

Effectiveness of Chemical Repellents in Managing Birds at Airports

Repellents include methods and devices used to manipulate behavior of animals to reduce damage or nuisance. Critical to the design and success of repellents is understanding how sensory modalities mediate perception of signals, and how ecological context and sensory inputs influence animal learning. A repellent's success is tied to the axiom of using the proper tool for the proper job. When repellents "fail," it is almost always because wildlife managers have not appropriately matched signal, receiving systems, message, and context. Reconciling such considerations can be a complex process. In this chapter we review components and processes essential for the successful use of repellents for managing birds at airports.

There is often great disappointment among managers on the performance of repellents, and chemical repellents may be among the most misunderstood wildlife management tools. Perceived failures of chemical repellents are not always accurate, as performance is aligned with the sensory biology of the target animal and context of application. Successful use of repellents requires (1) understanding the rules of animal learning; (2) understanding the sensory abilities of targeted animals; (3) appreciating that repellents are tools to shape and modify behavior, not toxicants; (4) understanding that repellents train individual animals and that, when populations turn over frequently, constant training may be required; and (5) understanding that repellents work best if alternative resources or places are available, and that if alternatives are not available, the animal may endure unpleasant side effects. In short, large numbers of animals with no alter-

native resources or places to go will swamp the defensive characteristics of a repellent. Given use based on the requisites described above, repellents can be effective and deserve a place in integrated and adaptive pest management strategies. The reviews on these topics should be sought for in-depth coverage (Garcia and Hankins 1977; Revusky 1977; Dooling 1982; Kare and Brand 1986; Clark 1997, 1998b; Mason and Clark 1997, 2000; Reidinger 1997; Domjan 1998; Conover 2002; Werner and Clark 2003).

Mediating Sensory Modalities

Mediating sensory modalities in birds includes the chemical senses (smell or olfaction, taste or gustation, irritation), hearing or audition, vision, and touch (see also Chapters 2 and 4). In general, birds have excellent auditory and visual capabilities and moderately developed chemical senses (Mason and Clark 2000, Walsh and Milner 2011).

Olfaction acts as a telereceptive system capable of receiving airborne chemical stimuli in extreme dilution over relatively great distances. Olfactory cues may generally orient some bird species toward food sources (e.g., Stager 1964, Verheyden and Jouventin 1994) or elicit specific discrimination behaviors from others (e.g., Clark and Mason 1987, Roper 1999). Gustation requires more intimate contact between the source of the signal and the receptors. Taste receptors in birds are located throughout the oral and pharyngeal cavities, and generally mediate sensory qualities also perceived by mammals: sweetness, saltiness, sourness, and bitter-

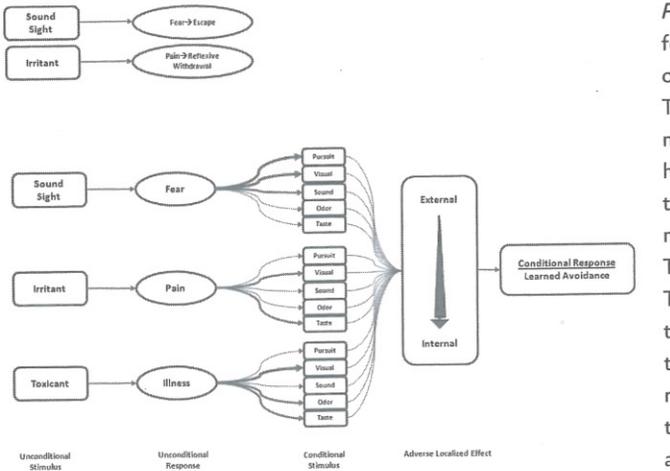


Fig. 3.1. Nonlearned and learned responses to stimuli for birds. The top illustration shows the likely pairings of sensory input and nonlearned behavioral responses. The bottom illustration shows the pairings between the nature of the unconditional stimulus and the effect it has on the animal (unconditional response), as well as the likelihood those pairings can be matched with an animal's mediating sensory modality (conditional stimulus). Thicker arrows indicate associations that are more likely. The more the unconditional stimulus (US)/unconditional response–conditional stimulus (CS) pairing is internalized in an animal, the stronger the CS–conditional response (CR) association is likely to be. The more likely the US/CR–CS pairing is self-limited by the animal, as might be the case for externally exposed cues, the weaker the CS–CR association is likely to be.

ness (Kare and Brand 1986). Bird species perceive taste qualities differently, however, reflecting their species-specific ecologies and food habits (Berkhoudt 1985). Chemesthesis is the perception of chemically irritating or painful stimuli. Noxious chemical stimuli may give rise to qualities such as stabbing, throbbing, burning, or itching, depending on the specific nociceptive fiber that is stimulated and the neurotransmitter released (Clark 1998a). Vision, like olfaction, is a telereceptive system (Zeigler and Bischof 1993). Unlike olfaction, the source of visual cues is more readily identified because of the linear relationship between source and receptor. Visual cues facilitate navigation, recognition of conspecifics and mates, predator avoidance, and food selection (Chapter 2). Sounds provide birds with information regarding territorial defense, mate selection, navigation, and recognition of predators, conspecifics, and prey location (Gill 1990, Beason 2004; Chapter 4). The sense of touch is integral to the feeding behavior of many birds, particularly many waders and shorebirds (Gill 1990; Chapter 4). Furthermore, while birds are flying, feathers are constantly being adjusted in response to tactile sensations received via nerves at the base of the shafts.

Types of Chemical Repellents

There are two fundamental repellent classes: primary and secondary (Clark 1997). A repellent is classified as primary or secondary based on the physiological mode of action and whether avoidance behavior is learned. Primary repellents possess a quality (e.g., unpalatable

taste, odor, irritation) that evokes reflexive withdrawal or escape behavior. Secondary repellents evoke an adverse physiological effect (e.g., illness), which the animal associates with a sensory cue (e.g., taste, odor, visual cue) and then learns to avoid. These definitions help to quickly assess the likely effectiveness of a chemical repellent in a particular ecological context.

Behavioral Bases for Repellency

Repellents evoke reflexive withdrawal, escape, or avoidance behaviors (Fig. 3.1). The behaviors differ, even though the manager may not be able to distinguish the underlying cause (characterized below) for an animal staying away from an object or area.

Reflexive Withdrawal

Painful or irritating stimuli may evoke innate, reflexive withdrawal from the stimulus. The response is adaptive because it precludes further damage or harm to the animal. In the parlance of learning psychology, the aversive stimulus is the unconditional stimulus (US) and the reflexive withdrawal is the unconditional response (UR). Because an animal limits exposure to potentially harmful stimuli, the degree and magnitude of exposure to the US are weak, and animals do not efficiently form learned associations to these types of stimuli (Clark 1996). Animals are therefore more apt to revisit sites or sample foods where the US produces a weak or external localized effect (see below).

Escape

Neophobia is generally associated with escape from a novel stimulus. Although escape behavior may confer a short-term advantage to an animal (i.e., the animal reduces its risk to the unknown), reliance on this behavioral paradigm is not a sound strategy for the animal in the long term, nor is it a sound management strategy. Habituation to the US may occur when there is no negative reinforcement. From the manager's perspective, habituation is the unwanted, learned response that the stimulus has no consequence. A classic example is the use of owl effigies to repel birds from an area (Chapter 2). A predator that does not pursue its prey quickly loses its perception as a threat.

Avoidance

Avoidance behaviors involve learning. The manager uses a repellent to train target animals to avoid an object or place. There are four elements in the formation of a learned avoidance response (Fig. 3.1). The repellent (US) elicits an unpleasant experience (UR) for the animal. The animal associates the UR with sensory cues (conditional stimulus, or CS) paired in space and time to form the learned avoidance (conditional response, or CR; Pavlov 1906, Garcia et al. 1966).

A widely known strategy for learned avoidance is the conditioned flavor avoidance paradigm (CFA), also known as conditioned taste aversion (CTA; Garcia et al. 1966, Garcia 1989). The former is a better characterization because it acknowledges the multi-sensory nature of oral exposure to stimuli (inclusive of taste, retronasal olfaction, chemical irritation, tactile cues). However, myriad UR-CS pairings exist, and some associations are more frequently paired in nature and hence are more readily established (Milgram et al. 1977). Most mammals readily develop aversions based on flavor cues (taste, odor, irritation) and gastrointestinal illnesses (Revusky 1977). In contrast, birds are less apt to form CFAs, whereas they are more likely to form aversions based on visual cues and gastrointestinal illness (Mason and Reidinger 1983; Fig. 3.1). The likelihood and strength of learned aversions based on sensory inputs have a neurophysiological basis that differs among taxa (Provenza 1995). For this

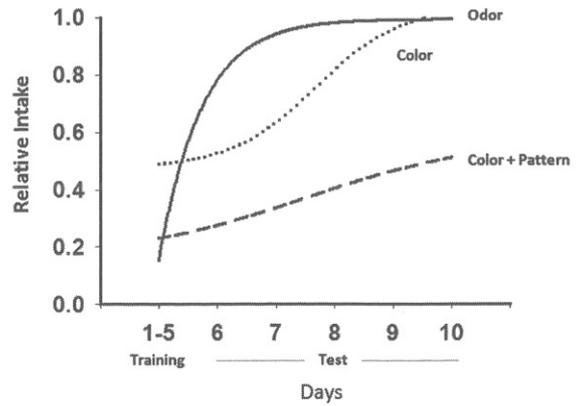


Fig. 3.2. Extinction curves for learned avoidance when unconditional stimuli are irritants in European starlings. Conditional stimuli (CS) were odor (solid line), colored target (dotted line), and colored-patterned target (dashed line). The curves indicate that visual cues are better CS in birds than are chemical cues, and that synergy can be observed for visual cues. Data derived from Mason (1989) and Clark (1996)

reason, development and application of effective repellents (i.e., reliable CRs) depend on understanding how an animal will sense and integrate the adverse experience.

Salience

Evolution (i.e., the development of sensory systems and neurophysiological interactions of sensory afferents) and ecological context constrain the salience of cues. In laboratory tests, European starlings (*Sturnus vulgaris*) were offered food treated with a chemical irritant paired with a sensory cue (either an odor, colored target, or colored target and pattern) during a five-day training period (Mason 1989, Clark 1996). Over the following five days, the starlings received unadulterated food paired with the odor or visual targets. Starlings avoided the color and pattern targets longer than the colored target alone, and exhibited almost no long-term avoidance when the sensory cue was an odor (Fig. 3.2).

The experiments demonstrate two things. First, starlings were more attuned to visual cues as conditional stimuli. Second, adding unique, independent features to the visual cue enhanced learned avoidance, both in magnitude and duration. These results are to

be expected for species such as birds that have a well-developed visual sensory system for color and pattern (Endler and Théry 1996). For most mammals, a similar experiment would place pattern and odor above color as the most salient sensory cues, because most mammals have poorly developed color vision but highly developed abilities to detect edges and motion (Jacobs 2009; Chapter 2).

Adverse Localized Effect

The intensity and duration of a learned avoidance response depend on the degree and location of the aversive experience (UR). The learned response is weakest when the animal has control over its exposure—when the animal can escape or withdraw from peripherally applied repellents (sound, sight, or chemical if delivered to mouth, eyes, or skin). The learned avoidance is strongest when the animal cannot escape the application of the US (e.g., a chemical that produces a gastrointestinal illness; Pelchat et al. 1983).

Concurrent Interference

Specific pairings of stimuli can influence what an animal learns, and understanding how can help a manager deploy effective repellent methods. An example begins with a bear (Ursidae) visiting a dump because it positively associates the dump with food. The US is food, the UR is caloric reward/satiety, the CS is food odor (or some other sensory aspect of dumps), and the CR is dump visitation. A ranger shoots the bear with rubber bullets in an attempt to train it to avoid the dump. From the park ranger's perspective, the rubber bullet is the US and the unpleasant experience—pain—is the UR. The ranger believes that the bear will associate the UR with the CS (i.e., connect the dump's visual cues or odors with pain, meaning the bear will avoid the dump). But the bear continues to visit the dump, only fleeing when the park ranger shows up. What went wrong? Concurrent interference (Sayre and Clark 2001), or the presentation of competing cues that selectively attend to the most relevant cues in an animal's learned associations between cause and effect (Fig. 3.3). Normally the bear would be trained to avoid the sensory cues associated with the dump. However, the arrival of the park ranger was exactly correlated with the pain from the

Scenario 1: Animal learns C_1 is the harmful agent, C_3 & C_2 are safe.

$$C_1 C_2 \rightarrow AE_{100\%}$$

$$C_3 C_2 \rightarrow AE_{0\%}$$

Scenario 2: Animal learns C_2 is the harmful agent, C_3 & C_1 are safe.

$$C_1 C_2 \rightarrow AE_{50\%}$$

$$C_3 C_2 \rightarrow AE_{5\%}$$

Fig. 3.3. Two scenarios of how pairings of cues influence inference about safety and harmfulness of a cue. C_1 is the sensory cue presented to an animal, AE is the aversive experience, and its subscript percentage is the frequency with which that aversive experience occurs.

rubber bullet, representing a higher degree of salience to the bear because the US was only experienced at the dump when the ranger was present. Had the ranger taken precautions to be less obvious, the negative reinforcement of the rubber bullet would not have been so predictable, and the bear might have learned to avoid the dump.

Ecological Context

Ideally, a repellent moves animals from an undesired place to a place where their presence is accepted. After successful application of a bird or mammal repellent, the total number of animals will not decrease, but they will be distributed differently. A realistic goal of repellent application is therefore not to eliminate birds or mammals at a location but to reduce their numbers to an acceptable, manageable level. To the extent that a repellent can help redistribute the local wildlife population from sensitive areas to nonsensitive ones, it will be a successful component of an airport wildlife management plan.

Understanding why wildlife species are attracted to a given site in the first place is central to determining the most effective strategy for moving them. Feeding opportunities are the most likely reasons for the presence of most animals (Chapter 8). Other possible explanations include nesting, roosting, access to drinking water, and refuge from predators. Making the resources unavailable to the animal eliminates its reason to be there. Whatever the resource, if it can be

removed, the animals will no longer frequent the site. If physical removal of the resource is not possible, then the resource can sometimes be rendered unappealing or undesirable by application of a chemical repellent.

Birds have high metabolic rates and are constantly seeking readily accessible sources of food to meet their nutritional requirements with low expenditure of effort. This is especially important to young birds that are not experienced foragers. In the late summer and fall, newly fledged birds constitute a large portion of many foraging flocks. At other times of year, alternative sources of food may be limited or lacking altogether. Given this situation, it is easy to appreciate why wetlands and other resources at airports can be powerful attractions to animals. With substantial potential benefits to animals from using airports, there must be commensurately high potential costs in order to discourage them.

To be effective, a chemical repellent must alter the balance in the airport environment, either by greatly reducing the benefits of feeding or by greatly increasing the costs. Increasing the cost to the animals usually means increasing the amount of time and energy required to feed at that site. The more time the animal has to spend acquiring the requisite nutritional resources, the less time it can spend on other essential activities such as territorial defense, mate acquisition, provisioning young, body maintenance, predator vigilance, and so on. There is therefore substantial pressure on an animal to feed efficiently. Caloric gain is not the only nutritional requirement, but it seems pervasive. If it becomes difficult for the animal to maintain a certain rate of energy intake, foraging theory predicts that the animal will look for other sources of food (MacArthur and Pianka 1966). The net effect of applying a chemical repellent is to lower the value of the food source by reducing the animal's rate of energy intake. Incorporation of other methods such as pyrotechnics, lasers, or shooting might reinforce the effectiveness of the repellent (Chapters 2 and 4).

Primary chemical bird repellents do not generally promote strong learned avoidance responses (Clark 1996), as illustrated by field observations where a formulation of methyl anthranilate (Nachtman et al. 2000), a primary repellent, was incorporated into day-covering material and sprayed onto the open

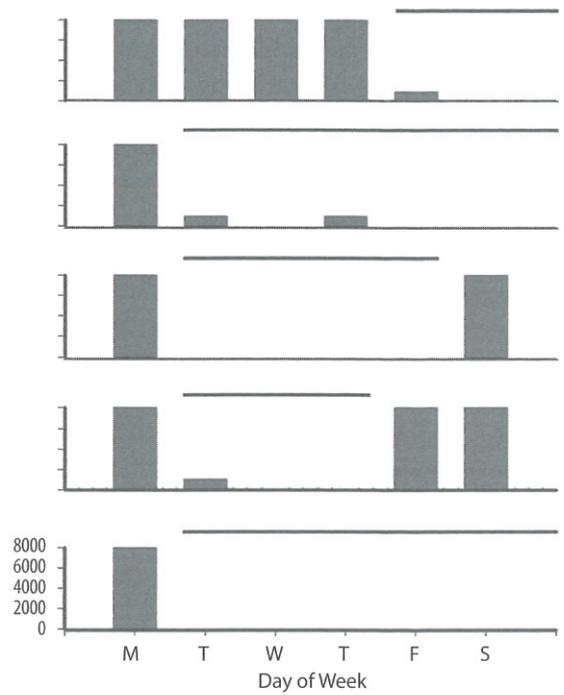


Fig. 3.4. Efficacy of a primary repellent at the Tullytown Landfill near Philadelphia, Pennsylvania, USA. Surface sprays containing 1% methyl anthranilate and yucca were applied several times per day (horizontal lines) throughout a five-week period in August 1994. Bar heights represent gull counts at the tipping face of the landfill and site where surface sprays were applied. Note that the formulation successfully repelled gulls from the site during intensive application. Gulls were always in close proximity, however. Sampling allowed the gulls to return as soon as the application of repellent was halted. Data source: L. Clark, unpublished data

tipping surface of Tullytown Landfill near Philadelphia, Pennsylvania, USA (Fig. 3.4). Gull (*Laridae*) counts were significantly lower after spraying. As long as spray coatings were applied, the gulls stayed away from the site. When spraying operations were stopped (e.g., weekends and holidays), however, gulls returned to the tipping site within 24 hr. The data are consistent with the interpretation that the repellent was effective at preventing the use of a valued resource because of its intrinsic irritating qualities, but did not have a paired salient cue that would promote long-term avoidance of the site. Does this mean that primary repellents are not useful? The answer is no. Depending on ecological context, the same repellent

may be quite effective. At Tullytown Landfill, gulls had an alternative nearby resource: the untreated Groves Landfill (about 1 km away) and nearby roosting sites.

A similar field observational study was conducted at Dane County Landfill in Madison, Wisconsin, USA, with markedly different results (Fig. 3.5). A single application of the methyl anthranilate formulation was applied, and gulls left the site. The gulls did not begin to return until 21 days later. Over the course of the next week, gull numbers increased and a second application of repellent was applied. Again, gulls left the site and did not return over the course of the next ten days. Why did the Dane County site produce such different results from the Tullytown site? The difference at Dane County was that the gulls' roosting site was at least 25 km distant, and there were no nearby alternative foraging sites. These results are consistent with the ecological foraging concept known as central place foraging (MacArthur and Pianka 1966). Central place foraging occurs when birds travel from a roost or nesting site to peripheral feeding locations and return to the roost or nest site each night. The choice of foraging sites is presumed to be an optimization among effort, distance traveled, and reward (Stephens et al. 2007). In this case the successful use of the primary repellent is entirely dependent upon the knowledge of its mode of action, how that mode influences learned avoidance, and the ecological context under which the repellent is applied. At Dane County Landfill, the repellent was the proper tool for the job, but at Tullytown Landfill, it was not.

Reducing the value of the food source is a key component to repellent use. The other crucial factor is the availability of alternative sources of food. An animal with no alternatives will tolerate much greater discomfort than will one with access to other food sources. Thus chemical repellents function more effectively with an available selection of food sources than with no alternative. The disparity in attractiveness between the airport site and potential alternative feeding sites will influence how noxious the repellent must be to effect a change in the animal's behavior. In an airport context, availability of attractive alternate food will be somewhat challenging, as such sites must be sufficiently distant from the operations area so as not to create hazardous situations themselves. Establishment

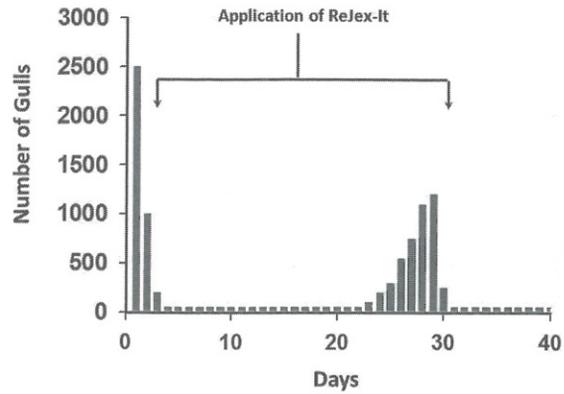


Fig. 3.5. Efficacy of a primary repellent at the Dane County Landfill, Madison, Wisconsin, USA. Two surface sprays containing a landfill coating of 1% methyl anthranilate and yucca were applied (arrows). Gulls left the landfill after one application, eventually returning during the third week after initial application. A second application reduced bird numbers at the site once more (L. Clark, unpublished data). The greater distance of available roost sites prevented frequent sample visitation by gulls; once repelled, the gulls tended to stay away, even though the repellent application was intermittent. This example illustrates how central place foraging can influence the efficacy of a repellent.

of feeding sites specifically to attract animals away from an airport is probably not intuitively pleasing, and the effectiveness of this management approach should be tested experimentally.

Water is a major attractant for wildlife, and airports usually include retention ponds and other permanent and ephemeral bodies of water (Chapter 9). Birds use such resources as feeding sites, and other wildlife are attracted because of loafing, bathing, and drinking opportunities. Consistent use of a fogger to disperse an aerosolized avian irritant such as methyl anthranilate along the periphery of the impoundment can likely change avian use patterns.

Chemical repellents are often applied to turf to repel Canada geese (*Branta canadensis*). The repellents are ingested while grazing, and the animal experiences pain (methyl anthranilate formulations) or a post-ingestional malaise (anthraquinone formulations; Dolbeer et al. 1998, Blackwell et al. 1999). In both cases the learned response is for geese to avoid feeding on the turf. When using turf repellents for geese, however, managers should be aware of possible underlying fac-

Scenario 1: Goose use of an area:

Feeding → repellent → forage unpalatable
 Loafing → repellent → no effect

Result: Geese remain on site

Scenario 2: Goose use of an area:

Feeding → repellent → forage unpalatable

Result: Geese leave site

Fig. 3.6. Scenarios of how expectation can misinform a manager about a repellent's success. If Canada geese are using a site for feeding, then applying a repellent will render the forage unpalatable, and the geese will move. If geese are attracted to the site for loafing and feeding, however, then even though the repellent makes the food unpalatable, geese will continue loafing at the site.

tors that may motivate geese to use the site. Managers often believe the repellent has failed because geese stay in the treated area. Even if geese remain in the area, the repellent worked as designed: it stopped the feeding behavior of geese on the treated turf. The repellent is not designed to repel geese from an area. The geese may no longer graze, but the area may still be suitable for loafing. If the geese do leave the area, it is likely that the area was used only for foraging. Once forage is removed or unpalatable, the geese move on. The manager may misinterpret this as a successful application of the repellent in that geese stayed away from the area. But what is missing is an accurate assessment of why the area is being avoided (Fig. 3.6). Without such assessment, the manager may experience success on some occasions and failure on others. The manager may consequently abandon a perfectly good tool, thinking it is not consistently effective.

Migratory behaviors of many bird populations and seasonal availability of food resources combine to produce variability in numbers and types of birds attracted to a given facility. Some species of migrant and wintering birds are attracted to stands of wax myrtle (*Myrica cerifera*) because of seasonal availability of the waxy, lipid-rich berries (Place and Stiles 1992). Similarly, migrating barn swallows (*Hirundo rustica*) and tree swallows (*Tachycineta bicolor*) can descend in large flocks to exploit seasonally abundant swarms of insects. At air-

ports, timely application of aerosolized chemical bird repellents (Engeman et al. 2002) has provided relief from large aggregations of such birds.

Bird roosts at or near airport facilities can pose serious problems for airport managers, because birds often exploit food resources at these sites. Birds arriving and departing the roost can elevate the risk to low-flying aircraft, even without the birds being on airport property. Roosting aggregations of vultures (*Cathartes aura* and *Coragyps atratus*), crows (*Corvus brachyrhynchos*), or other birds might be successfully dispersed with a fogged or aerosolized repellent. Appropriate visual deterrents or effigies (Chapter 2), reinforced as needed with laser or pyrotechnic harassment, can usually disperse roosts (Avery et al. 2002, 2008; Teague 2002).

Landfills are often located near airports and represent a major food resource for many birds. Safe operation of an airport might therefore also require bird management at a landfill. Persistent harassment with pyrotechnics and lethal control using shotguns are standard bird control methods at landfills, and it is not clear if repellent applications can play a significant role, especially on a large scale. To reduce bird use of ponds or temporary wetlands, fogging with methyl anthranilate could potentially be effective (Belant et al. 1995). Because the working face of a landfill is continually turning over and because of constant heavy equipment traffic, effective repellent use would be difficult and possibly cost-prohibitive.

Deer and coyotes, attracted to food resources near airports, are the mammals most often involved in damaging aircraft collisions (e.g., Dolbeer et al. 2010, Biondi et al. 2011). Some chemical repellents can reduce browsing damage by deer to crops and ornamental plantings. Application of such repellents at airports is conceivable, providing deer are attracted to discrete, identifiable food sources that can be readily treated with a repellent and that cannot be managed in other, more permanent ways. In addition, predator urine can potentially inhibit deer use of a given area (Swihart et al. 1991, Nolte et al. 1994), although this application in airport situations is untested. For coyotes, chemical irritants and aversive agents have been tested and evaluated, mostly for livestock protection (Mason et al. 2001, Shivik 2004). To date, there is no indication that any chemical repellent method tested will by itself repel coyotes from airports.

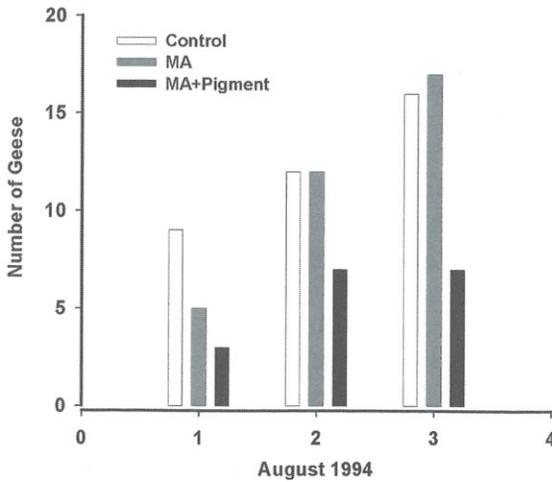


Fig. 3.7. Synergistic effects of sensory stimuli, an irritating repellent, methyl anthranilate, and a visual cue. When pigment (titanium dioxide) alone was applied to turf, geese grazed on the plots, and the use of those plots increased over time (an example of neophobia and eventual habituation to the novel stimulus; white bars). The bird irritant, methyl anthranilate (1%), had a more pronounced effect in the first week, but eventually the geese used those plots with increasing frequency (gray bars). The combination of the two cues (black bars), however, each of which yielded suboptimal avoidance, proved to be a highly effective deterrent. Data source: L. Clark, unpublished data

Integrated Management

If the target animal population is resident in the area of the airport facility, then a learned aversive response might be preferable, and a secondary repellent such as anthraquinone can be an effective management tool (Avery et al. 1998, Werner et al. 2011). But if the target population is transient, such as a wave of migratory birds, then conditioning individuals is not feasible. Instead, a more effective management approach is application of a primary repellent, such as methyl anthranilate, that produces an unlearned aversive reaction.

Chemical repellents, along with other wildlife damage management devices such as visual or aural deterrents, can expand the collective impact of management methods beyond their individual impact (Fig. 3.7). The appropriate combination or integration of methods and techniques is dynamic, contingent on local circumstances and the specifics of the pest animal population. Conditions at a given facility change seasonally at least,

so the management prescription should change accordingly. Regardless of target species, any value in the application of aversive chemical stimuli will come from integrated management approaches, including lethal and nonlethal techniques. For successful outcomes, ingenuity and resourcefulness are called for. Both anthraquinone and methyl anthranilate are registered as avian grazing deterrents on turf. Because they have different modes of action, their use in combination might provide greater impact than either used alone. Staggering the use of different repellents temporally or creating simultaneous patches with different repellents across sensitive areas on the airport facility will reduce the likelihood of habituation and will challenge the animal's perception of the local environment as it seeks acceptable foraging sites.

Available Repellents

The number of chemical repellents available for wildlife management is limited. Currently there are only two registered chemical bird repellents in the USA: those that contain methyl anthranilate and those that contain anthraquinone. Birds do not perceive capsaicin as irritating (Clark 1998a), and claims to the contrary are simply not scientifically credible. A number of chemicals have been tested as primary and secondary bird repellents (Clark 1997); however, most of these compounds are not available via U.S. Environmental Protection Agency registrations. Table 3.1 lists the products available for legal use in the USA (in addition to those containing methyl anthranilate and anthraquinone).

Summary

The effective use of chemical repellents to deter wildlife from airport environments requires an understanding of how animals learn from negative experiences as well as the sensory abilities of the target species. This information is critical in discerning the appropriate repellent for a particular behavioral context. In addition, alternative resources should be available and chemical repellents should be integrated with other management methods. Finally, use of chemical repellents must follow the guidelines set by the specific U.S. Environmental Protection Agency registration.

Table 3.1. Products and active ingredients of bird and mammal repellents registered by the U.S. Environmental Protection Agency (EPA). Label restrictions may apply.

EPA regulation no.	Active ingredient	Product	Species
<i>Agriculture crops, ornamentals</i>			
070703	Red pepper		Coyotes, dogs
100628	Meat meal		Rabbits, raccoons, deer
<i>Landscape, yards</i>			
66676-1-23	Denatonium benzoate	Ortho deer repellent	Deer
270-233	Morpholine, thiram	Detour deer and rabbit repellent	Deer, rabbits
64864-26	Ammonia soaps of higher fatty acids	Hinder deer and rabbit repellent	Deer, rabbits
67356-1-4	Whole egg solids	Bonide deer and rabbit repellent	Deer, rabbits
67356-2-4	Capsaicin, garlic extract	Bonide deer and rabbit repellent	Deer, rabbits
779-29-56644	Tobacco, naphthalene	Repel pet and stray repellent	Dogs, cats
59578-2-4626	Methyl nonyl ketone	XP-20 dog and cat repellent	Dogs, cats
779-29-4	Nicotine, naphthalene, animal blood, denatured	Bonide shotgun dog and rabbit repellent	Dogs, rabbits
64439-1-4	Castor oil	Bonide shotgun mole repellent	Moles, gophers
4-403	Ziram	Bonide rabbit scat	Rabbits
45735-2	Thymol: benzyl-diethyl (2,6-xylyl carbamoyl) methyl ammonium sacchari	Ropel animal, rodent, and bird repellent	Rodents, birds
<i>Ornamentals</i>			
122401	Fish oil		Rabbits, deer
<i>Ornamentals, nonfood</i>			
125001	1-butanethiol		Deer
<i>Pet care</i>			
11715-13-270	Methyl nonyl ketone, petroleum gases, liquefied, sweetened	Repel II dog and cat repellent	Dogs, cats
45987-1-270	Dihydro-5-pentyl-2(3H)-furanone 2(3H)-furanone, 5-heptyldihydro d-limonene	Repel II dog and cat repellent	Dogs, cats

LITERATURE CITED

- Avery, M. L., J. S. Humphrey, T. M. Primus, D. G. Decker, and A. P. McGrane. 1998. Anthraquinone protects rice seed from birds. *Crop Protection* 17:225-230.
- Avery, M. L., J. S. Humphrey, E. A. Tillman, K. O. Phares, and J. E. Hatcher. 2002. Dispersal of vulture roosts on communication towers. *Journal of Raptor Research* 36:44-49.
- Avery, M. L., E. A. Tillman, and J. S. Humphrey. 2008. Effigies for dispersing urban crow roosts. *Proceedings of the Vertebrate Pest Conference* 23:84-87.
- Beason, R. C. 2004. What can birds hear? *Proceedings of the Vertebrate Pest Conference* 21:92-96.
- Belant, J. L., S. W. Gabrey, R. A. Dolbeer, and T. W. Seamans. 1995. Methyl anthranilate formulations repel gulls and mallards from water. *Crop Protection* 14:171-175.
- Berkhoudt, H. 1985. Structure and function of avian taste receptors. Pages 463-495 in A. S. King and J. McLelland, editors. *Form and function in birds*. Volume 3. Academic Press, London, United Kingdom.
- Biondi, K. M., J. L. Belant, J. A. Martin, T. L. DeVault, and G. Wang. 2011. White-tailed deer incidents with U.S. civil aircraft. *Wildlife Society Bulletin* 35:303-309.
- Blackwell, B. F., T. W. Seamans, and R. A. Dolbeer. 1999. Plant growth regulator (Stronghold™) enhances repellency of anthraquinone formulation (Flight Control™) to Canada geese. *Journal of Wildlife Management* 63:1336-1343.
- Clark, L. 1996. Trigeminal repellents do not promote conditioned odor avoidance in European Starlings. *Wilson Bulletin* 108:36-52.
- Clark, L. 1997. A review of 117 carbocyclic compounds. Pages 343-352 in J. R. Mason, editor. *Repellents in wildlife man-*

- agement. National Wildlife Research Center, Fort Collins, Colorado, USA.
- Clark, L. 1998a. Physiological, ecological, and evolutionary bases for the avoidance of chemical irritants by birds. *Current Ornithology* 14:1–37.
- Clark, L. 1998b. Review of bird repellents. *Proceedings of the Vertebrate Pest Conference* 18:330–337.
- Clark, L., and J. R. Mason. 1987. Olfactory discrimination of plant volatiles by the European starling. *Animal Behaviour* 35:227–235.
- Conover, M. R. 2002. Resolving human–wildlife conflicts: the science of wildlife damage management. CRC Press, Boca Raton, Florida, USA.
- Dolbeer, R. A., T. W. Seamans, B. F. Blackwell, and J. L. Belant. 1998. Anthraquinone formulation (Flight Control™) shows promise as avian feeding repellent. *Journal of Wildlife Management* 62:1558–1564.
- Dolbeer, R. A., S. E. Wright, J. Weller, and M. J. Begier. 2010. Wildlife strikes to civil aircraft in the United States 1990–2009. Serial Report 16. U.S. Department of Transportation, Federal Aviation Administration, Office of Airport Safety and Standards, Washington, D.C., USA.
- Domjan, M. 1998. The principles of learning and behavior. Fourth edition. Brooks/Cole, Pacific Grove, California, USA.
- Dooling, R. J. 1982. Auditory perception in birds. Pages 95–130 in D. E. Kroodsma and E. H. Miller, editors. *Acoustic communication in birds*. Academic Press, New York, New York, USA.
- Endler, J. A., and M. Théry. 1996. Interacting effects of lek placement, display behavior, ambient light, and color patterns in three neotropical forest-dwelling birds. *American Naturalist* 148:421–452.
- Engeman, R. M., J. Peterla, and B. Constantin, 2002. Methyl anthranilate aerosol for dispersing birds from the flight lines at Homestead Air Reserve Station. *International Biodeterioration and Biodegradation* 49:175–178.
- Garcia, J. 1989. Food for Toman: cognition and cathexis in concert. Pages 45–85 in T. Archer and L. Nilson, editors. *Aversion, avoidance and anxiety*. Erlbaum, Hillsdale, New Jersey, USA.
- Garcia, J., and W. G. Hankins. 1977. On the origin of food aversion paradigms. Pages 3–19 in L. Baker, M. Domjan, and M. Best, editors. *Learning mechanisms in food selection*. Baylor University Press, Waco, Texas, USA.
- Garcia, J., R. Kovner, and K. F. Green. 1966. Cue properties vs. palatability of flavors in avoidance learning. *Psychonomic Science* 20:313–314.
- Gill, F. B. 1990. *Ornithology*. W. H. Freeman, New York, New York, USA.
- Jacobs, G. H. 2009. Evolution of colour vision in mammals. *Philosophical Transactions of the Royal Society B* 364:2957–2967.
- Kare, M. R., and J. G. Brand. 1986. Interaction of the chemical senses with nutrition. Academic Press, New York, New York, USA.
- MacArthur, R. H., and E. R. Pianka. 1966. On the optimal use of a patchy environment. *American Naturalist* 100:603–609.
- Mason, J. R. 1989. Avoidance of methiocarb-poisoned apples by red-winged blackbirds. *Journal of Wildlife Management* 53:836–840.
- Mason, J. R., and L. Clark. 1997. Avian repellents: options, modes of action, and economic considerations. Pages 371–391 in J. R. Mason, editor. *Repellents in wildlife management*. National Wildlife Research Center, Fort Collins, Colorado, USA.
- Mason, J. R., and L. Clark. 2000. The chemical senses in birds. Pages 39–56 in G. A. Whitow, editor. *Sturkie's avian physiology*. Fifth edition. Academic Press, New York, New York, USA.
- Mason, J. R., and R. F. Reidinger. 1983. Generalization of and effects of pre-exposure on color-avoidance learning by red-winged blackbirds (*Agelaius phoeniceus*). *Auk* 100:461–468.
- Mason, J. R., J. A. Shivik, and M. W. Fall. 2001. Chemical repellents and other aversive strategies in predation management. *Endangered Species Update* 18:175–181.
- Milgram, N. W., L. Krames, and T. M. Alloway. 1977. *Food aversion learning*. Plenum Press, New York, New York, USA.
- Nachtman, T. J., J. H. Hull, and L. Clark. 2000. Water fog for repelling birds. U.S. Patent 6,024,971. Filed 7 April 1977. Issued 15 February 2000.
- Nolte, D. L., J. R. Mason, G. Epple, E. Aronov, and D. L. Campbell. 1994. Why are predator urines aversive to prey? *Journal of Chemical Ecology* 20:1505–1516.
- Pavlov, I. P. 1906. *Conditioned reflex*. Oxford University Press, Oxford, United Kingdom.
- Pelchat, M. L., H. J. Grill, P. Rozin, and J. Jacobs. 1983. Quality of acquired responses to tastes by *Rattus norvegicus* depends on type of associated discomfort. *Journal of Comparative Psychology* 97:140–153.
- Place, A. R., and E. W. Stiles. 1992. Living off the wax of the land: bayberries and warblers. *Auk* 109:334–345.
- Provenza, F. D. 1995. Origins of food preference in herbivores. Pages 81–90 in J. R. Mason, editor. *Repellents in wildlife management*. National Wildlife Research Center, Fort Collins, Colorado, USA.
- Reidinger, R. F. 1997. Recent studies on flavor aversion learning in wildlife damage management. Pages 101–120 in J. R. Mason, editor. *Repellents in wildlife management*. National Wildlife Research Center, Fort Collins, Colorado, USA.
- Revusky, S. 1977. Learning as a general process with an emphasis on data from feeding experiments. Pages 1–71 in N. W. Milgram, L. Krames, and T. M. Alloway, editors. *Food aversion learning*. Plenum Press, New York, New York, USA.
- Roper, T. J. 1999. Olfaction in birds. Pages 247–332 in P. J. B. Slater, J. S. Rosenblatt, C. T. Snowden, and T. J. Roper, editors. *Advances in the study of behavior*. Volume 28. Academic Press, New York, New York, USA.
- Sayre, R., and L. Clark. 2001. Effect of primary and secondary repellents on European starlings: an initial assessment. *Journal of Wildlife Management* 65:461–469.

- Shivik, J. A. 2004. Non-lethal alternatives for predation management. *Sheep and Goat Research Journal* 19:64–71.
- Stager, K. E. 1964. The role of olfaction in food location by the turkey vulture (*Cathartes aura*). *Los Angeles County Contributions to Science* 81:1–63.
- Stephens, D. W., J. S. Brown, and R. C. Ydenberg. 2007. Foraging: behavior and ecology. University of Chicago Press, Chicago, Illinois, USA.
- Swihart, R. K., J. J. Pignatello, and M. J. I. Mattina. 1991. Aversive responses of white-tailed deer, *Odocoileus virginianus*, to predator urines. *Journal of Chemical Ecology* 17:767–777.
- Teague, D. D. 2002. Vulture roost dispersal—improving air safety at Eglin AFB. *Flying Safety* 58:22–25.
- Verheyden, C., and P. Jouventin. 1994. Olfactory behavior of foraging Procellariiformes. *Auk* 111:285–291.
- Walsh, S., and A. Milner. 2011. Evolution of avian brain and senses. John Wiley and Sons, New York, New York, USA.
- Werner, S. J., and L. Clark. 2003. Understanding blackbird sensory systems and how repellent applications work. Pages 31–40 in G. A. Linz, editor. Management of North American blackbirds. The Wildlife Society Wildlife Damage Management Working Group, Bismarck, North Dakota, USA.
- Werner, S. J., G. M. Linz, J. C. Carlson, S. E. Pettit, S. K. Tupper, and M. M. Santer. 2011. Anthraquinone-based bird repellent for sunflower crops. *Applied Animal Behaviour Science* 129:162–169.
- Zeigler, H. P., and H. J. Bischof. 1993. Vision, brain, and behavior in birds. Massachusetts Institute of Technology, Boston, USA.