Review of Synthetic Predator Odor Semiochemicals as Repellents for Wildlife Management in the Pacific Northwest

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ABSTRACT

The use of synthetic predator odor semiochemicals as area repellents has considerable potential for protection of forest and agricultural crops. Certain predator odors originating from feces, urine, or scent (anal) gland secretions elicit a "fear" response when detected by prey species. At least some genera (e.g., *Microtus*) appear to have an innate response to these odors. Synthetic constituents from the weasel family (Mustelidae) have been particularly effective in laboratory and field bioassays with a variety of mammal species. Semiochemicals from the stoat *(Mustela erminea)* and red fox *(Vulpes vulpes)* have successfully reduced feeding damage to forest seedlings by snowshoe hare *(Lepus americanus)*. Synthetic compounds from stoat anal gland secretions have generated significant avoidance responses in voles *(Microtus montanus* and *M. pennsylvanicus)* and northern pocket gophers *(Thomomys talpoides)* in small-scale field trials. When applied on a larger scale (1–4 ha), some degree of population disruption has been recorded for both pocket gophers and montane voles. Field trials of semiochemicals for protection of coniferous tree seedlings from feeding by black-tailed deer *(Odocoileus hemionus columbianus)* have yielded inconsistent results. However, commercialization of semiochemical products (mammal management devices) is expected in the very near future.

KEY WORDS

predator, odor, fear, repellent, semiochemical, innate

INTRODUCTION

Damage inflicted by the feeding habits of herbivorous mammals has been a growing concern for foresters since the beginning of artificial regeneration efforts during the early 1900's. In 1940, the first comprehensive description of wildlife damage within the Douglas-fir region of Oregon

and Washington was completed (Moore 1940). Today, it is recognized that the mammals responsible for the greatest amount of damage to forest and agricultural lands of the Pacific Northwest are white-tailed, black-tailed, and mule deer *(Odocoileus virginianus, O. hemionus columbianus,* and *O. h. hemionus,* respectively), northern pocket gophers *(Thomomys talpoides),* mountain beavers *(Aplodontia rufa),* voles *(Microtus* spp.), snowshoe hares *(Lepus americanus),* elk *(Cervus elaphus),* and porcupines *(Erethizon dorsatum).* These animals damage crop trees by feeding on the bark, vascular tissues, roots, buds, and/or foliage of seedling to pole-sized trees. Crop trees can also be damaged by animal activities not associated with feeding, such as antler rubbing by deer or nest construction by some rodents.

The economic impact of wildlife damage is very significant. Wildlife damage can be directly responsible for plantation failures as well as decreased and delayed yields for forest and agricultural crops. In 1984, approximately $5.5 million was spent on direct animal damage control on 40,470 ha of National Forest System lands (Black and Lawrence 1992). In 1988, direct control of animal damage on 84,178 ha of western National Forest System lands was estimated to have cost $9 million (Borrecco and Black 1990). Because today's forest practices are becoming more management intensive than ever before (intensive silviculture, stricter guidelines for reforestation, etc.) and the land base from which to practice forestry on is continually decreasing, future losses due to animal damage will be far more costly than in the past.

Traditional methods of controlling mammal damage have involved the use of toxicants (poison baits). However, there are two major disadvantages with this approach: (1) it is often not effective in reducing the numbers of target animals (resiliency of target animals to repopulate poisoned area, development of resistance to bait formulations, and poor bait acceptance) and (2) the unacceptable hazards to nontarget species (Sullivan et al. 1988*a*). The drawbacks of this traditional method of wildlife management suggests the need for an alternative approach.

The use of synthetic predator odors has considerable potential as area repellents for controlling problem mammals in forest and agriculture situations. Specific chemicals found in the urine, feces, and anal scent-glands of several predator species are thought to function as pheromones (intraspecific chemical signals). In addition, several studies (Epple et al. 1993; Melchiors and Leslie 1985; Merkens et al. 1991; Müller-Schwarze 1972, 1983; Nolte et al. 1993; Sullivan 1986; Sullivan and Crump 1984, 1986*a,b*; Sullivan et al. 1985*a,b*, 1988*a,b,c,* 1990*a,b*; Swihart et al. 1991; Vernet-Maury 1980; Vernet-Maury et al. 1984) support the hypothesis that predator odors also function as kairomones (interspecific chemical signals) for prey species that perceive the odors as "danger" signals and warn them that a predator is nearby. Perception of predator odors is thought to elicit a "fear-of-predation" response in prey animals which, in turn, causes the animal to seek out alternative, less threatening habitat.

The result is that the target animal is repelled from the treatment area and damage to treated crops consequently declines. In addition, the potential for synthetic predator odors to function as pheromones that attract the real predators into a treatment area also exists. An increased population of real predators would, of course, also aid in the control of prey animals.

This paper summarizes the results from numerous experiments designed to determine the effects that various synthetic predator odors have had on animal behavior, population dynamics, and, ultimately, degree of damage to both forest and agricultural crops.

STUDY AREAS

Several of the experiments reviewed within this paper were conducted in agricultural fields and fruit tree orchards located in the Okanagan Valley, a semiarid region of southern British Columbia, Canada. In addition, a great deal of research has been performed within young, forested environments, ranging in location from the north-central to the southern coast of British Columbia.

METHODS

Predator Odors

Several synthetic predator odor semiochemicals are referred to throughout this paper. Table 1 lists these semiochemicals, their abbreviations, the predator species and material from which they were derived, and relevant literature which can be consulted for more information regarding the properties and synthesis of these compounds.

Experimental Design

The design of the experiments reviewed within this paper generally involve observing the effects that synthetic predator odors have on animal behavior (trap success), abundance and distribution (live-trap inventories), and degree of feeding damage inflicted on test plants when compared with controls. Synthetic predator odors have been dispensed from a variety of release devices including capillary tubes, clay pellets, rubber septa, and plastic (PVC) rods. Depending on the experimental design, these release devices were either placed within live traps, throughout the treatment area (broadcast application), or near test plants.

Statistical Analysis

For the majority of the experiments reviewed within this paper, control-treatment pairs were compared and analyzed by Chi-square with significance levels of $P<0.05$ and $P<0.01$. Nonparametric data, such as percent data (e.g., percent of sampled trees damaged by voles), were normalized by an arcsin square root transformation prior to analysis.

RESULTS

Voles

Various trap bioassays performed in old field grassland habitat indicated that montane vole *(Microtus montanus)* captures were significantly (Chi-square, $P<0.01$) reduced in areas that had

Table 1. Synthetic Predator Odor Semiochemicals and the Source Material From Which They Were Derived

Semiochemical	Abbrev.	Source	Literature
2-propylthietane	PT	Anal gland secretion from stoat *(Mustela erminea)* and ferret *(M. putorius)*	Crump 1978, 1980*a,b,* 1982
3-propyl-1,2-dithiolane	PDT	Anal gland secretion from stoat and ferret and from cougar (*Felis concolor)* feces	Crump 1978, 1980*a,b* 1982, Sullivan and Crump, unpubl.
2,5-dihydro-2,4,5-trimethylthiazoline	TMT	Feces from red fox (*Vulpes vulpes*)	Vernet-Maury 1980, Vernet-Maury et al. 1984, Sullivan et al. 1988*b*
3,3-dimethyl-1,2-dithiolane	DMDIT	Anal gland secretion from stoat and ferret and feces from red fox	Crump 1980*a, Vernet-Maury et al. 1984*
3-methyl-3-butenyl methyl sulfide or $\triangle^3$- isopentenyl methyl sulfide	MBMS	Urine from red fox, wolf (*Canis lupus*), coyote (*Canis latrans)*, and domestic dog, and anal gland secretion from mink (*Mustela vison)*	Jorgenson et al. 1978, Wilson et al. 1978, Bailey et al. 1980, Sokolov et al. 1980, Whitten et al. 1980, Raymer et al. 1986, Sullivan and Crump 1986a, Schultz et al. 1985, 1988, Sullivan et al 1988*b*
2,2-dimethylthietane	DMT	Anal gland secretion from stoat and mink	Sokolov et al. 1980, Schildknecht et al. 1981
Indole	/	Anal gland secretion from stoat	Crump 1980*b, Sullivan and Crump 1986a*
o-aminoacetophenone	/	Anal gland secretion from stoat	Crump 1980*b, Sullivan and Crump 1986a*

traps treated with PT:PDT (1:1 molar mixture) dispensed via 140-μl capillary tubes (30 mg of test mixture per tube) compared with the control areas (Sullivan et al. 1988*b*). It is also interesting to note the dramatic change in vole abundance within the treatment area before, during, and after the application of the PT:PDT mixture. Fewer voles (74.4%) were captured during the treatment period than during the pretreatment period. During the subsequent trapping period (predator odors removed) vole abundance rebounded to pretreatment levels. No such trend was observed within the control area.

TMT (30 mg (neat) per capillary tube) significantly (Chi-square, $P<0.05$) reduced vole captures in one of two bioassays compared with control areas (Sullivan et al. 1988*b*). This study

noted similar, but insignificant, trends in vole captures for other mixtures of synthetic predator odors when compared with control areas.

During a long-term trapping program (July 1983 to May 1986), it was observed that montane vole abundance and survival decreased significantly (Chi-square, $P<0.05$ or 0.01) during three consecutive winter treatment periods when compared with control areas (Sullivan et al. 1988*a*). Treatments during this experiment involved the synthetic predator odors PT:PDT and TMT, dispensed in an identical manner as in the forementioned experiment. The decrease in abundance, survival, and damage to apple (*Malus* spp.) trees observed during this experiment suggests that the predator odor caused considerable mortality in the vole population. This mortality was speculated to have been caused by physiological stress induced by the predator odors and/or increased predation by predators attracted to the treatment odors.

Incidence of feeding (number of feeding attacks) and intensity of feeding (amount of bark removed) by montane and meadow *(Microtus pennsylvanicus)* voles on various ages of apple trees in orchards has, on several occasions, been shown to be significantly reduced by the application of synthetic predator odors. Percentages of apple trees undamaged by voles during overwinter field bioassays were significantly (Chi-square, $P<0.01$) higher for trees that had been treated with 30 mg of PT:PDT (dispensed within 140-μl capillary tubes and attached to trees with a twist-tie) than for control trees (Sullivan et al. 1988*a,b*). These two studies also reported an equally significant reduction in damage to apple trees treated with TMT. MBMS did not significantly reduce feeding damage. However, because a controlled release device was not used during this experiment, the very volatile nature of MBMS may have exhausted the capillary tube's supply of this repellent before the period of vole damage had passed (Sullivan et al. 1988*b*).

In 1987, an experiment was performed to determine which of four different release devices—clay pellets, capillary tubes, plastic rope, or rubber septa—would be most effective in reducing montane vole feeding damage to young, planted apple trees during an overwinter treatment period (Sullivan et al. 1990*a*). In order to ensure that sufficient feeding pressure was exerted on the test trees, trials were conducted within large pen enclosures, within which vole densities were kept extremely high (271 to 517/ha). All release devices were loaded with 20 mg of PT:PDT mixture (except clay pellets which had an average of 7.7 mg/pellet applied) and were attached or placed near the base of each tree. Results indicated that both the rubber septa and plastic rope release devices were superior to the clay pellets and capillary tubes in reducing both incidence and intensity of feeding damage. In addition, the rubber septa and plastic rope release devices were unique in their ability to significantly (Chi-square, $P<0.01$) suppress feeding damage relative to the control.

Snowshoe Hares

Pen and field bioassays were performed in 1983 to determine the effectiveness of several different synthetic odors (predator odors and closely related compounds) in suppressing feeding damage to lodgepole pine *(Pinus contorta)* seedlings by snowshoe hare (Sullivan and Crump 1984). Capillary tubes (140 μl) were loaded with 30 mg of test compound or mixture and attached with a twist-tie to the base of each treated seedling. Both pen and field bioassays were

consistent in their findings that DMT and PDT (pure) were the most effective semiochemicals for suppressing snowshoe hare feeding. In a field trial, PDT (pure) completely suppressed hare feeding for the entire 38-day treatment period. The longevity of PDT as a repellent indicates that hares certainly do not habituate to this odor. Moreover, the same capillary tubes (containing pure PDT) were used in a later pen trial and still found to be effective at 3.5 months after its initial application.

Bioassays indicated that PDT (in petroleum ether), DMDIT, and PT were less effective as snowshoe hare repellents than PDT (pure) and DMT (Sullivan and Crump 1984). PT, a very volatile compound (b.p. 140 °C), did successfully deter hare feeding for the first 2 days after treatment; however, the effect declined shortly thereafter. It is speculated that a controlled release device, rather than the capillary tubes used during this experiment, would extend the lifespan of this potentially effective repellent. It is interesting to note that this experiment also tested a 1:1 molar blend of PT:PDT and found it to be more effective than PT alone.

Snowshoe hares were quick to habituate to foul-smelling compounds closely related (analogs) to effective predator odors (Sullivan and Crump 1984). This supports the theory that snowshoe hares do not avoid certain synthetic predator odors because of their novel or foul odor (neophobia), but rather because effective predator odors stimulate specific olfactory receptors that, in turn, cause the hares to respond.

Several experiments were carried out to determine the effectiveness of numerous raw materials (feces, urine, anal gland secretions, body odor, and blood) as repellents for the snowshoe hare. The materials tested were feces and urine from bobcat *(Lynx rufus)*, lynx *(Lynx canadensis)*, cougar, coyote, wolf (Sullivan et al. 1985a), and wolverine (Gulo gulo) (Sullivan 1986), urine from red fox (Sullivan et al. 1985*a*; Sullivan and Crump 1986*a*), mustelid scent gland odors, coyote body odor, and some novel odors such as domestic dog urine and 2-methylbutyric acid (a stench compound) (Sullivan et al. 1985*a*). These raw materials were applied under both pen and field environments, undiluted on Petri dishes or within 5-ml plastic vials attached to the base of treated willow *(Salix* spp.) twigs or lodgepole pine seedlings with a twist-tie (fecal odors were prepared by mixing feces and water in a 4:1 ratio). Urine from wolf, coyote, fox, bobcat, lynx, and wolverine, feces from lynx and bobcat, and weasel anal gland secretions were the most effective materials for suppressing hare feeding (Sullivan 1986, Sullivan et al. 1985*a*, Sullivan and Crump 1986*a*). Nonpredator odors such as deer urine and hare blood did not affect the feeding behavior of the snowshoes hare (Sullivan 1986).

Although MBMS (believed to be the active ingredient in red fox urine) was found to be a very effective and significant (Chi-square, $P<0.01$) repellent for suppressing hare damage within both pen and field trials (Sullivan and Crump 1986*a*), results were less dramatic than those observed during an earlier experiment that used mustelid scent-gland compounds (Sullivan and Crump 1984).

Pocket Gophers

Avoidance response by pocket gophers to certain synthetic weasel odors, as indicated by trapping success in both laboratory and field environments, likely supports the hypothesis that predator odors are able to elicit a "fear" response within gophers. Sullivan and Crump (1986*b*)

report that in a laboratory environment gophers avoided traps treated with PT, PDT (polymerized), DMDIT, and a mix of mustelid anal gland compounds including PT, PDT, indole, and o-aminoacetophenone. Predator odors that did not appear to cause an avoidance response in pocket gophers were DMT, MBMS, DMDIT (Sullivan et al 1988*c*), and PDT (not yet polymerized) (Sullivan and Crump 1986*b*). It is not clear why DMDIT was an effective repellent in only one of these two experiments as methods of application were identical in both cases. All compounds and mixtures were dispensed in 140-μl capillary tubes loaded with 30 mg of test material. TMT was also found to be an effective gopher repellent in the laboratory; however, it has not yet been tested in a field application (Sullivan et al. 1988*c*).

During field trials it was reported that the PT repellent was not as effective a repellent as it had been in short-term laboratory trials. This may have been due to PT's high volatility and, therefore, short-term effectiveness when dispensed from an uncontrolled release device such as a capillary tube. Field trials have shown that synthetic predator odors do not appear to have promise as a tool for vacating resident gophers from an area (Sullivan et al. 1988*c*; Sullivan et al. 1990*b*). This is because of the gopher's apparent "antipredatory" strategy of plugging a burrow containing the predator odor release devices with soil. It became clear that for predator odors to successfully fumigate the gopher burrows, gophers must first be removed. Once gophers were removed, an application of PDT and DMDIT significantly (Chi-square, $P<0.05$) reduced the numbers of gophers that reinvaded the treatment grid when compared with control areas (Sullivan and Crump 1986*b*). Eventually, numbers of gophers residing within the treatment grid did increase to that of the control; however, this was mostly due to juvenile dispersal, and not, as with the control areas, from reinvasion by adults.

Unlike Sullivan and Crump (1986*b*), Sullivan et al. (1988*c*) did not report significantly fewer gophers within areas that had been treated with PDT, DMDIT, or a 1:1 mix of PT and PDT when compared with control areas. Although gopher abundance did not seem to be affected by the field application of these predator odors, their distribution was dramatically altered. It was observed that a significantly (Chi-square, $P<0.05$) higher proportion of gophers were captured near the perimeter of two of the three treatment trapping grids when compared with the control grids (Sullivan et al. 1988*c*). This relative lack of gophers within the interior of treatment grids suggests that gophers do, to a certain degree, avoid these synthetic predator odors.

After removal of gophers from a large area (4-ha), an application of PT:PDT or DMDIT (dispensed in clay pellets loaded with an average of 7.7 mg of semiochemical per pellet) was shown to maintain gopher abundance at a significantly (Chi-square, $P<0.01$ or 0.05) lower level than within control areas (Sullivan et al. 1990*b*). In addition, gopher abundance, post-treatment (as indexed by soil mounds), was significantly (Chi-square, $P<0.01$) less than pretreatment abundance. As with Sullivan et al. (1988*c*), gopher activity appeared to be greatest near the perimeter of the treated areas.

Ungulates

An initial screening of several raw predator odors (feces and urine) as repellents for reducing feeding damage caused by black-tailed deer was carried out by Sullivan et al. (1985*b*). This study

reported that all predator odors reduced deer feeding on salal (*Gaultheria shallon*) leaves and planted coniferous seedlings when compared with controls. Cougar, coyote, and wolf odors were the most effective and consistent repellents for this species of deer. In keeping with the results from Sullivan et al. (1985*b*), Burwash and Sullivan (unpublished) carried out field trials using synthetic predator odors from cougar (PDT) and red fox (MBMS—also found in wolf and coyote urine), dispensed in capillary tubes and attached to the base of coniferous seedlings with a twist-tie. Unfortunately, several of the control-treatment blocks did not have sufficient feeding pressure to warrant any meaningful statistical evaluation. Nevertheless, significantly less damage was observed on one of the control-treatment pairs. Although the results from these field trials lacked consistency, the synthetic cougar odor appeared to be more effective than that of the red fox.

The potential for synthetic predator odors as repellents for ungulates is clear as several other studies have reported on the efficacy of various raw predator odors and extracts as feeding repellents for deer (Van Haaften 1963; Müller-Schwarze 1972, 1983; Melchiors and Leslie 1985; Abbott et al. 1990; Swihart et al. 1991), elk (Andelt et al. 1992), and sheep *(Ovis aries)* (Arnould and Signoret 1993).

Mountain Beavers

Raw predator odors (urine and anal gland secretions) were investigated as potential repellents for the mountain beaver in a laboratory environment by Epple et al. (1993). Significantly less food (diced apple) was retrieved from bowls scented with either anal gland secretions from mink or urine from dog, mink, bobcat, or coyote than from control bowls. Novel odors did not affect food retrieval. Nolte et al. (1993) reported that feeding damage to salal and Douglas-fir *(Pseudotsuga menziesii)* seedlings was significantly reduced by the topical application of urine of mink and coyote.

An experiment comparing the effectiveness of raw predator odors and synthetic semiochemicals as mountain beaver repellents was carried out by Epple et al. (1995). The synthetic semiochemicals tested were MBMS, DMT, and PT:PDT. Mountain beavers retrieved less food from bowls scented with the 1:1 mixture of PT:PDT; however, they quickly habituated to this odor. Neither of the single compound odors (MBMS or DMT) affected the feeding behavior of this rodent. As with other studies (Epple et al. 1993; Nolte et al. 1993), raw coyote urine was found to be the most effective feeding repellent for the mountain beaver, indicating that complex natural predator scents appear to be more effective as repellents for this rodent than the simple synthetic compounds or mixtures that have been tested to date.

DISCUSSION

Successes With Synthetic Predator Odors—A Summary

The results of these studies have clearly demonstrated the potential for synthetic predator odors as effective area repellents for the management of several different species of mammals. The ultimate objective of suppressing feeding damage to crop plantations has been achieved on

several occasions for both voles and snowshoe hares, at least on a research scale. In addition, synthetic predator odors have caused significant avoidance responses and disruptions within populations of montane voles and northern pocket gophers.

Voles significantly avoid a 1:1 mixture of PT:PDT (weasel anal gland odors) or TMT (red fox feces odor). In addition, feeding damage to young apple trees, as well as survival and abundance of voles, was significantly reduced during a long-term application of these odors.

Snowshoe hare feeding damage was most significantly reduced by an application of PDT or DMT (weasel anal gland odors). MBMS (red fox urine odor) also significantly reduced hare feeding.

In a laboratory environment, northern pocket gophers were found to significantly avoid traps treated with PT, PDT, DMDIT (weasel anal gland odors), and TMT (red fox feces odor). After resident gophers were removed from an area, reinvasion (i.e., abundance) was significantly reduced by a treatment of PT:PDT or DMDIT (weasel anal gland odors) provided that treatment areas were large (4 ha). Small-scale treatments did not significantly decrease gopher abundance; however, their distribution became concentrated near the perimeter of the treatment blocks.

Although pen trials have shown that feeding by black-tailed deer can be significantly reduced by the application of raw predator odors (i.e., feces and urine), trials utilizing synthetic odors have not yielded consistent results.

Success with raw predator odors as repellents for mountain beavers, like the black-tailed deer bioassays, suggests that the potential for synthetic predator odor repellents for this rodent exists. However, the one experiment that has investigated the effectiveness of synthetic predator odors reports a lack of response or rapid habituation to the semiochemicals tested.

Habituation to the synthetic predator odor treatments is a frequently expressed concern for this repellent technology. However, the vast majority of experimental results obtained from predator odor repellent research indicate that animals do not habituate to these naturally occurring odors. Conversely, novel odors, stench compounds, and even analogs to effective predator odors consistently do not repel or alter the feeding behavior of target animals. If the biological premise for synthetic predator odor repellents is valid, and the correct semiochemical is used, then target animals are not expected to be able to habituate to the treatment odor. Because the risk associated with habituation to a stimulus such as predator odor is so great (may result in death by predation), natural selection should have selected against animals that did not habituated to such serious stimuli. Evolutionary processes should, therefore, have resulted in a genetically controlled, innate response by prey animals to predator odors that they have coevolved with.

Strong evidence exists for the hypothesis that prey response to certain predator odors is genetically controlled. For example, Gorman (1984) showed that *Microtus arvalis* from Orkney Island, avoided traps scented with stoat anal gland secretions in the field, and reduced their activity when surrounded by this odor in the laboratory. Because the *M. arvalis* used during this experiment had been isolated from the stoat on Orkney for at least 5,000 years, the observed responses must be innate. Similarly, Müller-Schwarze (1972) demonstrated that naive, hand-reared black-tailed deer (i.e., animals with no predator experience) were observed to significantly avoid predator odors. Because this response could not have been learned prior to the experiment, it appears as though the deer were genetically predisposed for this adaptive response.

Shortcomings and Improvements With Synthetic Predator Odors

A few problems with synthetic predator odor repellents have become evident during the process of compiling this review. Lack of consistency in efficacy is a primary concern for potential users of this repellent technology. It is believed that prey animals consistently perceive the predator odors as a "danger" signal, or an early warning that a predator is around. However, the response to this stimulus may vary, depending on the environmental conditions surrounding the prey animal, the physiological state of the animal, as well as the presence of the actual predator.

Questions such as, "How hungry are the target animals?" "What alternative habitat do they have to go to?" and "How much food and cover is available within the treatment area relative to nearby areas?" are all questions that have been largely ignored in the past. A few studies have indicated that these factors do have a significant influence on the efficacy of predator odors as repellents. For example, Merkens et al. (1991) demonstrated that availability of cover significantly affects the success of synthetic predator odor repellents for the Townsend's vole *(Microtus townsendii)*. Results from this experiment showed that predator odor repellents are most effective when a treated area has less cover than an adjacent area. As well, Andelt et al. (1992) indicated that increased levels of hunger decreased the effectiveness of various feeding repellents on captive cow elk. In keeping with these results, future research on synthetic predator odor repellents should take careful note of habitat quality (i.e., amount of available cover, food, etc.) of not only the treatment area, but also the areas adjacent to the treatment areas so that we can better explain the conditions required for predator odor repellents to be an effective wildlife management tool.

Over the years, several different types of release devices have been used to administer synthetic predator odors in the field and laboratory test arenas. Because an application of synthetic predator odor repellent should ideally last for the duration of the period of damage to the crop plants (usually overwinter), a controlled release device is required. Such a release device has been developed and is currently being produced by Phero Tech, Inc. (Delta, BC, Canada). This controlled release device incorporates the semiochemical compound, or mixture, into a plastic (PVC or thiourethane) rod which releases the odor over a longer period of time relative to the capillary tube release devices that were used for most of the earlier experiments reviewed in this paper. Volatile semiochemicals such as MBMS and PT, although often effective repellents during short-term laboratory trials, have generally not been as successful during long-term field trials. It would be interesting to retest the effectiveness of these volatile semiochemicals as long-term field repellents using improved controlled release devices.

Future of Synthetic Predator Odors as a Wildlife Management Tool

Although a clear potential exists for the commercialization of synthetic predator odor repellents in the near future, we need to further refine the effectiveness of this technology. Although an alternative to traditional means of managing problem wildlife is eagerly being sought, relatively few researchers have investigated the use of synthetic predator odors as repellents for wildlife management. There are still several questions that need to be answered such as, "Can we

develop a single repellent that works for a broad range of herbivores, or do we need to be genus or even species specific for the best results?" "How much repellent is required to be effective?" "How do different weather conditions affect release devices?" and "Can we create a longer lasting release device?" With the answers to these questions lies the information needed to create an environmentally sound repellent for wildlife management.

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