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Introduction

Throughout the livestock industry in the western United States, control of canid predators was considered to be of considerable importance to the livestock industry, especially to sheep producers, who suffered high losses from coyotes and wolves. In the 19th century, the demand for predator control was communicated to Congress and the western state assemblies, with the result that predator control was provided in western states by the Federal Bureau of Biological Survey in cooperation with state agencies, and by trappers hired by stockmen. Steel traps and poisons were the principal methods used for predator control during the early years of the program. Historically, predacides have been used in the United States primarily to control wolves, coyotes, and red foxes that prey on livestock. Strychnine was employed in the late 1800s and early 1900s to collect wolf carcasses (Quaife, 1973). Strychnine drop baits were employed for coyote and fox control through the 1960s. Drop baits consisted of strychnine tablets put in small pieces of perishable fats then placed around unpoisoned decoy carcasses (Robinson, 1962). Meat baits impregnated with a lethal agent, either thallium sulfate or Compound 1080, were used between 1937 and 1972 (Robinson, 1942). Currently, three predacides are available for use in controlling coyotes, foxes, wild dogs, and arctic fox. This paper will provide a description of these toxicants and the current status of their use in predator control in the United States.

Gas Cartridge

Gas cartridges were developed by the former Bureau of Biological Survey more than 40 years ago and have been used since then to control burrowing rodents and canid predators in dens. The USDA/Animal and Plant Health Protection Service (APHIS) currently registers the Large Gas Cartridge with the EPA. The gas cartridge is a fumigant for control of coyotes, red foxes, and striped skunks (*Mephitis mephitis*) in dens. It is not classified as a restricted-use pesticide, so no special training is required for its use. The APHIS gas cartridge contains two active ingredients, sodium nitrate and charcoal. The gas cartridge is placed in a den, ignited, and the entrance to the den is sealed. The main combustion product is carbon monoxide, which kills the animals quickly and humanely (Savarie et al., 1980; Savarie, 2002).

Gas cartridges are used primarily during the spring, when coyotes are rearing young and predation on livestock is highest (Till and Knowlton, 1983). The gas cartridge poses few non-target risks because the dens of target animals can be identified by tracks, scat, and animal observations and dens selectively fumigated. Because the cartridge contains only sodium nitrate and charcoal, the EPA has no concerns regarding the environmental fate of the cartridge ingredients. The nitrate is very mobile, and in soil and water serves as a plant nutrient source. The charcoal is immobile and is slowly degraded by microorganisms in soil, whereas in water it floats and disperses. Bioaccumulation in animal tissues does not occur.

Gas cartridges are available through the APHIS Wildlife Services Pocatello Supply Depot and can be purchased from Wildlife Services state directors or hardware stores.

Sodium Cyanide (M-44)

Sodium cyanide (NaCN) ejectors have been used in predator damage control programs since the late 1930s. The first device developed was called the Humane Coyote Getter, commonly known as the Coyote Getter (Blom and Connolly, 2003). When the coyote pulled on the top of the ejector, a .38 Special cartridge was fired that ejected sodium cyanide into the coyote's mouth from a case containing the toxicant. A scent attractant was used to draw the coyote to the device. The Coyote Getter was used in federal predator control programs until the 1970s. All predacidal uses of sodium cyanide were canceled by the EPA in 1972 because of non-target hazards.

In 1975, sodium cyanide was registered by the U. S. Fish and Wildlife Service (now transferred to APHIS) for use in the M-44, a device similar to the Coyote Getter. The M-44 consists of a base that is placed in the ground to contain the ejector, the capsule holder, a capsule containing sodium cyanide, and an ejector mechanism with a spring-driven plunger that expels the sodium cyanide capsule contents. The capsule holder is wrapped with absorbent material that contains an attractant scent and protrudes above the ground. As with the Coyote Getter, the attractant draws the coyote to the device; when the coyote pulls on the top of the M-44, the ejector is triggered and sodium cyanide is ejected into the animal's mouth. APHIS currently holds two registrations of the M-44 device with the EPA. One label is registered for control of coyotes, foxes and feral dogs that prey upon livestock and poultry, threatened or endangered species, or are vectors of communicable disease. The second label is for control of arctic foxes that prey on threatened or endangered species in the Aleutian Islands, Alaska.

Sodium cyanide is a white granular solid that, when in contact with carbon dioxide or fluids, such as in an animal's mouth, forms toxic hydrogen cyanide (HCN) gas, which is colorless. HCN poisons the cytochrome-oxidase system of cells and lethal doses are rapidly fatal. HCN is immediately dangerous at 150 ppm and a concentration of 200 ppm will quickly kill a human. Amyl nitrate is an effective antidote if used quickly after exposure. Non-target animals can be poisoned if drawn to the device, but few of these animals are killed. This reflects the use of specialized lures that selectively attract canids.

Sodium cyanide used in the M-44 does not pose an environmental risk to soil or water. It is moderately stable in light, is degraded by soil microorganisms to non-detectable levels in about 24 hours, and has low mobility. It is rapidly hydrolyzed in water and slowly degraded by aquatic organisms. Bioaccumulation in animal tissue does not occur because cyanide has low-fat solubility.

Compound 1080

Monofluoroacetic acid (Compound 1080) was first prepared in Belgium in 1896 but was not seriously investigated as a pesticide until World War II, when toxicants, such as strychnine and thallium sulfate, were not readily available from overseas sources. Compound 1080 was developed during the 1940s for use as a rodenticide. It proved to be highly toxic to canids as well, so 1080 was used for both rodent and predator control in the United States beginning in the mid-1940s. Compound 1080 replaced thallium sulfate (used beginning in 1937) as the preferred toxicant in meat bait stations used in Western states to reduce coyote populations that preyed on domestic livestock. While the two compounds were considered to be equally effective in controlling coyotes, 1080 was preferred because it was cheaper, more readily available, and somewhat more selective for target animals (Robinson, 1942). Use of bait stations increased until 1964, when approximately 16,000 toxic bait stations were placed by the U.S. Fish and Wildlife Service's Predator & Rodent Control program (Connolly, in press). After 1964, use of Compound 1080 declined until 1972, when an Executive Order banned use of 1080, sodium cyanide, and other predacides from use on Federal lands and in Federal programs.

Beginning in 1977, Compound 1080 use was allowed for experimental use in livestock protection collars. It was also allowed for use in single-dose coyote baits between 1983 and 1985 (Connolly, in press). In 1985, APHIS received a conditional registration from the EPA for technical Compound 1080 for use only in the Livestock Protection Collar (LPC). The collar has two rubber reservoirs containing a 1080 solution and is attached around the neck of sheep or goat in areas where coyotes are killing livestock. When the coyote attacks the collared sheep, it bites the collar and receives a lethal dose of the toxicant. The LPC is highly regulated. It can only be placed on livestock in fenced pastures by trained and certified applicators. Use of the LPC is highly selective because it targets only those coyotes doing the killing. However, successful implementation requires a high level of livestock management to direct the coyotes to the collared sheep, and its use is therefore not appropriate for many depredation situations.

Sodium monofluoroacetate is a white, tasteless compound that is soluble in water. It is absorbed in the gastrointestinal tract, where it is metabolized to fluorocitrate, blocking the Krebs cycle. Death results within 24 hours from cardiac arrest and/or central nervous system failure. A wide variation in toxicity exists between different species, with greater toxicity to mammals than to birds, and with very low toxicity to fish. Canids are among the most sensitive species. The use of 1080 in the Livestock Protection Collar allows little exposure to nontarget species; therefore, the potential for primary or secondary hazards to non-target species is low. Environmental hazards of 1080 are also minimal, both because of its limited and selective use and because of its chemical characteristics. Compound 1080 is degraded by soil microorganisms within one to two weeks. It is not hydrolyzed in water but undergoes a slow degradation by aquatic organisms; mobility is high because of its solubility.

Predacide Risks

Most pesticides hold some potential for risk to wildlife, but currently registered canid predacides are generally very safe, especially when compared to other pesticides. Several factors limit risks to wildlife, including: (1) safeguards provided by the registration process; (2) the low volume of use of these pesticides; (3) the limited area of application; (4) specificity in the action of these pesticides; and (5) the fact that the pesticides are targeted to specific animals or situations. Considering the first point, the EPA registration process lends a large degree of safety to pesticide products by requiring extensive data on product chemistry, human health hazards, environmental fate, and toxicity to nontarget birds, fish, and invertebrates. In addition, for vertebrate pesticides, the EPA frequently requires efficacy and non-target hazards data not generally required for other types of pesticides (Fagerstone et al., 1990; Ramey et al., 1994).

The second characteristic that provides a margin of safety for vertebrate pesticides is the low volume of use compared to insecticides, fungicides, and herbicides. The total use of pesticides in the United States (for residential, agricultural, and other uses) averages 1.2 billion pounds (Fagerstone, 2002). Use of canid predacides is an insignificant portion of pesticide use. To illustrate, in 2000, the Wildlife Services program used only 352 pounds of sodium nitrate in canid fumigants and less than one pound of Compound 1080 in the LPC. Wildlife Services and state cooperators used less than 200 pounds of sodium cyanide in the M-44 (compared to about 215 million pounds of sodium cyanide used each year in mining operations). Another factor limiting risk from canid predacides is the use pattern of the vertebrate pesticides. Most are used in very limited areas, such as the gas cartridge (placed in dens), the M-44 (placed on paths frequented by predators), and the LPC (placed around the neck of a few sheep in pastures where livestock depredation is occurring).

Future of Predacides in the United States

Sodium cyanide, Compound 1080 and the Large Gas Cartridge are the only predator toxicants legally available in the United States. However, several states have banned use of sodium cyanide and Compound 1080. As toxicants are an essential component of nearly all integrated pest-management programs, these bans severely restrict the ability of ranchers and pest-control operators to limit livestock losses caused by predators, such as coyotes. As development and U.S. Environmental Protection Agency (EPA) registration of new toxicants typically takes at least five to ten years, it behooves the agricultural community to proactively develop new predator toxicants that are compatible with existing delivery systems (M-44 and Livestock Protection Collar) and are safer to humans, non-target wildlife and the environment.

Because the USDA/APHIS/ Wildlife Services is committed to supporting the U.S. livestock industry, the Wildlife Service's National Wildlife Research Center (NWRC) is actively investigating new candidate predacides. Criteria for the selection and development of these new substances were outlined by Savarie and Connolly (1983). These include effectiveness, taste and odor, speed of action, hazard to humans, antidote, environmental safety, regulatory concerns, cost and availability. Candidate predacides currently under study include theobromine and caffeine. Both of these materials are selectively toxic to canids and are present in high concentration in extracts of tea, coffee and cocoa plants. Evaluating plant extracts that are rich in theobromine and caffeine against the predacide selection criteria provides insight into the advantages, disadvantages, and likely success of this research project.

Effectiveness. The propensity for canids to overdose on methylxanthines via ingestion of chocolate is well documented in the veterinary literature (Farbman, 2001; Gwaltney-Grant, 2001; Pittenger, 2002). While theobromine doses as low as 100 mg/kg have been acutely toxic to dogs (Paul, 1984) the median oral lethal dose (LD50) for caffeine and theobromine to domestic dogs is estimated at 140 and 300 mg/kg, respectively (RTEC, 2002). For most compounds, a dose of three times the LD50 is usually lethal to 100 percent of the population. Assuming that the toxicity of these compounds is similar in dogs and coyotes, we need to develop a product that is capable of administering oral doses of 420 to 900 mg/kg.

Taste and odor. Substances with noxious taste or odors are likely to be rejected by coyotes. Such substances are poor choices for predacides, even if they exhibit a high degree of toxicity to the target species (Savarie and Connolly, 1983). As indicated by statistics from the National Animal Poison Control Center and numerous articles in the veterinary literature, chocolate is readily consumed by canids (Farbman, 2001; Gwaltney-Grant, 2001; Pittenger, 2002). As such, we are hoping theobromine-rich chocolate extracts will likely be palatable to canid predators.

Speed of action. The speed of action of effective pesticides varies greatly. Some pesticides (i.e. zinc phosphide) exert their toxic effects on the target species within minutes of exposure. Other pesticides (i.e. diphacinone) may require several days post ingestion to effect acute toxicity (Connolly et al, 1976; Connolly, 1980). While a quick acting predacide may be preferable to some ranchers and pest-control personnel, a slower-acting predacide offers a higher margin of safety with respect to non-target pets and wildlife. This is because a gradual onset of toxicosis provides opportunities for veterinary intervention to assist accidentally exposed animals. As acute toxicity resulting from methylxanthine ingestion typically occurs 6 to 24 hours post ingestion, accidentally exposed canids may be successfully treated at a veterinary clinic.

Antidote. The availability of an antidote or effective medical treatment to reverse the toxic effects of a pesticide increases the safety associated with its use. Given the frequent exposure of dogs to chocolate, veterinary supportive therapy procedures to minimize the effects of the ingested methylxanthines are well known: (1) induced vomiting eliminates unabsorbed methylxanthines from the gastrointestinal tract; (2) multiple oral doses of activated charcoal accelerate depletion of methylxanthines from blood; and (3) an orally administered saline solution is beneficial to maintain electrolyte concentrations (Hornfeldt, 1987; Farbman, 2001). For humans and many other species, no antidote is generally required.

Hazard to humans. All currently registered predacides are extremely toxic to humans. Sodium cyanide is a well-known human toxicant. As Compound 1080 is a broad spectrum mammalian toxicant, it too is very toxic to humans. While the exact lethal doses for humans are unknown, the rat oral LD50s for sodium cyanide and Compound 1080 are 15 mg/kg (Budavari, 1996) and 0.2 mg/kg (Meister, 1998), respectively. For theobromine, the rat oral LD50 is 1,250 mg/kg. It is likely that humans are even more tolerant of caffeine and theobromine. Despite high consumption of caffeine and theobromine in coffee, tea, cola beverages and chocolate, there is no documented human mortality associated with consumption of these products (New York, 1979). Put another way, while a dose of just three ounces of baker's chocolate can be toxic to a 10 kg dog, an equivalent dose of 21 ounces of chocolate to a 70 kg human is essentially harmless (Kreiser and Martin, 1980; Blauch and Tarka, 1983; Winston and Nguyen, 1984).

Environmental safety. Selective toxicity is extremely desirable to minimize accidental poisoning of non-target animals. The available evidence suggests that methylxanthines are selectively toxic to canids, as reports of accidental poisonings due to the consumption of methylxanthines appear to be limited to these species. The enhanced toxicity of methylxanthines to canids is believed to be due to their inability to efficiently metabolize methylxanthines (particularly theobromine) via enzymatic N-demethylation to compounds which are readily excreted via urine. In a theobromine metabolism study of rats, mice, hamsters, rabbits, and dogs, dogs were unique in their near inability to demethylate theobromine at the N-3 position (Miller et al., 1984).

As stated previously, mode of application increases the selectivity of predacides. Most likely, methylxanthines would be most effectively delivered in devices such as the LPC, and thus, only livestock killing canids would be exposed. While non-target species may be exposed to low levels of methylxanthines on carcasses of predator-killed sheep wearing punctured livestock protection collars, the selective toxicity of methylxanthines to canids should minimize secondary hazard concerns. Environmental concerns associated with the contamination of soil and plant materials from punctured livestock protection collars should be insignificant as the methylxanthines will be composed of biodegradable, natural plant extracts.

Cost and availability. Pure analytical grade methylxanthines, such as caffeine, theobromine, and theophylline, are widely available through chemical supply sources. The livestock protection collar will likely need to contain approximately six grams of active ingredient. For the pure active ingredient, this would cost approximately $0.25 per collar. However, if the predacide is prepared as a crude extract of natural plant materials, the cost will likely be significantly less.

Regulatory concerns. All pesticides including predacides, must be approved for use by the U.S. Environmental Protection Agency. Acceptance criteria include efficacy, safety, and environmental hazards. As previously discussed, plant-derived methylxanthines, such as theobromine, should display high levels of efficacy and selectivity toward canid predators while being environmentally benign. Based on these characteristics, it is reasonable to infer that a methylxanthine-based predacide should fare well with respect to U.S. EPA pesticide-registration criteria.

Societal acceptance. Historically, the fear associated with the use of predacides has limited societal acceptance of these compounds. Groups which oppose predator control in the United States have successfully capitalized on this fear to garner support for anti-predator control initiatives. Development of a predacide based on the active ingredients in substances that the general population embrace daily (chocolate, tea, coffee) could permit society to evaluate these compounds based on realistic benefits and risks rather than emotion.

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