# MAMMAL REPELLENTS: OPTIONS AND CONSIDERATIONS FOR DEVELOPMENT

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ABSTRACT: Repellents include chemical substances, visual displays, and sonic and ultrasonic deterrent systems. The use of electric shock also can be considered as a repellent category. Each of these categories is discussed, together with their respective utilities, constraints on their usefulness, and possibilities for future development. Economic considerations that may impede or expedite the development of new strategies are presented. Repellent effectiveness depends upon a complex of variables, including the palatability of protected and alternative foods, weather conditions, and the number of animals causing problems. Invariably, repellents are most useful when used as components of integrated pest management strategies.

KEY WORDS: acoustic, avoidance, electric, irritation, mammals, repellents, smell, taste, vision

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The number of non-lethal tools available for vertebrate pest control has actually diminished during the past decade (Clark 1998b). Paradoxically, the popular demand for such tools continues to increase. Repellents in particular are receiving widespread attention (Mason 1997), although for many products almost no data exist to support claims for effectiveness. This lack of empirical support probably reflects the fact that it is not required as a precondition for registration.

Repellents can be chemical, visual, acoustic, or some combination of these characteristics (Mason 1989). For chemical repellents, sensory irritation (Norman et al. 1992), semiochemical mimicry (Lindgren et al. 1997), or gastrointestinal malaise (El Hani et al. 1998) underlie effectiveness. For visual and acoustic repellents, startle responding (i.e., neophobia) or the avoidance of sign stimuli (e.g., avoidance of eyespots) underlie avoidance. Each of these repellent types and their modes of action are discussed in greater detail below.

## CATEGORIES OF REPELLENTS AND MECHANISMS OF EFFECT

### Chemical Repellents

There are several effective chemical repellents for herbivores. This is not true for carnivores, although capsaicin-containing products (e.g., bear sprays) do cause irritation, and might cause avoidance under some circumstances. For omnivores, the patent literature suggests a variety of candidate repellents (Werner et al. 1998), albeit with little empirical support. Compounds that may repel dogs (and other canids) include cinnamaldehyde and beta-phenylacrolein (Haase, U.S. Patent No. 4,169,898), methyl nonyl ketone (Haase, U.S. Patent No. 4,555,015), allyl isothiocyanate (Downing, U.S. Patent No. 4,440,783), limonene and alpha-terpinyl methyl ether (Katz and Withycombe, U.S. Patent No. 4,735,803), various carboxylated hydrophilic acrylic copolymers (DeLong, U.S. Patent No. 4,169,902), gamma-n-alkyl-gamma-butyrolactone and gamma-n-alkyl-gamma-valerolactone (Meuly, U.S. Patent No. 3,923,997), various steroids (Hansen et al., U.S. Patent Nos. 4,534,976; 4,657,759; 4,668,455), red pepper (Loucas, U.S. Patent No. 5,368,866), quinine (Loucas, U.S. Patent No. 5,368,866), and pulegone (Mason, U.S. Patent Application No. 351,841).

Chemical repellents are most effective when they are applied directly to foods with the aim of reducing consumption. There is almost no evidence that they cause animals to abandon areas, except occasionally when highly palatable alternative foods are readily available at locations distant from the treated site (Milunas et al. 1994). When alternative foods are scarce or not especially palatable, animals typically return to treated areas and often resume feeding on treated vegetation (El Hani and Conover 1998).

Sensory irritants are nearly always more effective deterrents to depredation than semiochemicals or substances that cause malaise. Avoidance is immediate, no learning is required to sustain the aversion, and adaptation is minimal. A plausible explanation for the strength of responding is that irritants are chemically similar to the endogenous substances released when tissue is damaged (Clark 1998a). Examples of mammalian irritants include capsaicin, the "hot" principle in Capsicum peppers and the active ingredient in "hot sauces," allyl isothiocyanate, the active principle in mustard and the principle active ingredient in tear gas, ammonia, carbon dioxide, and formaldehyde (Mason and Otis 1990).

Irritants are globally effective within taxonomic groups (i.e., irritants that affect coyotes will affect mice). Between taxa, however, there are marked differences in sensitivity and/or perception (Norman et al. 1992). Substances that irritate mammals rarely affect birds. Capsaicin is universally repellent to mammals at concentrations between 10 to 100 ppm; birds are indifferent to capsaicin concentrations >20,000 ppm (Szolcsanyi et al. 1986). On the other hand, methyl anthranilate repels birds at concentrations well below those that are offensive to most mammals (Mason et al. 1991). One practical implication of the difference between taxa is that mammalian repellents that incorporate irritants as active ingredients are unlikely to repel birds. Conversely, the lack of differences within taxa implies that mammalian irritants are as likely to affect humans as they are the targeted pests, perhaps limiting their utility in some situation.

Although irritants may have odors or tastes, olfaction and gustation do not contribute substantially to repellency (Bryant 1997). Tastes, per se, are rarely (if ever) effective repellents. Bitter substances like sucrose octaacetate or denatonium benzoate are undeniably repulsive to humans, but there are few data consistent with the notion that they are aversive to other animals. Herbivores, in particular, are insensitive to these compounds (Nolte et al. 1994). There is no evidence that deer or rabbits are repelled by bitterness, even when these tastes cues are absorbed into plants (Andelt et al. 1991). Products that claim to act via noxious taste cues and purport to repel herbivores (e.g., deer, rabbits, elk) should be treated with skepticism.

Semiochemical odors (e.g., predator urines) and odors that result from protein degradation (e.g., blood meals, rotted egg formulations) will repel herbivores. Avoidance is mediated by sulfur compounds and volatile fatty acids (Lewison et al. 1995; Mason et al. 1997). Sulfur odors may be repellent because they signal the presence of carnivores (Nolte et al. 1994). Alternatively or in addition, sulfur may be aversive because it is a signal for toxicants; plants that bioaccumulate selenium also bioaccumulate sulfur (Mason 1997). Foods with sulfurous odors may "smell toxic" to herbivores. There is no evidence that the semiochemicals present in urine or glandular products are repellent to carnivores or omnivores. Avoidance (or approach) of these substances is predictable from the feeding guild of the animal in question (Mason 1993). Predator urines are aversive to herbivorous fish (Mason 1993), and the odor of rotted cabbages is repellent to grazing snow geese (Mason and Clark 1996a). Despite anecdotes to the contrary, there is little evidence that semiochemicals from one carnivore are repellent to another; for example, foxes are not repelled by coyote urine.

Unlike irritants, there is some evidence that semiochemicals may cause animals to leave areas (Milunas et al. 1994). The extent to which this occurs may depend on the size of treated areas (smaller areas are more likely to be avoided), the number of animals to be repelled (small numbers of animals are more easily repelled), and the palatability of treated foods (unpalatable foods are easier to protect). Unless semiochemical repellents are periodically reinforced with other cues that "validate" the signal quality of the semiochemical, avoidance is likely to be short-lived (Nolte et al. 1993).

Chemical repellency also can be mediated by gastrointestinal malaise (i.e., conditioned taste avoidance). Here, animals learn to avoid arbitrary flavors paired with sickness. Conditioned taste aversions have been tested as a strategy to limit coyote predation on sheep (Conover and Kessler 1994), raccoon predation on eggs (Nicolaus 1987), bird depredation on grain or fruits (Avery 1989; Stone et al. 1974), and in many other contexts (Conover 1998). Success depends on the degree of resemblance between treated and untreated items (Morell and Turner 1970).

Conditioning as a strategy depends on taste (Garcia and Hankins 1978). Mammals do not show strong food avoidance learning when odors or visual cues are used as conditioned stimuli (Reidinger and Mason 1983). Typically, avoidance of cues other than taste depends on the association of those cues with tastes.

Visual Repellents

Visual repellents (eyespots, predator effigies, mylar) are designed to affect birds, although some visual strategies may affect mammals. Birds are "more visual" than mammals insofar as they possess color vision, and the ability to see ultraviolet light (Hunt et al. 1997; Kreithen and Eisner 1978; Parrish et al. 1981). Mammals are often color blind or, if not, only sensitive to blue and green light (400 to 500 nanometers; Neitz and Jacobs 1989). Mammals generally cannot detect the aposematic colors (reds, yellows) that are used to advertised unpalatability and provoke avoidance by birds. Although explanations for insensitivity are few, color blindness may represent an adaptation rather than a weakness. Color blind humans are more able to see through camoflague (Sachs 1995).

Strobe lights may frighten coyotes and other predators (Linhart 1984; Linhart et al. 1984) and disrupt predation on sheep. However, maintanence of avoidance responding requires that devices are used sparingly, moved frequently, and combined with other deterrents (e.g., guard animals, shooting). Stobe lights are not aversive to deer (Dolbeer unpubl. commun.). Other visual strategies (e.g., mylar, scarecrows) may have limited utility, but effects appear to be short-lived. For some mammals (e.g., coyotes), avoidance is influenced by the size and location of the visual deterrent. Small strange objects (e.g., M-44s protruding from the soil) attract coyotes (Roughton and Sweeny 1982), while larger objects (16 cm x 16 cm x 16 cm wooden blocks) are avoided (Windberg 1997). Coyotes are more curious in unfamiliar areas of their home range, but tend to avoid new objects in areas that are well-known (Harris 1983). Unlike chemical repellents, neither the safety nor the efficacy of visual repellent strategies is regulated. Manufacturers' claims about products are often anecdotal.

Acoustic Repellents

Sonic devices include distress calls, pyrotechnics (e.g., live ammunition, shell crackers, firecrackers), propane exploders, and sirens (Hygnstrom et al. 1994). While these strategies are most often used against birds, they have been used to deter mammals (e.g., Bomford and O'Brien 1990; Sprock et al. 1967). At least some of these devices may have utility if use is coupled with other deterrent methods (e.g., hunting, guard dogs; Pfeifer and Goos 1982). However, mammals are at least as likely as birds to adapt to sonic devices.

There is little data that mammals are repelled by ultrasonic devices. In fact, there is almost no evidence that any animal (vertebrate or invertebrate) avoids ultrasonic cues for more than short periods of time (Shumake 1998). So-called "deer whistles," rodent ultrasound systems, and the experimental systems being employed to repel larger mammals have little demonstrated utility. Claims regarding the usefulness of these devices are essentially data-free and at best wildly speculative. Neither the safety nor the efficacy of acoustic repellent systems is actively regulated (Shumake 1998).

Electric Shock

Electric fences can deter deer (Caslick and Decker 1979; Craven 1983; McAninch and Winchcombe 1981) and coyotes (Linhart et al. 1981; Wade 1982) from entering areas. Electric collars can be used to stop predation events (Linhart et al. 1976; Phillips et al. pers. comm.). The utility of the former can be enhanced by attractants (e.g., peanut butter on foil twisted onto the fence wire) that focus animals' attention on the fence (Jordan and Richmond 1992). Principle disadvantages are the high initial cost of installing and maintaining fences.

Shock collars may be especially useful (and perhaps only practical) with "high value" animals (e.g., grey wolves, grizzly bears). Implementation, use, and maintainence are expensive, and a disadvantage is that shock must be delivered precisely. Merely shocking a predator in the presence of livestock will not reliably produce avoidance; shock must be delivered during the predation event, preferably at the moment when contact is made with prey.

## ECONOMIC CONSTRAINTS AND POSSIBILITIES FOR DEVELOPMENT

The number of chemical repellents available for vertebrate pest control has diminished in the past decade, despite increasing public interest (Clark 1998b). Simultaneously, the number and variety of visual and acoustic devices has increased. These changes undoubtably reflect the relative costs of new product development and commercialization. On the one hand, visual and acoustic repellents can be brought to market without oversight from regulatory agencies. Commercialization of chemical repellents, on the other hand, is closely monitored by federal and state environmental agencies. Development of methyl anthranilate as the only new bird repellent in the last 25 years took nearly a decade, and cost the manufacturer several million dollars (P. Vogt, pers. comm.). Methyl anthranilate is an approved (GRAS-listed) human and animal food additive (grape-flavoring) and has been so for decades.

Putting aside the issue of cost, attempts should be made to test new products as they become available (to assure that manufacturers' claims are justified). At present, there are few or no data to support claims of efficacy for the majority of commercially available repellents. One result is that strategies are being employed to the probable detriment of homeowners, agricultural interests, and (even) fish and game agencies. For example, ultrasound is being used to deter predation on endangered species in California despite any evidence that the strategy will work.

Wildlife managers need to become more seriously involved in the scientific evaluation of non-lethal methods. Agricultural and wildlife educators need to actively publicize research results so that the public can make informed choices among products. Efforts to develop new repellents might focus on natural products (Reichardt 1998) because environmental protection agencies are moving to expedite the registration of these products (Mason and Linz 1997). Efforts might also focus on broadening the potential applications for known effective substances. For example, products that include rotted egg as an active ingredient are repellent to deer (Lewison et al. 1993). The available evidence suggests that repellency is a consequence of sulfur odors and volatile fatty acids. Because herbivores (regardless of taxonomic class, genus, or species) generally avoid sulfurous odors, it follows that products that include rotted egg as an active ingredient may be broadly repellent to herbivores. A recent study suggests that Deer Away Big Game Repellent is as repellent to eastern cottontail rabbits as it is to white-tailed deer (Mason et al. unpubl. mans.)

Repellents are best considered a part of integrated strategies of pest management (IPM). Thus, chemical repellents are more effective when combined with visual cues (Avery 1998; Mason and Clark 1996b), and propane exploders are more effective when used with guard dogs (Pfeifer and Goos 1982). Non-lethal strategies also may be more effective when reinforced with lethal control. Acoustic repellents, for example, may be more effective when backed up by occasional shooting. Overall, integrating lethal and non-lethal control strategies remains a fertile topic for research. Efforts should be made to educate the public about when and where repellents can be used.

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