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Abstract

Wildlife is often responsible for causing extensive damage to personal property, human health and safety concerns, and other nuisance problems because of their feeding, roosting, breeding, and loafing habits. Frightening devices are tools used in integrated wildlife damage management to reduce the impacts of animals, but the effectiveness of such devices is often variable. An animal's visual and auditory capabilities affect how the animal will respond to a stimulus. Frightening devices include pyrotechnics, gas exploders, effigies, lights, lasers, reflective objects, guard animals, bioacoustics, and ultrasonic devices. We examined scientific literature on the use of frightening devices to reduce bird and mammal depredation and compiled results to determine the effectiveness of such devices. When used in an integrated system, frightening devices may be more effective than when used alone. We conclude that the total elimination of damage may be impossible, but frightening devices and/or combinations of devices are useful in reducing wildlife damage. Ultrasonic frightening devices are ineffective in repelling birds and mammals whereas other devices offer some protection. The timely use of a variety of frightening devices can be part of a cost-effective integrated system to reduce wildlife damage to tolerable levels.

Introduction

Wildlife damage is a major source of conflict between landowners and wildlife agencies (Van Tassel *et al.* 1999; Fall & Jackson 2000). Wildlife depredation is the act of animals causing damage to property, resulting in economic loss to the owner. Depredation to agricultural and aquacultural farms, livestock producers, and other property owners, is often severe and many may result in significant financial loss (DeNicola *et al.* 2000). Van Tassel *et al.* (1999) found that landowners who perceive their income is adversely affected by wildlife tolerate less damage. The amount of damage stakeholders tolerate varies depending on livelihood. For example, farmers' and rural landowners' tolerance of deer (*Odocoileus* spp.) is strongly influenced by concerns about crop damage (Brown *et al.* 1978). Agricultural producers typically accept damage levels of $\leq$10% of the crop value (Craven *et al.* 1992).

In most situations the public supports actions to control wildlife that are causing economic loss or threatening human health and safety (Green *et al.* 1997; Loker *et al.* 1999; Reiter *et al.* 1999). Public surveys show an overwhelming acceptance of non-lethal methods. The use of lethal control methods, however, is often controversial to control wildlife damage. The public will accept the use of lethal methods when there are no alternatives, but they also believe we need to continue research on non-lethal control methods to manage wildlife depredation (Reiter *et al.* 1999).

Suburban areas, like rural areas, can be subject to high levels of damage caused by wildlife. Solutions to problems are usually more complicated in urban areas. The need for non-lethal control methods that

do not disturb people living in or around communities is important. Lethal control methods are often not an option for controlling nuisance wildlife in urban areas because of safety concerns, hunting regulations, and local ordinances that restrict the use of firearms and trapping (Jones & Witham 1995; Kuser 1995; Mayer *et al.* 1995; Kilpatrick *et al.* 1997). When lethal methods are not acceptable to society, non-lethal control is the only option.

Integrated pest management (IPM) involves the timely use of a variety of cost-effective control methods to reduce wildlife damage to tolerable levels. Frightening devices are an important non-lethal component of integrated wildlife damage management systems. The goal of using frightening devices is to prevent or alleviate the damage of depredating animals by reducing their desire to enter or stay in an area where a resource is located (Koehler *et al.* 1990; Nolte 1999). The timing of application of frightening devices is often a critical factor that affects short and long term effectiveness. An effective control method that is accepted by the public and applicable to urban and rural areas can reduce wildlife damage and save millions of dollars in lost income. The following is a review of frightening devices and their use in wildlife damage management. Products or devices that rely on olfactory or tactile stimuli are typically considered 'repellents' and are not considered in this manuscript.

Visual and Auditory Stimulus Reception

Frightening devices use a single stimulus, or a combination of stimuli, to deter wildlife that are causing or about to cause damage. Reception of stimuli is dependent upon the animal's senses of sight, smell, taste, touch, and hearing. Most frightening devices influence the senses of sight and/or sound. Visual and acoustic sensitivity varies according to taxon, species, sex, and age of the animal. The following visual and auditory information is a cursory report of the capabilities of selected animals and is given to establish a basis in the development of frightening devices.

Visual reception

Color vision in animals has been the focus of several studies (Jacobs *et al.* 1994; Yokoyama & Radlwimmer 1998). The retina of an animal's eye is composed of rod and cone cells. Rod cells are sensitive to light, whereas cone cells allow for color vision (McIlwain 1996). The location of the eyes affects an animal's stereoscopic vision. Animals with eyes toward the front of the head that face forward (i.e. humans and most predators) have binocular vision, and thus better depth perception (McIlwain 1996). Animals with eyes located on the sides of their head (i.e. most birds and herbivores) have better lateral vision than frontal vision (Smythe 1975).

Activity habits (i.e. diurnal or nocturnal) affect the adaptation and development of the biological design of the eye. Animals that are nocturnal have retinas dominated by rods, and many species have a tapetum, which is a reflective layer in the eye that causes light to pass through vision cells more than once (Ali & Klyne 1985). The tapetum is the structure that causes 'eye-shine' in animals such as deer and coyotes (*Canis latrans*). The tapetum increases light sensitivity and is never present in the eye of a truly diurnal animal (Ali & Klyne 1985). McIlwain (1996) suggests that color vision is most valuable for diurnal species. Most nocturnal animals, however, have a rudimentary ability to see color (Jacobs 1981). Arrhythmic animals (e.g. deer) are active during day and night, some especially during crepuscular periods. The retinas of arrhythmic animals tend to have both rods and cones that allow for color vision and vision during light and dark periods (Ali & Klyne 1985).

Birds use color vision for food and sex recognition (Smythe 1975; Ali & Klyne 1985). Colored oil droplets often found on cone cells are thought to aid in color vision (Ali & Klyne 1985; McIlwain 1996). Red and orange oil droplets on the cones of diurnal passerine birds aid in food selection by enabling the bird to distinguish between foliage and berries (Ali & Klyne 1985). Herring gull (*Larus argentatus*) chicks react specifically to the red spot on their parent's bill, further indicating color vision in birds (Ali & Klyne 1985). Birds, such as rock doves (pigeons) (*Columba livia*), that have eyes on the sides of their head have monocular vision. Monocular vision improves the orientation of birds that fly in dense flocks (Smythe 1975). Nocturnal predatory birds (e.g. owls) have binocular vision and retinas with few oil droplets and cones, which is consistent with their nocturnal habits (Smyth 1975; Ali & Klyne 1985).

Tetrachromatic color vision systems are apparent in the retinas of many species of birds. Most biological mechanisms that have the capability of vision use light energy in the narrow band of 400–700 nm (blue, green, and red wavelengths) (Jacobs 1992). Ultraviolet (UV) light energy is in the range of 300–400 nm. Many birds have the capability to use light energy in the UV range (Hart *et al.* 1998; Bowmaker *et al.* 1997;

Yokoyama 1999). Kevan *et al.* (2001) suggest UV vision does not appear to be any more significant than that of other wavelengths. Scientists believe birds use UV vision for foraging, signaling (e.g. mate choice), and species recognition (Jacobs 1992; Bennett & Cuthill 1994; Cuthill *et al.* 2000; Hunt *et al.* 2001). The visual capability of birds affects their behavior and allows individuals to distinguish between sexes and species, and aids in food selection.

The variety of visual capacities in birds is comparative to that of mammals. Predatory mammals usually have eyes on the front of their heads, providing binocular vision and improved depth perception. Herbivores with eyes on the sides of their heads (e.g. deer, horses) can detect moving objects behind their own bodies (Ali & Klyne 1985). Many animals, such as white-tailed deer (*O. virginianus*), have excellent eyesight (Sauer 1984). Tree-dwelling mammals such as squirrels and primates are reported to have color vision and like birds, use it to distinguish among foods (Jacobs 1981; Ali & Klyne 1985). Ali & Klyne (1985) suggest color vision is more important to tree-dwelling species than to herbivores and carnivores because of their food habits. However, Yokoyama & Radlwimmer (1998) and Jacobs *et al.* (1994) recently reported that white-tailed deer have dichromatic color vision that allows deer to see blue and green wavelengths. Rodents such as rats, mice, and some gophers also have the ability to use UV vision for foraging and species recognition (Jacobs 1992; Jacobs *et al.* 1991). Vision in the animal world is very complex and new technologies have allowed for interesting new findings of such capabilities.

Auditory reception

The auditory capability of animals is important when considering acoustic frightening devices. The frequency of sound is measured in Hertz (Hz), and sound pressure (volume) is measured in decibels at sound pressure level (dB SPL). Sound pressure level is given as 2×10^{-5} Pa. Humans can detect sounds from approximately 20–20,000 Hz (Bomford & O'Brien 1990) with an absolute sensitivity of 0 dB SPL (Durrant & Lovrinic 1984). Ultrasonic frequencies are those above 20,000 Hz and infrasonic frequencies those below 20 Hz. See Table 1 for reference to decibel levels for some familiar sounds.

Birds appear to be most receptive to sounds from 1,000–3,000 Hz, with an absolute sensitivity of −10 to 10 dB SPL (Dooling 1980; Stebbins 1983; Fay 1988; Dooling *et al.* 2000). Nocturnal predatory birds (e.g. owls) generally hear better than other birds, while songbirds hear low frequencies better than non-songbirds (Dooling *et al.* 2000). For example, barn owls (*Tyto alba*) hear best at 6,000–7,000 Hz with volumes as low as −18 dB SPL (Fay 1988). Reception of high frequencies (>10,000 Hz) is very poor in birds (Dooling 1980). Pigeons can detect frequencies as low as 0.05 Hz (i.e. infrasound), but it is unclear how the birds use this capability (Yodlowski *et al.* 1977; Kreithen & Quine 1979; Fay 1988). Birds can also overcome presbycusis, the deterioration of auditory sensitivity with age, because they have the ability to regenerate damaged hair cells in the inner ear (Cotanche 1987; Corwin & Cotanche 1988; Langemann *et al.* 1999).

Table 1. Decibel level of some environmental sounds (Durrant & Lovrinic 1984)

Sound level (dB SPL*)	Sound
0	Softest sound humans can hear
10	Normal breathing
20	Leaves rustling in a breeze
30	Very soft whisper
40	Quiet residential community
50	Department store
60	Normal speaking voice
70	Inside moving car
80	Loud music from radio
90	City traffic
100	Subway train
110	Loud thunder
120	Amplified music in night club
130	Machine gun fire at close range
140	Jet engine at takeoff
180	Space rocket at blastoff

*re: 2×10^{-5} Pa.

Mammals have the greatest range in sound reception and sensitivity (Fay 1988). The variability is likely due to the diversity of habitats that mammals occupy. Mammals can hear a wide range of acoustic frequencies but are most receptive within a narrow range. For example, house mice (*Mus musculus*) and Norway rats (*Rattus norvegicus*) have lower and upper auditory ranges of about 0.5–120,000 Hz, respectively, but they are most sensitive to frequencies around 15,000 Hz at the 0–5 dB SPL range (Borg 1982; Ehret 1983; Fay 1988). Elephants (*Elaphus maximus*) can hear infrasonic frequencies and may use infrasound in their communication (Heffner & Heffner 1982). Carnivores such as dogs (*Canis familiaris*), cats (*Felis catus*), raccoons (*Procyon lotor*), and weasels (*Mustela* spp.) appear to be most sensitive to frequencies of 1,000–20,000 Hz,

while herbivores such as cattle are most sensitive to frequencies of 1,000–15,000 Hz (Fay 1988). Studies have shown that cats have very sensitive hearing, from −18 to −1 dB SPL in the range of 1,000–2,000 Hz (Gerken *et al*. 1985; Fay 1988). The least weasel (*Mustela nivalis*) can hear sounds of −10 to 0 dB SPL in the range of 1,000–20,000 Hz (Heffner & Heffner 1985). Livestock have an absolute sensitivity of −10 to 10 dB SPL within the range of 1,000–15,000 Hz (Fay 1988).

Among the more highly evolved vertebrates, the ability to detect ultrasound and frequencies above 12,000 Hz is distinctly a mammalian feat (Forschungsgemeinschaft 2000). Echolocating bats (e.g. big brown bat (*Eptesicus fuscus*), little brown bat (*Myotis lucifugus*), greater horseshoe bat (*Rhinolophus ferrumequinum*)) can hear ultrasonic frequencies (Dalland 1965, 1970; Long & Schnitzler 1975; Forschungsgemeinschaft 2000). These bats can detect frequencies of 50,000–90,000 Hz with an absolute sensitivity of 0–20 dB SPL (Dalland 1965; Long & Schnitzler 1975). Rats (Borg 1982) and mice (Fay 1988) are also capable of detecting ultrasonic frequencies.

Frightening Device Stimuli

Visual stimuli used to frighten problem animals include lights, moving/reflective objects, and threatening images (Koehler *et al*. 1990). Strobe lights (Linhart *et al*. 1992; Green *et al*. 1994) and floodlights are often used to deter animals from an area. Moving and/or reflective objects include flags, wind propellers, plastic jugs, aluminum reflectors (Scott & Townsend 1985) and reflective tape (Bruggers *et al*. 1986; Dolbeer *et al*. 1986; Conover & Dolbeer 1989). Threatening objects may consist of scarecrows (Scott & Townsend 1985; Stickley & King 1995) or predator models such as hawk-kites (Conover 1984), hawk or owl decoys, scary-eyes or eyespots (Belant *et al*. 1998b) and rubber or inflatable models of snakes. Some animals have a fear of new objects (neophobia) in their environment, and may avoid that area for a short time (Koehler *et al*. 1990). Effectiveness of these visual stimuli will be discussed later.

Because animals often have very acute and sensitive hearing, acoustic frightening devices may discourage animals from an area. Loud noises, including explosions from gas exploders (Figure 1), sirens, and recorded animal sounds, are commonly used as frightening devices. Animals tend to initially avoid areas with loud and/or unfamiliar sounds (Koehler *et al*. 1990).

A type of acoustic stimuli that are promising for future frightening devices is bioacoustics. Bioacoustics are animal communication signals, often in the form of alarm or distress calls. An alarm call is a vocalization used to warn other individuals of possible danger, for example, the snort of a deer that senses a predator (Sauer 1984) or the loud calling of a disturbed Canada goose (*Branta canadensis*) (Mott & Timbrook 1988; Aguilera *et al*. 1991). A distress call is emitted when an animal is being physically traumatized or restrained (Sprock *et al*. 1967; Marchinton & Hirth 1984). Communication signals in animals are usually species-specific (Frings 1964; Bomford & O'Brien 1990). Most studies using bioacoustics have been conducted on birds (Frings 1964; Thompson *et al*. 1968a,b; Mott & Timbrook 1988; Aguilera *et al*. 1991). Knowledge of the potential use of mammalian communication signals is limited (Frings 1964; Koehler *et al*. 1990).

Several advantages of bioacoustics over other acoustic frightening devices are apparent. Loud noises used to frighten animals are disturbing to humans or domesticated animals and can be expensive to produce (Frings 1964; Conover 1984). Alarm and distress calls are meaningful to animals at low intensities (Frings 1964; Sprock *et al*. 1967), therefore, it is not necessary to produce a loud alarm or distress call to frighten an animal. High quality recording and broadcasting equipment should be used to record and reproduce bioacoustic stimuli (Schmidt & Johnson 1983).

Periodicity of Stimuli

Frightening devices can be periodic, random, or animal-activated. Periodic frightening devices create sound at repetitive intervals. For example, gas exploders can be set to fire every 15 min. Randomly activated devices operate by a randomization timer. The Electronic Guard has a small electronic panel that activates the device at 6–7 min intervals (Belant *et al*. 1998a).

Frightening devices can also be activated by electronics that detect motion and/or body heat. Infrared sensors detect movements to activate frightening devices. Examples include the Ground Intercept System (Field System 1, Inc., Huron, South

Figure 1. Gas exploder connected to a 9-kg propane tank on edge of a cornfield.

Dakota), Yard Gard (Weitech, Inc., Sisters, Oregon), Usonic Sentry (Medline of Colorado, Grand Junction, Colorado), and TrailMaster® (Goodson & Associates, Inc., Lenexa, Kansas, USA). The TrailMaster® uses a cone of infrared light to detect animal movements and/or body heat and activates a camera or video recorder. Radars are another possible animal detection unit that can be used to activate frightening devices. Motion detectors like these have been used recently to activate frightening devices (Belant *et al.* 1996; DeNicola *et al.* 2000; Stevens *et al.* 2000).

Lasers or infrared beams directed at a receiving device could also be used to activate frightening devices. For example, automatic garage door openers use an infrared light beam that signals the door to reopen if the light beam is broken as the door is closing to avoid striking an object. To our knowledge, lasers have never been used to activate frightening devices.

Random or animal-activated frightening devices may reduce habituation and increase the time of protection over non-random devices (Koehler *et al.* 1990; Belant *et al.* 1996, 1998a; Nolte 1999). We believe such devices should be integrated with frightening systems (Figure 2).

Use of Frightening Devices

Frightening devices are best used in integrated systems to protect property that is vulnerable to wildlife damage for short periods, such as a few days to a couple weeks (Frings 1964; Koehler *et al.* 1990; Belant *et al.* 1996, 1998a). Nolte (1999) reported that ungulates avoid areas with visual displays that appear threatening. Simply placing the frightening devices out in an area may provide a few days of protection. The presence of a novel item along with audible and visual stimuli aids in deterring animals. Animals are generally wary of new sights and sounds in their environment, but will become less wary over time unless the object or noise is paired with a negative reinforcement (Nolte 1999). Table 2 provides information on frightening devices/methods used to provide wildlife damage relief.

The major limitation with the use of frightening devices is that animals habituate rather quickly to external stimuli after a short time (Bomford & O'Brien 1990; Koehler *et al.* 1990; Craven & Hygnstrom 1994; Nolte 1999). Habituation is the process by which animals adjust to and ignore new sights, sounds, and smells over time (Bomford & O'Brien 1990). Altering the position

Figure 2. Infrared transmitting unit (left) and receiving unit (right) of the deer-activated bioacoustic frightening device that integrates an infrared detection system and a compact disk that repeatedly plays distress calls of white-tailed deer when activated.

of the devices and using a combination of sight and sound stimuli, may help to delay habituation (Belant *et al.* 1996; Koehler *et al.* 1990; Nolte 1999; Whisson & Takekawa 2000). Although total elimination of damage often is impossible, a combination of frightening stimuli over a short time often reduces damage to a tolerable level.

Control programs for birds and mammals should begin at the first sign of damage before feeding or roosting patterns become established (Koehler *et al.* 1990; Nolte 1999; DeNicola *et al.* 2000). For example, cornfields are susceptible to deer damage during the silking-tasseling growth stage (Hygnstrom *et al.* 1992). VerCauteren & Hygnstrom (1998) found that deer adjusted their feeding behavior in response to corn growth, selecting the newly developing ears of corn. Frightening devices applied before deer begin feeding on corn may protect the crop from damage. Spalinger *et al.* (1997) suggested that food selection by white-tailed deer is largely an innate behavior and that deer may rely on mechanisms that enhance gustatory or olfactory detection to evaluate forage quality. Frightening devices deployed before animals have developed a feeding or roosting pattern may be more effective than trying to stop damage already in progress.

Birds

Birds cause problems by means of their feeding, roosting, breeding, or loafing habits. Commensal birds, including house sparrows (*Passer domesticus*), European starlings (*Sturnus vulgaris*), pigeons, and Canada geese, often cause nuisance problems in urban areas. House sparrows, starlings, and pigeons cause problems because of their droppings, feeding, roosting,

Table 2. Frightening devices/methods most effectively used to control damage from selected species*

Pest	Frightening techniques	Duration of results	Comments
Blackbirds Family Icteridae	Gas exploders, human/predator effigies, pyrotechnics, mylar ribbon, Avitrol®	Few days to a few weeks	Habituation may limit effectiveness, may help to move flocks to other areas, integrated approach may improve results
Geese (*Branta canadensis*) (*Chen caeruluscens*)	Gas exploders, mylar ribbon, reflective objects, distress/alarm calls	Few days to a few weeks	Habituation may limit effectiveness
Gulls Family Larinae	Pyrotechnics, mylar ribbon distress/alarm calls, Avitrol®	Few days to a few weeks	Habituation may limit effectiveness, integrated approaches may improve results
Picivorous birds (*Ardea herodias*) (*Ardea alba*) (*Pelecanus erythrorhynchos*) (*Phalacrocorax auritis*)	Gas exploder, mylar ribbon, pyrotechnics, lasers, human/predator effigies, alarm/distress calls	Few days to a few weeks	Effectiveness is variable, integrated approach may improve results
Pigeons (*Columba livia*)	Ultrasonic devices, Avitrol®	Few days at best	Very little evidence that ultrasound deters birds
Starlings (*Sturnus vulgaris*)	Distress/alarm calls, predator effigies, Avitrol®	Few days to a few weeks	May help move roosting/feeding flocks to other areas
Deer (*Odocoileus* spp.)	Gas exploders, rope firecrackers, revolving lights	Few days to a week	May help move migrating herds on to other areas
Raccoons (*Procyon lotor*)	Lighting the area, playing a radio, gas exploders, pyrotechnics	Few days at best	Raccoons accustomed to people are difficult to frighten
Foxes (*Vulpes* spp.) (*Urocyon* spp.)	Gas exploders, rope firecrackers, revolving lights	Few days at best	Flooding a backyard garden with light may discourage foxes from damaging melons, etc.
Coyotes (*Canis latrans*)	Gas exploders, rope firecrackers, Electronic Guard	Few days at best	Highly unpredictable in their response to frightening devices
Rabbits (*Sylvilagus* spp.) (*Lepus* spp.)	Gas exploders, rope firecrackers	Few days to a week	For very temporary relief. Provides time to install fence
Rodents Order Rodentia (*Rattus Norvegicus*) (*Mus musculus*)	Ultrasonic devices	—	Frightening techniques rarely have any appreciable effects on small rodents

*Based in part on Koehler *et al*. (1990).

and nest-building activities (Fall & Jackson 2000). Canada geese often live in city parks and golf courses where their droppings accumulate on turf causing unsanitary conditions that can lead to health concerns. Blackbirds (*Icterinae*) cause millions of dollars in damage to crop fields annually (Conover 1984; Bergman *et al*. 1997; Dolbeer 1999). Aquaculture facilities experience substantial yield losses from piscivorous birds, including great blue herons (*Ardea herodias*), great egrets (*Ardea alba*), white pelicans (*Pelecanus erythrorhynchos*) and double-crested cormorants (*Phalacrocorax auritis*) (Stickley & King 1995; Mott *et al*. 1998; Tobin 1998). Bird strikes at airports are also an important issue because of the potential for catastrophic loss of human life (Curtis *et al*. 1995; Montoney & Boggs 1995).

Pyrotechnics

Pyrotechnics used to disperse birds include shell crackers, bird bangers, and screamers. Aguilera *et al.* (1991) reported that screamer shells were effective in dispersing flocks of Canada geese. They also found no habituation to the screamer shells because all the geese dispersed after each treatment. Mott *et al.* (1998) reported that harassing double-crested cormorants at their night roost using pyrotechnics was effective in reducing depredation on nearby catfish farms. Efficacy of pyrotechnics varies with the amount of harassment. Disadvantages of pyrotechnics are that (1) they have to be fired by an operator, (2) they can be expensive, (3) they could disturb the public, and (4) birds may habituate to the noises.

Gas exploders

Conover (1984) reported that gas exploders reduced red-winged blackbird (*Agelaius phoeniceus*) damage on 2- to 8-ha cornfields by 77%. A drawback to using gas exploders is that noise associated with them may disturb nearby residents and non-target animals. Habituation to the exploders also may limit their effectiveness. Cummings *et al.* (1986) reported that a combination Purivox® Double-John carousel gas exploder and a CO_2 pop-up scarecrow device was variably effective for reducing red-winged blackbird and yellow-headed blackbird (*Xanthocephalus xanthocephalus*) damage to sunflowers. The average damage reduction on 3 of 5 test fields was 84% during an initial 10-day test, but was lower (59%) during subsequential tests, probably due to habituation (Cummings *et al.* 1986). The two remaining fields experienced an average damage reduction of 20% (Cummings *et al.* 1986).

Effigies

Effigies, including scarecrows, scary-eyes, and predator-mimicking devices (hawk or owl) can provide a visual stimulus. Conover (1984) reported that hawk-kites reduced red-winged blackbird damage to small cornfields (<8 ha) by 83%. The Hawk-kite (manufactured by K.G. Gunter Co., West Germany, distributed by Tiderider, Inc., Baldwin, New York) is a clear plastic kite imprinted with a picture of a flying hawk and suspended by helium-filled balloons. Belant *et al.* (1998b) tested eyespots and two predator effigies to deter nesting starlings. Eye spots (2-cm diameter, straw-colored taxidermy eyes with 1-cm black pupils) and predator effigies (great-horned owl (*Bubo virginianus*) and merlin (*Falco columbarius*)) were ineffective in reducing starling use of nest boxes (Belant *et al.* 1998b). Stickley & King (1995) reported that the inflatable Scary Man device (R. Royal, P.O. Box 108, Midnight, Mississippi 39115), a pop-up inflatable human effigy (Figure 3), reduced double-crested cormorant pressure to catfish ponds by 98% during the first 7 days of implementation.

Figure 3. Scary man pop-up inflatable effigy device. (USDA/APHIS/WS Photo)

Lasers

Lasers are a relatively new frightening device used for bird dispersal. Glahn *et al.* (2001) used lasers to disperse double-crested cormorants from night roosts in the lower Mississippi Valley. Two types of lasers, the Desman© laser (model FL R 005, distributed by Reed-Joseph International, Greenville, MS) and the Dissuader® laser (SEA Technologies, Albuquerque, NM) were tested. The Desman© laser is a red

(632.8 nm) helium–neon laser, while the Dissuader® laser is a red (650 nm) diode laser. The beam diameter of the Desman© and Dissuader® lasers are 2.5 and 58 cm at 183 m, respectively. Lasers were shinned into the roost trees at or near sunset. In field trials the lasers were effective in dispersing cormorants, reducing roost populations by at least 90% after 1–3 evenings of harassment.

Blackwell *et al.* (2002) reported the effectiveness of lasers varied among bird species. The Dissuader® laser and an AC-powered, Class-III B, High-performance Uniphase, He–Ne, red (633 nm) laser were tested. Brown-headed cowbirds (*Molothurs alter*) and European starlings were not repelled from perch sites by the laser. Starlings were not repelled from night roosts while rock doves avoided the laser beam in roosts for approximately 5 min, then habituated to the laser. Contrary to cowbirds, starlings, and doves, Canada geese and mallards (*Anas platyrynchos*) exhibited avoidance behavior to the lasers. An average of 96% of the geese moved from the laser treated plot to a control plot following the laser treatment. An average of 57% of the mallards moved from the laser treated plot to a control plot following the laser treatment, however the mallards habituated to the laser after about 20 min (Blackwell *et al.* 2002).

Lasers are a quiet, species-specific, non-lethal dispersal tool that can be used in urban and rural situations. A disadvantage of the lasers is their cost. The Desman© laser is available at a cost of $7,500 and the Dissuader® laser costs $5,600. However, prices are coming down, a laser is now available from SEA Technologies for less than $1,000.

Reflective ribbons and other reflective devices

Reflective ribbons and other shiny devices are sometimes used to deter birds. Mylar ribbons are strips of reflective tape with silver and red colors on opposite sides. When strung and slightly twisted between posts, the ribbons reflect sunlight and make a humming sound in the wind. Effectiveness of mylar ribbon is variable. Mylar ribbon was effective in protecting corn, millet, sunflower, and sorghum fields from damage by birds (Bruggers *et al.* 1986; Dolbeer *et al.* 1986). Conover & Dolbeer (1989) reported that mylar ribbons spaced at 16-m intervals were ineffective in reducing blackbird damage to ripening cornfields. Closer spacing of the mylar ribbons may be more effective, however, the mylar ribbons may be cost-effective only for high value crops, or those that are low to the ground (Conover & Dolbeer 1989). Mylar ribbon was ineffective in protecting blueberries from birds, although birds may have habituated to the mylar because it was erected 10–12 days before observations were recorded (Tobin *et al.* 1988). Belant & Ickes (1997) reported that mylar ribbons were ineffective in deterring herring gulls and likely, other gulls (Subfamily Larinae), from nesting colonies but did reduce the use of loafing areas. The varying response to mylar ribbon may have been related to the fidelity and availability of the treated area to the gulls.

Mason *et al.* (1993) found white plastic flags to be effective in repelling snow geese (*Chen caerulescens*) from rye and winter wheat fields. Large flocks of snow geese (up to 15,000) had been grazing in treatment fields, but stopped when the flags were placed in the fields (Mason *et al.* 1993). The outcome of this study seems contrary to what is known, as snow goose hunters use white decoys and white plastic rags to attract geese. The explanation is not fully understood but it is thought that the shiny plastics used in the study deterred geese because of reflective and noise-making properties. The method of applying the flags, spread throughout the fields, could have also been a factor.

Guard animals

Dogs can be trained to harass nuisance wildlife. Castelli & Sleggs (2000) reported that border collies reduced Canada goose numbers on a 44 ha property in New Jersey comprised of buildings, walkways, a helicopter landing pad, turf, and a 1.7 ha pond. Canada geese, numbering as high as 2000 with about 100 resident breeding birds, used the area. The border collies were placed on the property and allowed to chase geese day and night. Three years after implementing the dogs, geese were seldom seen on the property, and the project was a considered a success. Initial cost was about $9,400 (2 dogs @ $1,200 each, $5,000 for invisible fencing, $2,000 for kennel), and company personnel cared for the dogs. To maintain the project from 1990 to 1997, costs were about $2,000/year for food and veterinary services (Castelli & Sleggs 2000).

Chemical frightening agent

Avitrol® (Avitrol Corp., Tulsa, OK) containing the active ingredient 4-aminopyridine, is a chemical frightening agent registered by the United States Environmental Protection Agency (Dolbeer 1994). After ingesting treated bait, birds become disoriented

and emit distress calls while flying erratically, which frightens other birds from the site (Timm 1994c). The bird ultimately succumbs to the chemical and dies. Special care must be taken to minimize non-target poisoning.

Knittle *et al.* (1988) report that Avitrol® baits reduced red-winged blackbird damage to sunflower fields within 2 miles of blackbird roosts. Avitrol®-treated cornfields had less damage than untreated control fields, however, it was not cost-effective when compared to gas exploders and hawk-kites (Conover 1984). The 4-aminopyridine agent was also effective in reducing blackbird damage to corn with minimal hazards to non-target species (Stickley *et al.* 1976).

Bioacoustics

The use of bird alarm and distress calls to disperse birds is based on sound biological principles. Alarm and distress calls warn other birds in the area that danger is present, typically causing the other birds to flee. Birds are less likely to habituate to alarm and distress calls than to other sounds (Thompson *et al.* 1968b; Johnson *et al.* 1985; Bomford & O'Brien 1990).

Animals often react physiologically to alarm and distress calls. Thompson *et al.* (1968a,b) reported starlings were startled and experienced increased heart rates when exposed to recorded distress calls. Some starlings responded to the distress calls with a heart rate of over 700 beats/min, which is 130% above the normal heart rate (Thompson *et al.* 1968b). This heart rate is near the physiological upper limit for starlings and is characteristic of adrenal stimulation.

Gorenzel & Salmon (1993) reported that tape-recorded crow distress and alarm calls were effective in dispersing crows from individual urban roosts. Crows responded to the recorded calls by taking flight and circling overhead while giving assembly and scolding calls. The calling crows attracted additional crows from nearby roosts (up to 240 m away) to join in on the circling and calling. The tape recording was played for 30 s. The crows stopped vocalizing and flew away after the tape was played, leaving the roost empty.

Mott & Timbrook (1988) tested alarm and distress calls alone and in combination with pyrotechnics on Canada geese. Goose numbers were reduced an average of 71% with alarm and distress calls alone. In another study, Canada geese became alert and moved up to 100 m away from the calls but never left the area (Aguilera *et al.* 1991).

Ultrasonic devices

Producers of ultrasonic devices for birds often make unsubstantiated claims about their aversive effects. Although ultrasound and infrasound can be detected by some vertebrate pests (Curtis *et al.* 1997; Forschungsgemeinschaft 2000), empirical evidence that birds can hear and will avoid ultrasound is lacking (Frings 1964; Wright 1982). Woronecki (1988) reported that the Ultrason UET-360 ultrasonic device was completely ineffective at keeping pigeons from residing inside vacant buildings.

Integrated approaches

An integrated management system for controlling pest birds is recommended over any single method used alone (Godin 1994; Montoney & Boggs 1995; Belant 1997; Tobin 1998). Integrated management using strictly non-lethal methods can be effective in reducing damage. When goose alarm and distress calls were combined with pyrotechnics at campgrounds in Tennessee, goose numbers declined by 96% (Mott & Timbrook 1988). To reduce red-winged blackbird damage to cornfields, Dolbeer (1990) recommended integrated techniques such as bird resistant cultivars, deployment of frightening devices at specific times, and increased availability of alternate feeding areas.

Stevens *et al.* (2000) tested a radar-activated integrated hazing system to deter waterfowl from contaminated ponds. Frightening devices were activated when the radar detected waterfowl approaching the site. Deterrents included alarm calls, pyrotechnics, and methyl anthranilate in the form of an aerosol. Waterfowl were 12.5 times less likely to fly over, and 4.2 times less likely to land on hazed ponds relative to the control pond. The integrated demand-performance system was effective at keeping waterfowl away from protected areas throughout the year and waterfowl did not habituate to the system.

Integrated management with lethal control has been used for reducing local populations and for reinforcing non-lethal frightening techniques (Thomas 1972; Dolbeer *et al.* 1993; Curtis *et al.* 1995; Tobin 1998). Thomas (1972) recommended the use of trapping, poisoning, shooting, frightening, sterilization of eggs, and habitat modification to control gull damage in nature

reserves. Tobin (1998) reported aquaculture facilities use a combination of frightening devices and lethal control to control great blue herons, great egrets, white pelicans, and double-crested cormorants at fish rearing ponds.

When non-lethal control at aquaculture facilities is deemed ineffective, the United States Fish and Wildlife Service (USFWS) may issue depredation permits that allow farmers to kill a limited number of problem birds. Analysis of bird count data for the past decade indicated lethal control of double-crested cormorants, great blue herons, and great egrets at aquaculture facilities through depredation permits did not adversely affect the continental populations of these birds (Mastrangelo *et al*. 1996; Belant *et al*. 2000).

Dolbeer *et al*. (1993) used lethal control at John F. Kennedy International Airport in an integrated approach to reduce gull strikes by aircraft. During 1991 and 1992, observers shot 28,352 gulls flying over runways. The reduction in gull strikes was 70% and 89%, respectively (Dolbeer *et al*. 1993). Dolbeer *et al*. (1993) concluded the reduction in strikes was due to the reduced number of gulls rather than the gulls avoiding the area. Montoney & Boggs (1995) reinforced distress calls and pyrotechnics by shooting gulls at the Atlantic City International Airport to reduce bird/aircraft strikes. Curtis *et al*. (1995) recommended an integrated management strategy consisting of pyrotechnics, lethal control to reinforce fear, and habitat modification to disperse birds from E.A. Link Airport. Falconry has been used with other bird-frightening techniques to reduce the number of birds at airports and in agricultural fields (Erickson *et al.* 1990). Falconry is expensive, however, and time consuming to implement.

Mammals

Mammals also cause problems by means of their feeding, breeding, or loafing habits. White-tailed deer, mule deer (*O. hemionus*), and elk (*Cervus elaphus*) damage agricultural crops, landscape plantings, haystacks, vehicles, and other personal property. Farmers and wildlife agencies rank deer as causing more overall crop damage than any other group of wildlife (Conover & Decker 1991; Wywialowski & Beach 1992; Fagerstone & Clay 1997). Every year, wildlife causes an estimated 316 million dollars in damage to crops across the nation, with deer being cited as the primary species responsible for the damage (Fagerstone & Clay 1997). Agricultural crops, orchards, and landscape vegetation are especially susceptible to heavy damage. Deer are also a hazard on highways and airports across the nation (Wright *et al*. 1998). Dolbeer *et al*. (2000) analyzed the Federal Aviation Administration's (FAA) National Wildlife Strike Database for civil aircraft in the United States and reported deer were ranked as the most hazardous wildlife species in wildlife–aircraft collisions. The size and mass of a deer, and the damage sustained by the aircraft from the impact, influenced this ranking. Human safety is at stake when vehicles collide with deer on highways. The concern for human safety becomes even greater when aircraft are involved in wildlife collisions on the runway.

Other mammalian species including raccoons, foxes (*Vulpes* and *Urocyon* spp.), rabbits (*Sylvilagus* and *Lepus* spp.), beaver (*Castor canadensis*), rats (*Rattus* spp.), mice, and other rodents (Order Rodentia) can be responsible for damage to crops, gardens, and orchards (Dolbeer 1999). Predators such as coyotes cause significant losses to livestock producers (Linhart *et al*. 1992; Knowlton *et al*. 1999).

Gas exploders

Belant *et al*. (1996) tested the periodic firing of propane cannons and deer-activated gas exploders. The deer-activated system used infrared motion sensors to detect movement and stimulate a gas exploder to fire. The deer-activated propane cannons were effective at reducing deer incursions of feeding stations for up to 6 weeks while, periodically firing exploders (set to detonate every 8–10 min) were effective for only 2 days (Belant *et al*. 1996).

Gas exploders, pyrotechnics, and lights have been used to disperse raccoons, foxes, rabbits, beaver, and other rodents. Gas exploders were effective for a few days up to one week for these species (Koehler *et al*. 1990; Dolbeer 1999).

Lasers

The recent success of lasers to disperse bird species has prompted similar research involving mammals. VerCauteren *et al*. (in press) tested the effectiveness of the Desman© laser and the Dissuader® laser to frighten deer from fields at night. Only 10 (5.6%) of 177 encounters resulted in deer fleeing from the laser treated field. The authors suggest that white-tailed deer were not repelled from fields following laser treatment.

Figure 4. Electronic Guard suspended along sheep pasture. (USDA/APHIS/WS Photo)

Lights and sirens

The Electronic Guard (Figure 4) is a frightening device designed to reduce coyote predation on sheep and livestock (Linhart *et al*. 1992; Green *et al*. 1994). The Electronic Guard consists of a timer, a blinking strobe light, and a warbling siren enclosed in a polyvinyl chloride (PVC) case. The Electronic Guard has a photocell built into the side, that automatically activates and deactivates the system at sunset and sunrise, respectively. When operational, the timer randomly activates the system to flash and sound for about 7–10 s at about 6–7 min intervals throughout the night. Linhart *et al*. (1992) found the Electronic Guard was effective in protecting sheep on their summer range from coyote attacks. Habituation to the devices may be delayed if the devices are moved periodically, used in appropriate numbers, and programmed to vary the pattern of multiple stimuli (Linhart *et al*. 1992). Frightening devices with white strobe lights were effective against deer for less than one week (Belant *et al*. 1998a). Studies that have used lighting techniques found they were effective only for a few days to a couple of weeks (Koehler *et al*. 1990; Bomford & O'Brien 1990; Knowlton *et al*. 1999; DeNicola *et al*. 2000).

Guard animals

Guard dogs have been used for centuries by rural societies in the Old World to guard livestock from predators (Linhart 1981). Great Pyrenees, Akbash, Anatolian shepards, and Komondors are the breeds that are most often used as guard dogs. Great Pyrenees were rated as being the most effective breed for controlling coyote predation on sheep ranches (Green & Woodruff 1983; Green 1989a). Andelt (1992) reported that 91% of the sheep producers responding ($n = 22$) rated their dogs' performance at reducing predation as excellent or good. Eleven producers in the study estimated that each of their dogs saved an average of $3,216 in sheep annually (Andelt 1992). Coppinger *et al*. (1983) reported that 63% of the dogs tested ($n = 98$) had fewer attacks on their flocks, and 25 of these dogs reduced attacks from $\geq$6 per year to zero. The average first-year cost for one guard dog, including cost of purchase, shipping, feed, health care, travel associated with care, training, damage caused by dogs, and miscellaneous, was $834, while subsequent yearly average expenses were $286 (Green *et al*. 1984). Green & Woodruff (1983) recommended using 2 dogs that are compatible with each other to protect a herd of sheep. Two dogs that can work together are more effective because while one pursues the predator, the other can remain with the livestock (Green & Woodruff 1983).

Guard dogs can also be used to protect agricultural plantings. Berringer *et al*. (1994) reported guard dogs were effective in protecting a white pine plantation from browsing by white-tailed deer. Average browse rates in plots protected by dogs compared to unprotected plots were 13% and 56%, respectively, during the 3-year study. Dogs were provided with houses, shade structures, self-feeders, and water. Houses and feeders were placed some distance apart, forcing the dogs to travel and increase the potential for deer–dog encounters. An electric containment fence (Invisible Fence Co. Inc., Berwyn, PA) in conjunction with a shock collar was used to confine the dogs to the plantation. Berringer *et al*. (1994) recommend using dogs with herding instincts such as Australian shepards, blueheelers, and border collies. Dogs should be neutered or spayed, and used in pairs to allow for social interaction.

Donkeys can also be used as guard animals to protect livestock. Donkeys have an inherent dislike for canids. They will vocalize (bray) and chase canids and try to kick and bite intruders (Green 1989b). One jenny (female) or one gelded jack (neutered male) is recommended per herd of livestock. Non-neutered jacks are too aggressive and using one donkey forces the guard animal to bond with the livestock rather than a conspecific (Green 1989b; Walton & Feild 1989). Effectiveness of donkeys as guard animals is highly variable and usually not as successful as guard dogs (Green 1989b; Walton & Feild 1989). Benefits to using donkeys is that they can be purchased at stockyard auctions for about $100–300, are easier to care for than dogs, require no special feeds, and are long-lived (Green 1989b; Walton & Feild 1989).

Llamas are another guard animal used to reduce livestock depredation. Meadows & Knowlton (2000) reported llamas reduced canine predation on lambs during the first year of their study, but not during the second year. Surveys indicated that 90% of the responding producers rated their llamas as being effective in reducing depredation losses. When producers were given the option to purchase the llama for $350, 94% did so. When these producers were contacted one year later, 94% ($n = 15$) were still using the llama as a guard animal and considered the llama effective in reducing sheep loss to predators.

As with most depredation control methods, effectiveness of guard animals is variable. Guard animals must be used within their capabilities, because there is a limit to the herd size and area they can protect. Green (1989b) and Walton & Feild (1989) recommend using donkeys on small open pastures with no more than 200–300 sheep. Cost-effectiveness must be considered for each livestock producer. Guard animals are most effective when used in an integrated wildlife damage management program (Green 1989a; Meadow & Knowlton 2000).

Bioacoustics

Use of bioacoustics to alleviate mammalian damage has been limited (Koehler *et al.* 1990). Sprock *et al.* (1967) reported that distress calls appeared to be more promising than other sounds for dispersing rats. The effects of distress calls on coyote behavior is limited and short term (Wade 1983). Bioacoustic sounds may be applicable to other mammals and aid in the development of frightening device technology.

Ultrasonic devices

Although some animals can hear ultrasound, there is controversy around its efficacy for deterring mammals (Frings 1964; Bomford & O'Brien 1990; Koehler *et al.* 1990). The Yard Gard and the Usonic Sentry are ultrasonic devices that are marketed to repel pests from areas of concern. Both products are motion-activated and emit ultrasound for about 7–18 s. The Yard Gard was ineffective at repelling deer from an area and from preferred foods (Curtis *et al.* 1997; Belant *et al.* 1998a). The Usonic Sentry, with and without a white strobe light, was ineffective in repelling deer from feeding stations for more than one week (Belant *et al.* 1998a). There is little evidence that rats and mice are repelled by ultrasound (Sprock *et al.* 1967; Timm 1994a,b). Efficacy of ultrasonic devices for rodents depends on the frequency and intensity of the ultrasound, and pre-existing population levels (Sprock *et al.* 1967; Shumake *et al.* 1982).

Integrated approaches

Integrated management is also recommended for controlling mammalian damage (Coffey & Johnston 1997; Campbell III *et al.* 1998; Engeman & Witmer 2000). Rodent damage to agricultural production is an area of concern. Murua & Rodriguez (1989) compared toxicant (Brodifacoun and Bromadialone) use to an integrated management technique to reduce rodent damage to bark in tree plantations. Integrated practices included a barrier (4-m wide strip cleared of all vegetation), erecting 2.5-m perches for predatory birds, and snap traps in and around the protected area. Maximum rodent damage was observed in April, during this time there was 50% less damage in barrier/perch plots and 75% less damage in barrier/trap plots when compared to control sites. Murua & Rodriguez (1989) reported integrated protection methods were equally as effective at reducing rodent damage as applications of toxicants.

Conclusion

The use of frightening devices is an important area in integrated wildlife damage management. Public acceptance for implementing non-lethal methods to control problem wildlife is high. Non-lethal methods are often the only allowable or feasible method to control wildlife in urban settings. It is important, however,

that devices be tested to determine their efficacy. Many frightening devices are ineffective in deterring animals and should be set aside to allow for the development and testing of new devices. Frightening devices used in an integrated management system with varying application procedures, and those that incorporate multiple stimuli are most effective for reducing bird and mammal damage. A frightening device that can effectively and humanely reduce wildlife damage has the potential to save millions of dollars in lost revenue.

Studies that compare the use of individual control methods to integrated management are scarce. We recommend more rigorous testing of the efficacy of integrated approaches and compare them to individual management methods. A well-planned IPM program includes identification of the problem, determining acceptance thresholds, defining precise goals and objectives, and developing and implementing a monitoring program (Coffey & Johnston 1997; Engeman & Witmer 2000). The development of an IPM program could aid in the effective management of wildlife species.

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