2011a

FM Maxim 0.4% strychnine-treated oats made with newly produced 2% liquid concentrate (2010 study)	54.1-62.3 (spring)	
FM Nu-Gro 0.4% strychnine-treated oats made with newly produced 2% liquid concentrate + peanut oil and peanut butter (2010 study)	58.2-59.2	
FM Nu-Gro 0.4% strychnine-treated oats made with newly produced 2% liquid concentrate + corn syrup (2010 study)	52.6-84.2	
FM Nu-Gro 0.4% strychnine-treated oats made with newly produced 2% liquid concentrate + sunflower and canola oils (2010 study)	67.3-71.1	
FM Nu-Gro 0.4% strychnine-treated oats made with newly produced 2% liquid concentrate + salt and mineral mix (2010 study)	75.7-77.8	
RTU Strychnine		
RTU Nu-Gro 0.4% strychnine-treated oats (2007 study)	≤53% (spring)	Proulx and Walsh 2007
RTU Nu-Gro 0.4% strychnine-treated oats (2008 study)	≤54% (spring) ≤26% (summer)	Proulx et al. 2009
RTU Nu-Gro 0.4% strychnine-treated oats (2009 study)	60.3--64.6 (spring) 27.1-53.6 (summer)	Proulx et al. 2010b

Non-target and Secondary Poisoning

Bait rejection at burrow entrances is particularly frequent with strychnine-treated oats and canary seeds during spring and summer (Proulx and Walsh 2007, Proulx et al. 2009). Proulx (2011b) reported a large number of songbirds and small mammals that fed on strychnine-treated baits found on the surface. Uresk et al. (1987) reported high losses of Horned Larks (*Eremophila alpestris*) when controlling Black-tailed Prairie Dogs (*Cynomys ludovicianus*) with strychnine baits. Wamock and Schwarzbach (1995) reported strychnine poisoning of Dunlin (*Calidris alpina*) and Killdeer (*Charadrius vociferous*). Non-target poisoning is aggravated by an improper placement of strychnine baits on surface rather than in rodents' burrow openings (Howell and Wishart 1969, Hegdal and Gatz 1977, Wobeser and Blakley 1987), a practice still in effect today. From 2007 to 2010, I observed farmers spreading strychnine-treated baits on surface, depositing piles of treated oats or barley near the entrance of all animal burrows, or mixing it with chlorophacinone-treated oats in bait stations.

Non-target and secondary poisoning has been repeatedly documented. Proulx (2011b) reported finding a deceased Northern Harrier (*Circus cyaneus*) in spring 2009 in a study plot treated with FM 0.4% strychnine baits. One Deer Mouse (*Peromyscus maniculatus*) was found in its stomach. An autopsy of the mouse revealed the presence of at least two strychnine-treated oat kernels. Mendenhall and Pank (1980) reported secondary poisoning of owls. James et al. (1990) observed American Crow (*Corvus brachyrhynchos*), Black-billed Magpie

(*Pica pica*), California Gull (*Larus californicus*), Northern Harrier, and Burrowing Owl (*Athene cunicularia*) feeding, or attempting to feed, on dead ground squirrels poisoned with strychnine. Each year, accidental human poisoning continues to be a problem (Eisemann and Petersen 2002).

Value as a Rodenticide

On the basis of Proulx et al.'s (2010a) extensive studies in Saskatchewan, freshly produced strychnine may be effective to control Richardson's Ground Squirrels during drought periods when green vegetation is scarce. However, when vegetation is green and abundant, even after a short rainy period during drought years, strychnine-treated baits are unreliable. Poor strychnine performance may be caused by poor bait acceptance, but also by bait shyness. Because strychnine has a bitter taste and acts rapidly even at sub-lethal doses, animals can associate the poison bait with their illness and curtail their feeding (Record 1978). Furthermore, Ling et al. (2009) suggested that Richardson's Ground Squirrels inhabiting fields treated with strychnine could develop resistance to toxins by enhancing the functional capacity of enzymes (hepathic cytochrome CYP450 system) responsible for detoxification (Ling et al. 2009).

Littrell (1990) believes that strychnine is the worst rodenticide for wildlife because of its toxicity to a variety of species and because of its secondary persistence. On the basis of my experience in southwestern Saskatchewan, I believe that strychnine may be useful to control Richardson's Ground Squirrel populations in specific areas, if users place fresh baits in their burrow systems and monitor the treated sites to collect the carcasses of poisoned animals. However, due to its general unreliability and misuse by farmers who spread poison baits across fields without discrimination and do not remove the carcasses of poisoned animals (which are eaten by predators and scavengers), I believe that this rodenticide should not be made available to the general public. Yet, despite its unreliability to control Richardson's Ground Squirrels, and its impact on wildlife communities, strychnine is now a registered rodenticide that is available to producers (Benoit 2012; also see http://rdcounty.ca/News/News-Releases/2-Liquid-Strychnine-Available-to-Red-Deer-County-Farmers-In-2012), and it is promoted as being the most effective poison to control ground squirrels by Conservative Party MP Leon Benoit (Morgan 2012).

Chlorophacinone

Since their introduction in the early 1950s, anticoagulant poisons have replaced many acute and hazardous poisons, and revolutionized control programs (Meehan 1984, Berdoy and Smith 1993). Their main advantage is that they do not induce 'bait or poison shyness'. They are slow acting and when symptoms of toxicosis develop, animals have already consumed a lethal dose (Nacham and Hartley 1975). In Canada, chlorophacinone is sold to control Northern Pocket Gophers and Richardson's Ground Squirrels.

Use in the Control of Pocket Gophers

Control Efficacy

Laboratory work where pocket gophers were fed only poisoned baits suggested that anticoagulants could be efficient rodenticides (Tunberg et al. 1984, Vossen and Gadd 1990). However, Proulx et al. (1994) found that Northern Pocket Gophers fed poor quality alfalfa ingested 6.1 to 17.5 mg chlorophacinone/kg (LD_{50} = 2.1 mg/kg for 0.25% concentrate) without adverse effects (Table 3). Proulx et al. (1994) concluded that several feedings with concentrations of chlorophacinone markedly higher than the recommended LD_{50} would be necessary to kill Northern Pocket Gophers feeding on fresh alfalfa. Tickes (1983) also found that

chlorophacinone 0.005% on wheat or in paraffinized pellets failed to achieve any control over Botta's Pocket Gophers inhabiting alfalfa fields (Table 3). Vitamin K is a natural antidote to anticoagulants (Hadler and Buckle 1992; Miller 1984). Arjo and Nolte (2004) noted that green vegetation rich in vitamin K such as alfalfa may counteract the effect of anticoagulants on rodents. Since the control of Northern Pocket Gophers is conducted mainly in alfalfa fields, the use of chlorophacinone (and other similar anticoagulants) is not effective.

Table 3. Control efficiency of chlorophacinone to control alfalfa-fed Northern Pocket Gophers.

Species	***Bait***	***Control efficiency (%)***	***Reference***
Northern Pocket Gopher	Chlorophacinone on alfalfa	0	Proulx et al. 1994
Botta's Pocket Gopher	Chlorophacinone on wheat	0	Tickes 1983
	Chlorophacinone in paraffinized pellets	0	

Non-target and Secondary Poisoning

Along with some pocket gophers, mice and voles inhabiting in or near pocket gopher burrow systems treated with chlorophacinone baits will be poisoned. Because anticoagulants are slow acting, Northern Pocket Gophers and non-target species feeding on chlorophacinone-treated baits may be captured and eaten by predators. These predators that are exposed to sub-lethal doses of anticoagulants would be expected to continue to hunt and consume additional poisoned prey, and die of secondary poisoning (Hosea 2000). Secondary poisoning would therefore be a threat to known predators of Northern Pocket Gophers: Long-tailed Weasel (*Mustela frenata*; Proulx and Cole 1998, Proulx 2000), Great Horned Owl (*Bubo virginianus*) and Long-eared Owl (*Asio otus*) (Stewart and Barss 1985), Swainson's Hawk (*Buteo swainsoni*; Bechard 1982), Ferruginous Hawk (*Buteo regalis*; Schmutz 1987) and others.

Value as a Rodenticide

Chlorophacinone is not a valuable rodenticide for the control of Northern Pocket Gophers because 1) it is mixed with grains and seeds that pocket gophers do not feed on; and 2) it has little or no effect on pocket gophers feeding on alfalfa. Yet, chlorophacinone is still registered in Canada as an effective rodenticide for Northern Pocket Gophers.

Use in the Control of Richardson's Ground Squirrels

Control Efficacy

Extensive research in southwestern Saskatchewan showed that, in most cases, chlorophacinone-treated oats or winter wheat control more than 70% of Richardson's Ground Squirrels in spring (Proulx et al. 2009, 2010b; Table 4). In summer, control efficacy may vary among grasslands, but often is above 70%. In alfalfa fields, however, in spring and summer, chlorophacinone-treated oats or winter wheat usually control less than 70% of Richardson's Ground Squirrels (Proulx et al. 2009, 2010b; Table 4).

Table 4. Control efficiency of chlorophacinone to control Richardson's Ground Squirrels.

Bait	***Control efficiency (%)***	***Reference***
Grasslands		
Chlorophacinone-treated oats placed in burrow openings or in bait stations (spring 2008)	73-100	Proulx et al. 2009
Chlorophacinone-treated winter wheat in burrow openings (spring 2008)	72-95	
Chlorophacinone-treated canary seeds placed in burrow openings (spring 2008)	83-92	
Chlorophacinone-treated oats placed in burrow openings or in bait stations (summer 2008)	50-75	
Chlorophacinone-treated winter wheat in burrow openings (summer 2008)	67	
Chlorophacinone-treated oats placed in burrow openings (spring 2009)	75-86	Proulx et al. 2010b
Chlorophacinone-treated winter wheat in burrow openings (spring 2009)	79-93	
Chlorophacinone-treated oats placed in burrow openings (summer 2009)	86	
Chlorophacinone-treated winter wheat in burrow openings (summer 2009)	93-100	
Alfalfa fields		
Chlorophacinone-treated oats placed in burrow openings (summer 2008)	40-51	Proulx et al. 2009
Chlorophacinone-treated winter wheat in burrow openings (summer 2008)	67	
Chlorophacinone-treated oats placed in burrow openings (spring 2009)	59-67	Proulx et al. 2010b
Chlorophacinone-treated winter wheat in burrow openings (spring 2009)	59-75	
Chlorophacinone-treated oats placed in burrow openings (summer 2009)	61-93	
Chlorophacinone-treated winter wheat in burrow openings (spring 2009)	61-93	

Non-target and Secondary Poisoning

Proulx (2011b) reported the loss of small mammals and songbirds that fed on baits, and the secondary poisoning of small carnivores that fed on Richardson's Ground Squirrels that were poisoned by chlorophacinone-treated baits. From 2007 to 2010, I often saw chlorophacinone-treated baits not being applied as per instructions. The use of spreaders (Figure 1), bait stations in all agricultural fields even when ground squirrels

were absent (Figure 2), and overflowing or improper bait stations (Figure 3) was frequent in southwestern Saskatchewan. In 2008 and 2009, the registered Rozol® chlorophacinone product was also being sold as Rozol+ by an exterminator who modified the original product by adding mineral oil and peanut butter. This modified chlorophacinone was not more effective than the original Rozol® to control Richardson's Ground Squirrels (Proulx et al. 2010b) but, because of the presence of peanut butter in the grain mixture, domestic dogs fed directly on baits and were poisoned (Proulx, unpublished observations).

Value as a Rodenticide

Chlorophacinone-treated grains are effective to control Richardson's Ground Squirrels in grasslands. They are not effective in alfalfa fields because vitamin K, which is abundant in alfalfa, counteracts the effect of chlorophacinone. Because of its misuse by farmers, chlorophacinone poses a threat to wildlife communities.

Figure 1. This farmer used a spreader to distribute chlorophacinone-treated baits across the field, southwestern Saskatchewan, 2010.

Figure 2. Improper bait stations made of discarded chemical containers in fields that were not inhabited by Richardson's Ground Squirrels, southwestern Saskatchewan, 2009 and 2010.

Figure 3. Overflowing and improper bait stations used by farmers in southwestern Saskatchewan, 2009 and 2010.

Why do Farmers Continue to Use Strychnine and Chlorophacinone?

The efficiency of strychnine and chlorophacinone to control Northern Pocket Gophers has been overestimated in the past due to poor assessments of populations before and after treatment. Because the presence of pocket gophers in agricultural fields can be confirmed by the presence of dirt mounds, it has been suggested that pocket gopher populations could be monitored with mound counts to determine treatment efficiency (e.g., Anthony and Barnes 1983, Baldwin 2011). The technique consists in counting and destroying dirt mounds before treatment, and counting new mounds after treatment with poison baits. Post-treatment counts are then used as an index of activity and, by extrapolation, as an index of population densities. Using this approach, Lewis and O'Brien (1986) concluded that 1% and 1.7% strychnine-laced alfalfa baits could achieve 78% and 69% control, respectively. However, pocket gopher mounding is a highly variable activity (Miller 1948, Laycock 1957, Miller and Bond 1960) and can be misleading (Engeman et al. 1993). Proulx et al. (1995b) showed that the proportion of newly built mounds was dependent on the time of year, and was markedly higher in August-September than in June-July. This was likely due to a dispersal of young from the maternal burrows and a gradual change in above-ground movements coinciding with a change in vegetation (Miller and Bond 1960, Proulx et al. 1995a). Also, some pocket gophers produce more mounds than others. Therefore, assessing the efficacy of strychnine baits to control Northern Pocket Gophers on the basis of mound counts in summer may be misleading and give the false impression that strychnine is effectively controlling pocket gophers.

Controlling Richardson's Ground Squirrels with strychnine is almost a tradition in the Canadian Prairies. Since the beginning of the 20th century, the Saskatchewan Government has subsidized the utilization of strychnine to control Richardson's Ground Squirrels during each and every drought period (Isern 1988). Controlling ground squirrels became a recurring event sponsored by politicians. However, since strychnine failed to provide farmers with long-term relief from ground squirrel population outbreaks, it became obvious that this rodenticide was unreliable (e.g., Isern 1988). The use of strychnine was taught to children who, in turn, taught it to their own children.

Farmers do not know about the inefficacy of chlorophacinone to control Northern Pocket Gophers and Richardson's Ground Squirrels in alfalfa fields. Salesmen do not mention it to buyers, and PMRA's registration does not indicate that it is inefficient in alfalfa fields. Because chlorophacinone is sold as a pocket gopher and a ground squirrel rodenticide, farmers do not consider its impact on other vertebrates. In 2008, the exterminator selling Rozol+ to Saskatchewan farmers to control ground squirrels distributed information sheets stipulating that his product posed no secondary poisoning problems like strychnine (Schultz 2008).

Finally, the use of rodenticides by farmers is poorly monitored by either PMRA or provincial government agencies. There are no inspectors to verify that 1) concentrated solutions are properly mixed with grains or seeds; 2) poison baits are properly used in burrow systems instead than on surface; 3) bait stations (if such stations are allowed) are adequate; 4) bait mixtures are not modified by adding unregistered products or mixing more than one rodenticide together; and 5) farmers use poison baits in a responsible manner, with concerns for Species-at-Risk. The latter point is particularly interesting since large amounts of money have been expended in the past to ensure the future of endangered species such as the Burrowing Owl and the Swift Fox (*Vulpes velox*). Unfortunately, to my knowledge, no Conservation Officer monitors the use of rodenticides in regions inhabited by Species-at-Risk.

Impact of Strychnine and Chlorophacinone on Farmers

Sixteen years ago, in Manitoba, applying strychnine baits annually to control Northern Pocket Gophers cost at least CAN $30/ha (DeWandel et al. 1997). Because poisoning leaves behind an important proportion of the pocket gopher population that may reproduce and compensate for losses induced by baits, costs associated with poison baiting may be high in the long-term.

During the 2009 wet summer and in presence of green vegetation, Proulx et al. (2009, unpublished data) treated, on average, 85 Richardson's Ground Squirrel burrow openings with one bottle of 2% strychnine concentrate (approximately $9/bottle). They achieved <65% control (Proulx et al. 2010b). Proulx et al. (2009, unpublished data) used 15g of chlorophacinone-treated oats per burrow opening in alfalfa fields, and they achieved <70% control (Proulx et al. 2009, 2010b). Treating entire sections (260 ha/section) of green vegetation (namely alfalfa) with more than 1000 ground squirrel burrow openings would cost several thousands of dollars without successful management.

Impact of Strychnine and Chlorophacinone on Wildlife Communities

It is known that strychnine and chlorophacinone kill many non-target small mammals and songbirds which feed on poison baits, and predators that feed on dead or dying animals (Proulx 2011b). Also, in southwestern Saskatchewan, Proulx and MacKenzie (2012) investigated the relative abundance of American Badgers (*Taxidea taxus*) and Red Fox (*Vulpes vulpes*) in two study areas with similar road access and crops, but with different levels of poisoning. In the study area with relatively low poisoning (19.6% of the area traversed by roads), there were 2.2 times more American Badgers per km of road and 6.4 times more Red Foxes per km than in the study area with high poisoning (89.7% of the area). The use and misuse of poisons resulted in a loss of predators and impoverished wildlife communities.

The Need for Integrated Pest Management

There is a need to establish Integrated Pest Management (IPM) programs in which population monitoring, preventive cultural practices, and various control methods (mechanical, chemical, physical, and biological) are strategically coordinated to maintain rodent population densities at acceptable pest levels (Witmer and Proulx 2010). In order to be acceptable, an IPM program must control at least 70% of rodent populations. Otherwise, the annual productivity of young will compensate for losses resulting from control activities, and populations densities will likely continue to increase over time. On the basis of Proulx's (2002b) assessment of Northern Pocket Gopher control methods, selected methods must:

1. remove most of the breeders before the birth or emergence of young-of-the-year;
2. eliminate immigration, usually associated with the dispersal of young-of-the-year from adjacent areas;
3. be applicable independently of the quality and quantity of surrounding vegetation, and under diverse environmental conditions;
4. include a population monitoring strategy;
5. be species-selective;
6. be safe for humans to implement;
7. be socially acceptable; and
8. be financially available.

A Proposed IPM Program for Northern Pocket Gophers

An IPM program for Northern Pocket Gophers hinges on the implementation of the border control strategy where killing traps are used to remove resident pocket gophers and to intercept invaders in perimeter traplines (Table 5; see Proulx 1997a for details). It also involves natural predators, mainly birds of prey and Long-tailed Weasels. In order to maintain predators in their fields, farmers must create shelter belts and rock piles to provide small carnivores with cover protection and dens, and large trees to provide birds of prey with nest sites. Post fences usually provide raptors with appropriate perches.

The success of an IPM program depends on an effective population monitoring program that allows farmers to recognize signs of re-invasion by Northern Pocket Gophers. The presence of mounds and earth plugs (see Proulx 1997b, 2002b) indicates that pocket gophers have reinvaded empty burrow systems.

In the past, the efficacy of the border control strategy was publicized through education pamphlets that were distributed to farmers (Proulx 1996). This control technique was used by many farmers for a few years. However, pesticide companies continued to promote their products and they claimed that poisons were faster to apply and more efficient than trapping. After a few years, farmers reverted to the use of poisons (Proulx, personal notes). Educating farmers about the efficacy of control methods must be repeated year after year, and ineffective control methods must also be denounced yearly. I recommend that municipalities organize regional meetings for farmers. At these meetings, specialists who have worked with the species to be controlled, and have scientifically tested different control methods, should explain the ecology and management of species, the advantages and disadvantages of various control methods, and answer questions. During these meetings, it is important to involve local, successful farmers who have used the recommended control techniques or who endorse the proposed IPM program. Farmer and naturalist associations, PMRA, and provincial government agencies should work in concert to produce a website where farmers may find factual information about the control of rodents in various crops and at different times of year, and about other techniques such as field rotations and habitat management for predators. The website needs to be updated regularly to make sure that the information is current and relevant.

Finally, in order to control Northern Pocket Gophers over landscapes, I recommend that farmers meet and develop a strategy to work together at the implementation of an IPM program. Working together, farmers can implement methods such as the border control strategy, reduce their costs, and better control re-invasions from adjacent fields.

Table 5. Proposed IPM program for Northern Pocket Gophers.

Activity type	***Method***	***Requirement***	***Advantage***
Chemical control	None	-	This saves money to farmers
Mechanical Control	Border control strategy (Proulx 1997a) with killing box traps (Proulx 1997b).	Control must be initiated in spring before the birth of the young of the year, and maintained during the growing periods to intercept invaders in perimeters traplines.	The trapping technique is selective, safe to people, more acceptable than harmful poisons, and cheaper in the long-term.
Cultural	Maintain or establish shelterbelts along fences	The shrub border must be thick and with grasses to protect pocket gopher predators in their movements.	While the shrub border will retain snow, it will entice terrestrial and avian predators to visit fields that may be invaded by pocket gophers.
Natural Control Agents	Protect predator communities, namely birds of prey and Long-tailed Weasels.	Protection cover for terrestrial predators and perches for birds of prey must be present.	Predators help in capturing invading pocket gophers during summer, and to kill them in winter when trapping cannot be conducted.
Population Monitoring	Border control strategy (Proulx 1997a)	The border control strategy includes a monitoring strategy that allows farmers to identify re-invasion by pocket gophers.	This allows farmers to maintain control over their fields.
Education	Pamphlets and websites to explain the biology and control of pocket gophers to farmers.	Pamphlets must be made available before the beginning of the growing season to allow farmers to acquire necessary control equipment and develop a strategy for their own fields.	Farmers can find out about the true efficacy of products, eliminate ineffective poisons, and implement an effective multi-faceted control program.
Community Approach	Involving neighbors and local councils at meetings to establish a community-wide control program.	Meetings must be conducted before the growing season to put in place a strategy for the whole community.	Farmers would help each other in the control of populations and the maintenance of complex communities with natural predators.

A Proposed IPM Program for Richardson's Ground Squirrels

An IPM program for Richardson's Ground Squirrels encompasses many different control methods (Table 6). However, farmers should not initiate a program to control Richardson's Ground Squirrels until they have determined the extent of the infestation. Concentrations of ground squirrels at the edge of a field does not justify poisoning the whole field. The use of site-specific poisons such as aluminum phosphide allows one to kill ground squirrels in their burrow system while the animals are sleeping (see Proulx et al. 2011a for methodology). If some animals escape treated burrow systems, they pose no danger for predators and scavengers. If the ground squirrel infestation is over large areas, farmers may use strychnine and chlorophacinone (not in alfalfa fields) but they must implement a strict protocol to treat burrow systems and retrieve animals that are dying or are dead on surface. Because it is particularly difficult to find carcasses in fields with taller grass (e.g., McKinnon et al. 2002), I recommend that farmers treat small portions of their field, particularly those with the highest ground squirrel densities. This will allow farmers to assess the efficacy of the poison (since some rodenticides such as strychnine may not be reliable under specific environmental conditions) and to be more successful in their search of carcasses over smaller areas.

Although more research should be conducted on shooting, this control technique has long been used by farmers in the last decades (Proulx, personal observations). It allows farmers to be highly selective in the removal of animals. When controlling large populations, farmers may consider amalgamating two different methods. For example, shooting could be followed by a treatment with aluminum phosphide. Then, there is little risk of secondary poisoning while controlling large populations.

Finally, natural control by predators must be included in the IPM program. Proulx et al. (2011b) showed that American Badgers, Long-tailed Weasels, and Red Fox were effective ground squirrel predators. Michener (1979) and Proulx et al. (2011b) suggested that Long-tailed Weasels could control more than 50% of Richardson's Ground Squirrels in spring and early summer. Lokemoen and Duebbert (1976) reported the presence of Richardson's Ground Squirrel remains in 96% of Ferruginous Hawk regurgitation pellets. Schmutz et al. (1980) found that ground squirrels averaged 89% of the total prey items for Ferruginous Hawks during the nestling period. Schmutz and Hungle (1989) found that Richardson's Ground Squirrels represented 82% of prey items of Swainson's Hawks. In Alberta, Richardson's Ground Squirrels represented 68% of preys brought by Prairie Falcons (*Falco mexicanus*) at nests (Hunt 1993). All these predators have a significant impact on ground squirrel populations. It is therefore advantageous to farmers to establish shelters for these animals at the edge and within their fields.

As with Northern Pocket Gophers, education tools, the enlistment of successful producers, and a community approach are vital for the development of an effective IPM program for Richardson's Ground Squirrels.

Table 6. Proposed IPM program for Richardson's Ground Squirrels.

Activity type	***Method***	***Requirement***	***Advantage***
Chemical control	Aluminum phosphide (Proulx et al. 2011a) where ground squirrels exceed >5 animals/ha over relatively small areas, and where there is a risk of poisoning predators. Chlorophacinone in grasslands and strychnine in alfalfa fields, with strict placement of baits in burrows and daily removal of carcasses and moribund animals, to control ground squirrel population outbreaks over large areas	Control must be conducted early in early spring to remove male adults, and in late spring to remove female adults. Chemical control should be conducted immediately after severe rainstorms when many animals have already perished because of hypothermia or drowning (Proulx 2012).	Removing breeders in the spring would reduce the number of juveniles during summer.
Mechanical Control	Shooting to selectively remove ground squirrels.	Control must be initiated in spring before the births of the young of the year. Shooting must be conducted even when the controlled population has been largely reduced in numbers.	Shooting is highly selective, safe to people, more acceptable than harmful poisons, and protects predator populations.
Cultural	Maintain grasslands with ≥15cm-high vegetation to reduce invasion by ground squirrels (Proulx et al. 2012).	A strict rotation system must be implemented to avoid over-grazing by cattle. Grassland vegetation should be diversified to survive droughts and floods.	Maintaining healthy fields with tall vegetation reduces the need for ground squirrel control over summer, and provides predators with cover when hunting for ground squirrels and other rodents.
Natural Control Agents	Protect predator communities, namely birds of prey, American Badgers and Long-tailed Weasels.	Protection cover for terrestrial predators and perches for birds of prey must be present.	Predators help in capturing resident and invading ground squirrels. Badgers are particularly efficient to control ground squirrels in winter when other control methods cannot be implemented.

Activity type	*Method*	*Requirement*	*Advantage*
Population Monitoring	The densities of ground squirrels can be monitored using Proulx et al.'s (2012) 280-m-long transect method. Regular field visits allow farmers to confirm the presence of ground squirrels in their fields.	Better knowing the location of ground squirrel concentrations allow farmers to select appropriate control techniques and to act rapidly before the juveniles of the year emerge from burrow systems.	This allows farmers to maintain control over their fields.
Education	Pamphlets and websites to explain the biology and control of Richardson's Ground Squirrels to farmers.	Pamphlets must be made available before the beginning of the growing season to allow farmers to acquire necessary control equipment and develop a strategy for their own fields.	Farmers can find out about the true efficacy of products, eliminate ineffective poisons, and implement an effective multi-faceted control program.
Community Approach	Involving neighbors and local councils at meetings to establish a community-wide control program.	Meetings must be conducted before the growing season to put in place a strategy for the whole community.	Farmers would help each other in the control of populations and the maintenance of complex communities with natural predators.

Registration and Enforcement

The registration of products used in the chemical control of rodents, and the enforcement of the baiting directions and use restrictions, are important to minimize rodenticide misuse and abuse. The effectiveness of a rodenticide, and its registration, must be based on scientific assessments carried out in the field. If a registered product is found to be ineffective to control a species under specific conditions, its registration should be reviewed by PMRA. A federal-provincial system needs to be established so that farmers can report when, where and how they plan to use a rodenticide. Provincial and Federal Conservation Officers and PMRA Inspectors could then visit treated sites and confirm that poison baits have been properly used. Inspectors should travel rural areas and recognize improper applications of poison baits on surface or with the use of inadequate bait stations. The use of poisons, and the implementation of IPM programs, requires that government authorities keep a strong watch on people who misuse rodenticides and falsely claim that they are following the recommendations of IPM programs.

Finally, there is a need to integrate IPM and Species-at-Risk programs. Where the presence of Species-at-Risk is known, federal and provincial Conservation Officers should work together to ensure that actions to

control Northern Pocket Gophers and Richardson's Ground Squirrels do not endanger the future of Species-at-Risk at the local level.

Discussion

Much has been learned about poison efficacy and selectivity during the Northern Pocket Gopher and Richardson's Ground Squirrel control research programs. These research programs led to the development of the border control strategy for Northern Pocket Gophers (Proulx 1997a), the confirmation that aluminum phosphide was an effective control method for Richardson's Ground Squirrels (Proulx et al. 2011a), and the identification of predators that can contribute significantly to the control of pocket gophers and ground squirrels population densities (Proulx 2000, Proulx et al. 2011a). The IPM programs proposed in this paper integrate these findings and those from other research programs over several years. The proposed IPM programs are based on a state-of-the-art understanding of the biology of the rodent species, and on factual information about control methods. However, these IPM programs still need to be tested under different environmental conditions to determine how and when to use control methods to effectively control rodent populations and avoid destroying non-target populations and predator communities. Not one of the control methods for Northern Pocket Gophers and Richardson's Ground Squirrels will work alone. Even with the border control strategy for pocket gophers, there is a need to maintain Long-tailed Weasels to control Northern Pocket Gopher in winter. Although tall vegetation will help maintain low densities of Richardson's Ground Squirrels, aluminum phosphide will be needed in areas with larger concentrations of animals.

None of the methods identified in IPM programs will succeed in controlling pocket gophers and ground squirrels during population outbreaks (Witmer and Proulx 2010). An IPM program must be perceived as a preventive approach to avoid population outbreaks. It is therefore necessary to continuously monitor populations at landscape level, and determine how and when an IPM program needs to be implemented to avoid population outbreaks.

Season after season, and year to year, farmers have used large quantities of strychnine and chlorophacinone baits to control Northern Pocket Gophers without success. One would think that these repeated uses and poor control performances would suffice to convince farmers to use alternative methods. However, old ways die hard! When farmers complain that trapping is labour-intensive, they fail to recognize that applying poison baits also takes time, and it is a waste of time if these poisons do not work well. The use of strychnine to control Richardson's Ground Squirrels and the use of chlorophacinone in alfalfa fields are examples of poor registration standards and undue political interference in the practice of pest control. Fortunately, with the proposed IPM programs, errors of judgement and poor poison management practices can be corrected. Knowing that healthy predator communities can control more than 50% of rodent populations, farmers can change their attitude towards American Badgers, Long-tailed Weasels and Red Foxes and find ways to accommodate their needs and benefit from their hunting activities. Education is often enough to convince farmers to change their ways. However, for those farmers who are concerned only with making profits at all costs, enforcement may be necessary to ensure they implement control alternatives.

Registering strychnine, even though it is unreliable and non-selective, is an example of a lack of logic within our governments. Indeed, every year millions of dollars are spent on the assessment of the status of species and the development of recovery programs often involving the re-introduction of Species-at-Risk. At the same time the government allows farmers to endanger Species-at-Risk with poison baits that are ineffective

towards the intended target species. PMRA, provincial agriculture departments, and Environment Canada need to work together to ensure that IPM programs are being used instead of devastating poisons.

In conclusion, registering poisons and developing prescription labels on how to use them will not ensure the long-term control of Northern Pocket Gopher and Richardson's Ground Squirrel populations, and the protection of predators and Species-at-Risk. The long-term control of these rodents and the conservation of wildlife in agricultural regions are tied to the successful development and implementation of IPM programs, along with an effective registration of chemical products, and the proper enforcement of bait application directions to minimize the misuse of poisons.

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ANTICOAGULANT RODENTICIDES ARE PERVASIVE CONTAMINANTS OF TERRESTRIAL BIRDS OF PREY

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Abstract: Previous studies, including our own, have reported a high incidence of liver residues of commonly used second generation anticoagulant rodenticide (SGAR) compounds, in raptors, especially rodent-eating hawk and owl species. A proportion of birds tested commonly exhibit symptoms of anti-coagulant poisoning. In the present study we widened the scope of sampling to include other hawk and falcon species. Of 130 raptors analyzed using high resolution GC/MS/MS from a recent survey of birds collected between 2005 -2011, from a predominantly agricultural and/or urban landscape, 94% had detectable liver residues of at least one SGAR compound. Barred (*Strix varia*) and Great Horned Owls (*Bubo virginianus*) had the highest incidence of exposure and the greatest residue concentrations. The mechanism by which this occurs might be partly explained by a shift in the diet of Barred and Great Horned Owls, as a concurrent diet study showed that the consumption of rats and house mice coincides with increased urbanization within home ranges. In particular urban Barred Owls had the largest proportion of rats in their diet, with some individuals' diet consisting primarily of rats. The shift in the diet of owls living in urbanized areas may potentially lead to an increased risk of secondary SGAR poisoning. However, 5 of 5 Peregrine Falcons (*Falco peregrinus*) and 5 of 5 Sharp-shinned Hawks (*Accipter striatus*) tested had residues of at least two SGAR compounds, indicating pervasive contamination of the food chains of terrestrial birds of prey. The process by which smaller avian prey of falcons and accipiter hawks are contaminated is not known. Temporal trends and spatial patterns of SGAR contamination will be discussed within the context of prairie ecosystems.

Editor's note: Due to unforeseen circumstances, this talk was not given at the conference. The abstract is included in case any readers want to contact the authors about the topic.