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Effectiveness of Frightening Devices for Reducing Deer Damage in Cornfields

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EFFECTIVENESS OF FRIGHTENING DEVICES FOR REDUCING DEER DAMAGE IN CORNFIELDS

by

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EFFECTIVENESS OF FRIGHTENING DEVICES FOR REDUCING DEER DAMAGE IN CORNFIELDS

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University of Nebraska, 2002

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The goal of this research was to test the efficacy of three frightening devices to reduce damage caused by white-tailed deer (*Odocoileus virginianus*) in cornfields. We tested propane cannons, electronic guards, and a deer-activated bioacoustic device during the silking-tasseling stage of corn growth on the DeSoto National Wildlife Refuge and the Loess Hills State Forest near Missouri Valley, IA, USA. We used track indices, damage assessments, crop yields, and use-areas of radio-collared female deer to evaluate the effectiveness of each device.

Propane cannons and electronic guards were ineffective in deterring deer from cornfields. Track count indices ($F_{6,8} = 0.84, P = 0.575$), corn yields ($F_{2,6} = 0.14, P = 0.873$), and estimated damage levels ($F_{2,12} = 0.96, P = 0.412$) did not differ between treatment and control fields. The size ($F_{4,13} = 0.86, P = 0.513$), location ($F_{4,9} = 0.97, P = 0.471$), and percent overlap ($F_{4,9} = 1.86, P = 0.203$) of use-areas of radio-collared female deer did not differ among before, during, and after treatment periods. In a related study we placed propane cannons in cornfields that were being used by 12 radio-collared female deer. The deer did not react appreciably to the devices as the size ($F_{2,17} = 0.08, P = 0.921$), location ($F_{2,22} = 1.37, P = 0.275$), and percent overlap ($F_{2,10} = 0.47, P = 0.636$) of the use-areas did not differ among before, during, and after treatment periods.

The ineffectiveness of the propane cannons and electronic guards prompted us to design and develop a new type of frightening device that was deer-activated to reduce habituation to the stimuli. The device consisted of an infrared detection system, which activated an audio component that broadcast distress calls of deer. We tested the device against untreated controls in cornfields during the silking-tasseling stage of growth. The device was not effective in reducing damage as track count indices ($F_{5,19} = 1.52$, $P = 0.232$), corn yield ($F_{1,9} = 1.27$, $P = 0.289$), and estimated damage per field ($F_{1,10} = 1.66$, $P = 0.227$) did not differ between treatment and control fields. The use-area size ($F_{2,25} = 1.49$, $P = 0.245$), location ($F_{2,25} = 0.39$, $P = 0.684$), and percent overlap ($F_{2,25} = 0.20$, $P = 0.818$) of use-areas of radio-collared female deer did not differ between during and after treatment periods.

The effectiveness, costs, and maintenance associated with each frightening device is discussed with recommendations for use. Frightening devices tested in this study may be more effective if used to protect small areas such as gardens or if used in an integrated management program. The effectiveness of the deer-activated bioacoustic device may be increased if used on smaller areas where the entire perimeter of the area can be encompassed. Further testing of such a device in additional settings may provide more desirable results for protecting property from deer damage.

Chapter 1 is written in the Integrated Pest Management Reviews format and has been accepted for publication. Chapters 2 and 3 are written in the Wildlife Society Bulletin format and the manuscripts will be submitted to the journal for publication.

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Use of Frightening Devices in Wildlife Damage Management

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, propane cannons, 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 and 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, the tolerance of farmers and rural landowners of deer (*Odocoileus* spp.) is strongly influenced by concerns about crop damage (Brown *et al.*, 1978). Agricultural producers typically accept damage levels of ≤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 to control wildlife damage, however, is often controversial. 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 seldom 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 and 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 Stimuli 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 is a cursory report of the visual and auditory capabilities of selected animals, given to establish a basis in the development of frightening devices.

Visual Reception

Color vision in animals has been the focus of several studies (Yokoyama and Radlwimmer, 1998; Jacobs *et al*., 1994). 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 (McIlewain, 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 (e.g. 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 and 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 and 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 of rods and cones that allow for color vision and vision during light and dark periods (Ali and Klyne, 1985).

Birds use color vision for food and sex recognition (Ali and Klyne, 1985; Smythe, 1975). Colored oil droplets often found on cone cells are thought to aid in color vision (Ali and 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 and 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 and 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 (Ali and Klyne, 1985; Smyth, 1975).

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 light energy is in the range of 300-400 nm. Many birds have the capability to use light energy in the ultraviolet range (Yokoyama, 1999; Hart *et al.*, 1998; Bowmaker *et al.*, 1997). Kevan *et al.* (2001) suggest ultraviolet vision does not appear to be any more significant than that of other wavelengths. Scientists believe birds use ultraviolet vision for foraging, signaling (e.g. mate choice), and species recognition (Hunt *et al.*, 2001; Cuthill *et al.*, 2000; Bennett and Cuthill, 1994; Jacobs, 1992). 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 and 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 (Ali and Klyne, 1985; Jacobs, 1981). Ali and Klyne (1985) suggest color vision is more important to tree-dwelling species than to herbivores and carnivores because of their food habits. White-tailed deer have dichromatic color vision that allows deer to see blue and green wavelengths (Yokoyama and Radlwimmer, 1998); Jacobs *et al.*, 1994). Rodents such as rats, mice, and some gophers also have the ability to use ultraviolet 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 x 10^{-5} Pascal. Humans can detect sounds from approximately 20 Hz to 20,000 Hz (Bomford and O'Brien, 1990) with an absolute sensitivity of 0 dB SPL (Durrant and Lovrinic, 1984). Ultrasonic frequencies are those above 20,000 Hz and infrasonic frequencies those below 20 Hz. Decibel levels of some familiar sounds range from nearly 0 to 180 (Table 1).

Birds appear to be most receptive to sounds from 1000 Hz to 3000 Hz, with an absolute sensitivity of -10 to 10 dB SPL (Stebbins, 1983; Fay, 1988; Dooling, 1980; 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 6000 to 7000 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 *et al.*, 1979; Fay, 1988). Birds can also overcome presbycusis, the deterioration of auditory sensitivity with age, because they have the ability to regenerate damaged cells in the inner ear (Langemann *et al.*, 1999; Cotanche, 1987; Corwin and Cotanche, 1988).

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 Hz to 120,000 Hz, respectively, but they are most sensitive to frequencies around 15,000 Hz at the 0 to 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 and 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 1000 Hz to 20,000 Hz, while herbivores such as cattle are most sensitive to frequencies of 1000 Hz to 15,000 Hz (Fay, 1988). Studies have shown that cats have very sensitive hearing, from -18 to -1 dB SPL in the range of 1000 to 2000 Hz (Fay, 1988; Gerken *et al.*, 1985). The least weasel (*Mustela nivalis*) can hear sounds of -10 to 0 dB SPL in the range of 1000 to 20,000 Hz (Heffner and Heffner, 1985). Livestock have an absolute sensitivity of -10 to 10 dB SPL within the range of 1000 to 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; Dalland, 1970; Long and Schnitzler, 1975; Forschungsgemeinschaft, 2000) at 50,000 to 90,000 Hz with an absolute sensitivity of 0 to 20 dB SPL (Dalland, 1965; Long and 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 and Townsend, 1985) and reflective tape (Bruggers *et al.*, 1986; Dolbeer *et al.*, 1986; Conover and Dolbeer, 1989). Threatening objects may consist of scarecrows (Scott and Townsend, 1985; Stickley and 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.

Acoustic frightening devices may discourage animals from an area because animals often have very acute and sensitive hearing. Loud noises, including explosions from propane cannons (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).

Acoustic stimuli that are promising for future frightening devices are 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 has sensed a predator (Sauer, 1984) or the loud calling of a disturbed Canada goose (*Branta canadensis*) (Mott and 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 and Hirth, 1984). Communication signals in animals are usually species-specific (Frings, 1964; Bomford and O'Brien, 1990). Most studies using bioacoustics have been conducted on birds (Frings, 1964; Thompson *et al.*, 1968a, b; Mott and 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 and Johnson, 1983).

Periodicity of Stimuli

Frightening devices can be periodic, random, or animal-activated. Periodic frightening devices create sound at repetitive intervals. For example, propane cannons can be set to fire every 15 minutes. Randomly activated devices operate by a randomization timer. The Electronic Guard has a small electronic panel that activates the device at 6-to 7-minute 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 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 could 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 nonrandom 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 of 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). Several frightening devices/methods have been used to provide relief from wildlife damage (Table 2).

The major limitation with the use of frightening devices is that animals habituate to external stimuli after a short time (Bomford and O'Brien, 1990; Koehler *et al.*, 1990; Craven and Hygnstrom, 1994; Nolte, 1999). Habituation is the process by which animals adjust to and ignore new sights, sounds, and smells over time (Bomford and O'Brien, 1990). Altering the position of the devices and using a combination of sight and sound stimuli, may help to delay habituation (Koehler *et al.*, 1990; Nolte, 1999; Whisson and Takekawa, 2000; Belant *et al.*, 1996). 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 and 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, and nest-building activities (Fall and 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 and 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 and 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) there are restrictions on use, 4) they could disturb the public, and 5) birds may habituate to the noises.

Propane Cannons

Conover (1984) reported that propane cannons reduced red-winged blackbird (*Agelaius phoeniceus*) damage on 2-to 8-ha cornfields by 77%. A drawback to using propane cannons is that noise associated with them may disturb nearby residents and nontarget animals. Habituation to the cannons also may limit their effectiveness. Cummings *et al.* (1986) reported that a combination Purivox® Double-John carousel propane cannon and a CO_2 pop-up scarecrow device was variably effective for reducing damage to sunflowers by red-winged blackbirds and yellow-headed blackbirds (*Xanthocephalus xanthocephalus*). The average damage reduction on 3 of the 5 test fields was 84% during an initial 10-day test, but was lower (59%) during subsequential tests, probably due to habituation, while 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 (K. G. Gunter Co., West Germany) 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 and King (1995) reported that the inflatable Scary Man device (R. Royal, Midnight, Mississippi), 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.

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 38701) 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 cm and 58 cm at 183 m, respectively. Lasers were shined 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 to 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, helium-neon laser, 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 minutes, and 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 minutes (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. A laser is now available, however, from SEA Technologies for less than $1000.

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 and 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 and Dolbeer, 1989). Mylar ribbon was ineffective in protecting blueberries from birds, although birds may have habituated to the mylar because it was erected 10 to 12 days before observations were recorded (Tobin *et al.*, 1988). Belant and 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.

Guarding Animals

Dogs can be trained to harass nuisance wildlife. Castelli and 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 $9400 (2 dogs @ $1200 each, $5000 for invisible fencing, $2000 for kennel), and company personnel cared for the dogs. To maintain the project from 1990-1997, costs were about $2000/year for food and veterinary services (Castelli and Sleggs, 2000).

Chemical Frightening Agent

Avitrol® (Avitrol Corp., Tulsa, OK), which contains 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 nontarget 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 propane cannons and hawk-kites (Conover, 1984). The 4-aminopyridine agent was also effective in reducing blackbird damage to corn with minimal hazards to nontarget species (Stickley *et al.*, 1976).

Bioacoustics

The use of bird alarm and distress calls to disperse birds is based on reliable 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 and 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 and 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 seconds. The crows stopped vocalizing and flew away after the tape was played, leaving the roost empty.

Mott and 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 (Tobin, 1998; Godin, 1994; Montoney and Boggs, 1995; Belant, 1997). 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 and 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 the repellent 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 (Tobin, 1998; Godin, 1994; Montoney and Boggs, 1995; Curtis *et al.*, 1995). 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 that aquaculture facilities should use a combination of frightening devices and lethal control to manage 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 (Belant *et al.*, 2000; Mastrangelo *et al.*, 1996).

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 and 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 and Decker, 1991; Wywialowski and Beach, 1992; Fagerstone and 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 and 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 United States (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 that 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).

Propane Cannons

Belant *et al.* (1996) tested the periodic firing of propane cannons and deer-activated propane cannons. The deer-activated system used infrared motion sensors to detect movement and stimulate a propane cannon to fire. The deer-activated propane cannons were effective at reducing deer incursions of feeding stations for up to 6 weeks, while periodically firing cannons (set to detonate every 8-10 minutes) were effective for only 2 days (Belant *et al.*, 1996). Periodic-firing cannons (set to detonate every 15 minutes) were ineffective at reducing deer damage in cornfields at the silking-tasseling stage (Gilsdorf *et al.*, unpublished data).

Propane cannons, pyrotechnics, and lights have been used to disperse raccoons, foxes, rabbits, beaver, and other rodents. Propane cannons 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.*, (Unpublished data) 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.

Lights and Sirens

The Electronic Guard (Pocatello Supply Depot, Pocatello, ID, 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 seconds at about 6-7 minute 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). Electronic Guards were ineffective at reducing deer damage in cornfields at the silking-tasseling stage (Gilsdorf *et al.*, unpublished data). Frightening devices with white strobe lights were effective against deer for less than one week (Belant *et al.*, 1998a). Lighting techniques have been effective only for a few days to a couple of weeks (Koehler *et al.*, 1990; Bomford and O'Brien, 1990; Knowlton *et al.*, 1999; DeNicola *et al.*, 2000).

Guarding Animals

Guarding 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 and 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 ≥ 6 per year to 0. 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 and 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 and Woodruff, 1983).

Guarding 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, blue-heelers, and border collies. Dogs should be neutered or spayed, and used in pairs to allow for social interaction.

Donkeys can also be used as guarding 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 males are too aggressive and using one donkey forces the guarding animal to bond with the livestock rather than a conspecific (Green, 1989b; Walton and Feild, 1989). Effectiveness of donkeys as guard animals is highly variable and usually not as successful as guard dogs (Green, 1989b; Walton and Feild, 1989). Benefits to using donkeys is that they can be purchased at stockyard auctions for about $100 to $300, are easier to care for than dogs, require no special feeds, and are long-lived (Green, 1989b; Walton and Feild, 1989).

Llamas are another guarding animal used to reduce livestock depredation. Meadows and 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, 93% (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. Guarding 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 and Feild (1989) recommend using donkeys on small open pastures with no more than 200 to 300 sheep. Cost-effectiveness must be considered for each livestock producer. Guarding animals are most effective when used in an integrated wildlife damage management program (Green, 1989a; Meadow and Knowlton, 2000).

Bioaccoustics

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). A deer-activated bioacoustic device that used distress calls was ineffective at reducing deer damage in cornfields at the silking-tasseling stage (Gilsdorf *et al.*, unpublished data). 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 and 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 to 18 seconds. 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 (Engeman and Witmer, 2000; Campbell III *et al.*, 1998; Coffey and Johnston, 1997). Rodent damage to agricultural production is an area of concern. Murua and Rodriguez (1989) compared toxicant (Brodifacoun and Bromadialone) use to an integrated management approach 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 and Rodriguez (1989) reported integrated protection methods were equally as effective as 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 at 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 (Engeman and Witmer, 2000; Coffey and Johnston, 1997). The development of an IPM program could aid in the effective management of wildlife species.

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Table 1. Decibel levels of some environmental sounds (Durrant and Lovrinic, 1984).

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

[a] re: 2×10^{-5} Pascal

Table 2. Frightening devices/methods most effectively used to control damage from selected species of wildlife[a].

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.

(*Table 2 cont.*)

Pest	Frightening techniques	Duration of Results	Comments
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.

(*Table 2 cont.*)

Pest	Frightening techniques	Duration of Results	Comments
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.

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

Figure 1. Propane cannon connected to 9-kg bottle of propane on the edge of a cornfield.

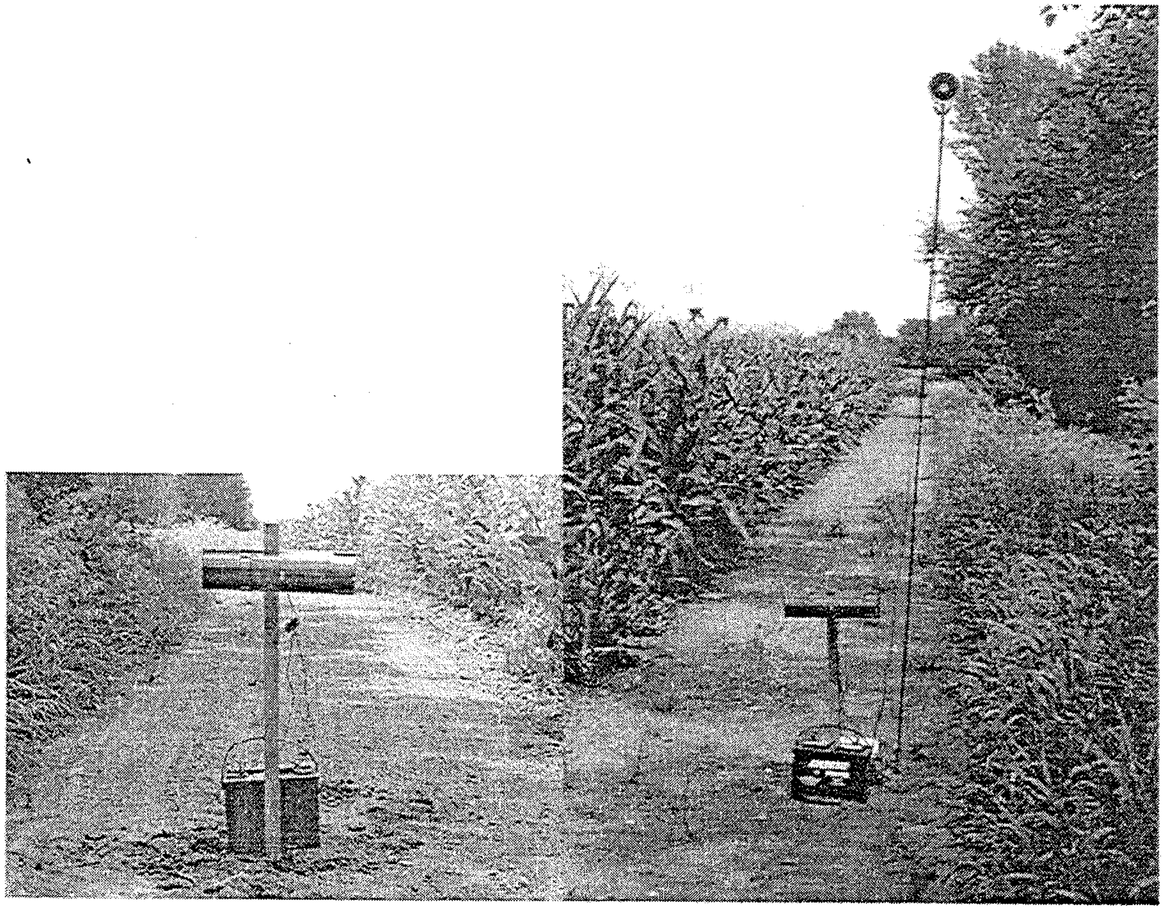

Figure 2. Deer-activated bioacoustic device integrates an infrared detection system (transmitter on left, receiver on right) and a compact disk that repeatedly plays distress calls of white-tailed deer when activated.

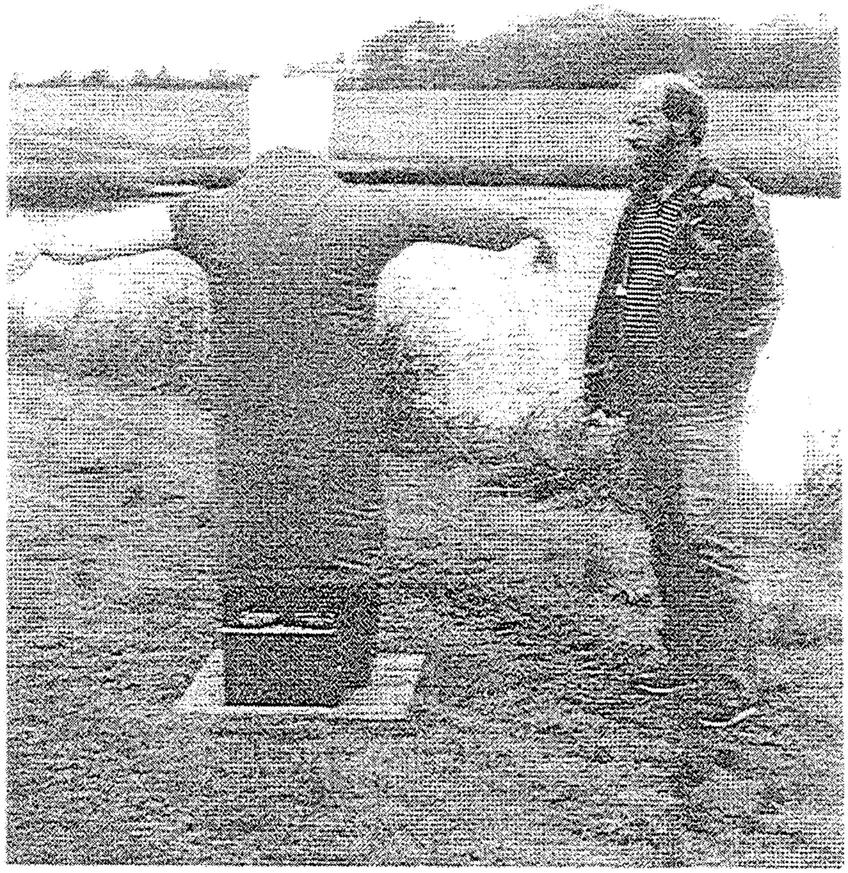

Figure 3. Scary Man pop-up inflatable effigy device (USDA/APHIS/WS photo).

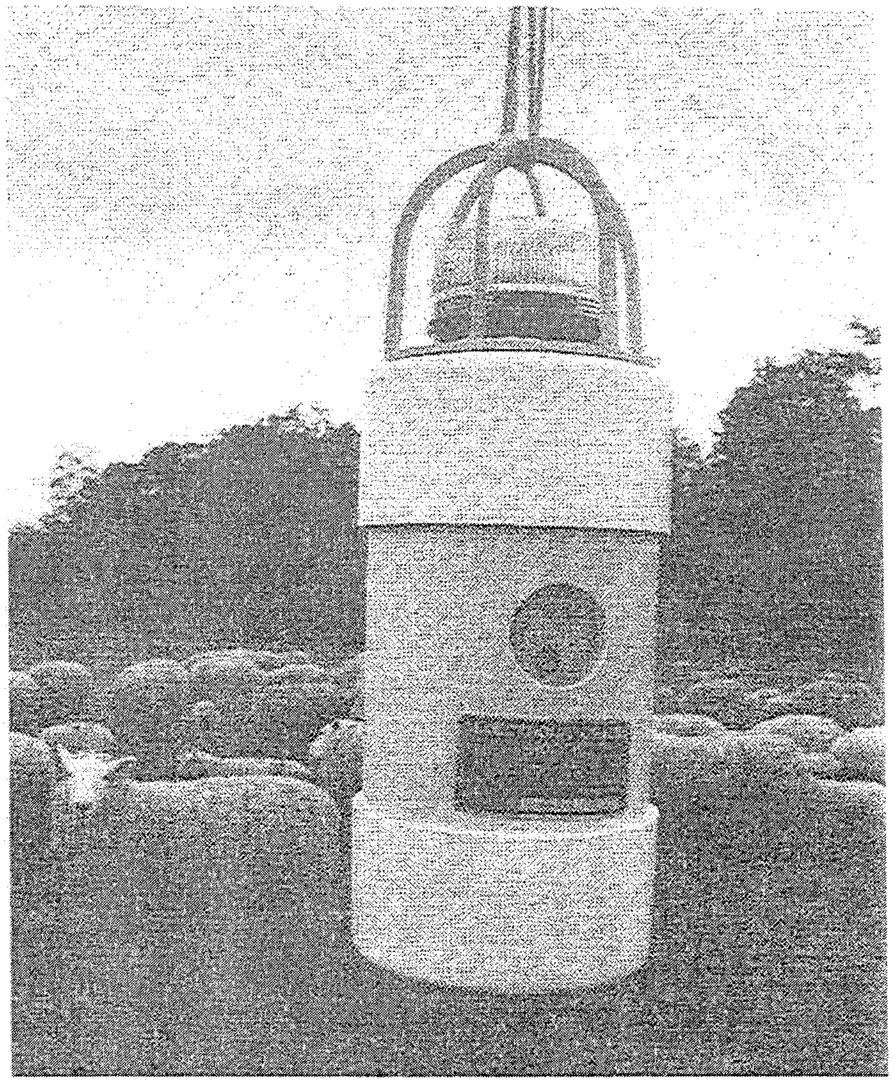

Figure 4. Electronic guard suspended in a sheep pasture (USDA/APHIS/WS photo).

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Chapter 2.

Efficacy of Propane Cannons and Electronic Guards to Reduce Deer Damage in Cornfields.

***Abstract*:** Propane cannons and electronic guards were not effective in reducing deer damage in cornfields when applied during the silking-tasseling stage of growth. Track count indices ($F_{6,8} = 0.84$, $P = 0.575$), corn yields ($F_{2,6} = 0.14$, $P = 0.873$), and estimated damage levels ($F_{2,12} = 0.96$, $P = 0.412$) did not differ between treatment and control fields. The size ($F_{4,13} = 0.86$, $P = 0.513$), location ($F_{4,9} = 0.97$, $P = 0.471$), and percent overlap ($F_{4,9} = 1.86$, $P = 0.203$) of use-areas of radio-collared female deer did not differ among before, during, and after treatment periods. In a related study, we placed propane cannons in cornfields being used by 12 radio-collared female deer. The deer did not react appreciably to the devices as the size ($F_{2,17} = 0.08$, $P = 0.921$), location ($F_{2,22} = 1.37$, $P = 0.275$), and percent overlap ($F_{2,10} = 0.47$, $P = 0.636$) of the use-areas did not differ among before, during, and after treatment periods. Propane cannons and electronic guards have limited potential for reducing deer damage to corn.

Introduction

Wildlife, especially white-tailed deer (*Odocoileus virginianus*), often cause problems for agricultural producers. In the United States, annual economic loss of agricultural crops from wildlife depredation can be as high as $316 million (Fagerstone and Clay 1997). Deer (*Odocoileus* spp.) are the species most responsible for crop damage in many areas of the United States (Conover and Decker 1991, Wywialowski and Beach 1992). In 1993, over $30 million of corn was lost to deer damage in the 10 largest corn-producing states alone (Wywialowski 1996). Deer feed on corn from emergence through harvest (VerCauteren and Hygnstrom 1998). Hygnstrom et al. (1992) reported that use of corn by deer peaks in late June to early July. The peak coincides with the silking-tasseling stage, at which developing ears first emerge from the corn plant with silk and pollen-producing tassels emerge from the top of the corn plant. Corn is highly susceptible to deer damage during the silking-tasseling stage because of high use by deer, more plants are necessary to satiate their appetite, and corn plants are more susceptible to physical damage (Hygnstrom et al. 1992). Hygnstrom et al. (1992) concluded that landowners may be able to reduce the amount of damage and the cost of control by implementing control methods, such as frightening devices, at the silking-tasseling stage.

Methods used to manage deer damage consist of lethal and nonlethal techniques. Lethal techniques in the form of sharpshooting or controlled hunting can be difficult to implement because of safety concerns, local ordinances, and public attitudes against the use of firearms and harvesting of animals (Jones and Witham 1995, Kuser 1995, Mayer et al. 1995, Kilpatrick et al. 1997). In many situations nonlethal techniques are the only options available. The public supports management of wildlife that are causing damage to personal property, especially when nonlethal techniques are employed (Green et al. 1997, Loker et al. 1999, Reiter et al. 1999).

Propane canons are the most commonly used frightening devices for deer depredation (Kohler et al. 1990, Craven and Hygnstrom 1994). Belant et al. (1996) reported that periodically firing (8-10 minutes) propane cannons are effective in frightening deer for 2 days while motion-activated cannons may provide protection to artificial feeding sites for one to two weeks. Electronic guards are frightening devices originally developed for reducing coyote (*Canis latrans*) predation on sheep (Linhart et al. 1992). Belant et al. (1998) stated that electronic guards protected feeding sites from deer for less than 1 week.

Koehler et al. (1990) suggested that frightening devices should be tested in field conditions rather than artificial feeding sites to generate more applicable results. The objective of this study was to determine the efficacy of propane cannons and electronic guards in reducing deer damage to cornfields during silking-tasseling. In addition, we evaluated the influence of propane cannons on the use-areas of female white-tailed deer.

We hypothesized that treatment fields protected with frightening devices would experience less deer-use and damage than control fields. We predicted that if the frightening devices were effective in repelling deer 1) track counts would increase from the "Before" period to the "During" period, then decrease over time through the "After" period with fewer tracks in treatment fields than in control fields, 2) corn yield would be higher in treatment fields than in control fields 3) treatment fields would sustain less damage than control fields, and 4) radio-collared deer in the vicinity of the frightening devices would shift their use-areas to avoid the disturbance.

Study area

The study was conducted during the summer of 1999 at the DeSoto National Wildlife Refuge (DNWR, Figure 5) and the Loess Hills State Forest (LHSF, Figure 6). The DNWR is located about 32 km north of Omaha, NE in the Missouri River valley. The 3,166-ha area consists of a patchwork of forest, grassland, wetland, and cropland habitats. Corn (238.5 ha), soybeans (257.6 ha), grain sorghum, alfalfa, and a wheat/clover mix are cultivated on a 3-year rotation. Approximately 10-16% of the corn is left standing as food plots for wildlife on DNWR. The average size of test fields on DNWR was 9 ha (4-15 ha). The deer density at DNWR was about 19 deer/km^2 during the study (VerCauteren 1998). The LHSF is located about 80 km north of Council Bluffs, IA. Four individual units include 3,774 ha of forest, prairie, and agricultural fields. Corn (215 ha), soybeans (161 ha), grain sorghum, and alfalfa are cultivated on a crop rotation plan. One-to 3-ha plots of unharvested corn (total of 65 ha) remained as food plots in the LHSF. The average size of the test fields on the LHSF was 2 ha (1-3 ha). The deer density in the LHSF was 5-7 deer/km^2 (personal communication, Iowa Department of Natural Resources).

Methods

Efficacy of propane cannons and electronic guards

The treatments tested included propane cannons, electronic guards, and a control with no frightening device. Each propane cannon (Thunderbird Scare away, made in Belgium, distributed by Reed-Joseph International, Greenville, MS) was connected to a 9.1-kg bottle of propane. A valve in the propane cannon controlled the rate at which the gas entered a holding chamber and a flint striker ignited the gas in an ignition chamber.

The propane cannons were set to discharge at about 15-minute intervals (range of 10 to 20 minutes) and were manually turned on and off at sunset and sunrise, respectively.

The electronic guard (Pocatello Supply Depot, Pocatello, ID) consisted of a timer, a blinking strobe light, and a warbling siren enclosed in a polyvinyl chloride case. A 12-volt lantern battery provided power to the unit. The white strobe light (70,000 cp, flash rate = 60/minute) and a 1.4 kHz modulating siren (15 to 20 modulations/minute) with a 116 dB output (at 1 m) provided the visual and acoustic stimuli (Linhart et al. 1992, Belant et al. 1998). The electronic guard has a photocell built into the side that automatically activates and deactivates the device at sunset and sunrise, respectively. When operational, the timer randomly activates the system to sound for about 7-10 seconds at about 6-7 minute intervals throughout the night.

Cornfields on DNWR and LHSF were used as test fields for this study. We located and grouped test fields with similar size, shape, and location. A group of similar fields was considered a block. Four groups of three test fields were located on DNWR. The test fields were a minimum of 1 km apart to maintain independence among fields (Belant et al. 1996). The average distance between pairs of treatment and control fields on DNWR was 1.4 km (range = 1.0-2.5 km). Four groups of three test fields were also used on the LHSF. The average distance between pairs of treatment and control fields in the LHSF was 0.8 km (0.5-1.4 km). The test fields in the LHSF were located in valleys where ridges and dense forests dissipated the sounds from the devices, maintaining independence among test fields. A total of 24 (8 groups of 3 fields) test fields were used for this study.

Treatments were randomly assigned to each of the 3 fields in each group. Two frightening devices of the same type were placed on opposite sides of each treatment field. The devices were placed on the edges of each field in a position to maximize the visual and auditory effectiveness of the device. If applicable, the devices were placed on the corners or along forest-field edges that experienced the highest levels of damage. The propane cannons were placed on the ground just inside the cornfield with the end of the cannon facing out of the field, flush with the edge of the corn (Figure 7). The electronic guards were positioned in the cornfields in the same manner as the propane cannons and were suspended about 2.4 m above the ground on metal rods (Figure 8).

The frightening devices were applied at the first sign of silking-tasseling in the cornfields (13 July 1999) and were active for 18 nights. We found that 18 nights was sufficient time for the ears of corn to develop past the silking-tasseling phase and become less susceptible to deer damage. The locations of the devices in each test field were repositioned on the field perimeter after the 9th night to minimize habituation to the devices (Koehler et al. 1990, Nolte 1999).

We used track count indices, corn yield data, damage assessments, and use-areas of radio-collared deer to determine the efficacy of the frightening devices. Use-areas are the area the radio-collared deer used during the study. Given the time permitted to collect telemetry locations for radio-collared deer, it was impossible to collect enough locations to consider the area a "home range" (Kernohan et al. 2001, Leban et al. 2001). All four assessment methods were used on DNWR test fields. Track counts, corn yield data, and radio-collared deer were not available to assess the frightening devices in the LHSF. We used only damage assessments on LHSF test fields because of limitations in personnel, time, and finances.

A randomized complete block design was used for this study, with blocks considered random. We used analysis of variance (ANOVA) in SAS (SAS Institute, Inc. 2000) to analyze all data and to determine significant differences among control and treatment fields. Assumptions of ANOVA include 1) independence among treatments, 2) normal distribution of data, and 3) equal variances (Dowdy and Wearden 1991).

The data collected before, during, and after treatment was from a repeated measures experiment and we used Akaike's information criteria (AIC) as a means of selecting which covariance structure provided the best-fit model for those analyses. Potential covariance structures included compound symmetry (CS), first-order autoregressive (AR(1)), toeplitz (TOEP), unstructured (UN), heterogeneous compound symmetry (CSH), and heterogeneous first-order autoregressive (ARH (1)). We selected the model that yielded the smallest AIC value because this model is estimated to be the closest to the unknown reality that produced the data from all models considered (Burnham and Anderson 1998). We used the Kenward-Roger adjustment for denominator degrees of freedom when repeated analysis was used for track count indices and home ranges.

Track counts were conducted around the perimeters of all test fields on DNWR every 6 days, weather permitting. We recorded track counts before treatment application, during the 18-night treatment period, and after treatment application. The 18-night before, during, and after subdivisions would allow for 3 track count assessments to be conducted per subdivision, however rainfall events prevented this for all periods. The

"Before" period included tracks counted from 27 June 1999 to 4 July 1999. Excessive moisture for 10 days allowed for only one "Before" track count. The "During 1" period was from 17 July 1999 to 20 July 1999 and "During 2" was from 22 July 1999 to 26 July 1999. Excessive moisture for 9 days allowed for two "During" track counts. The "After" period was from 30 July 1999 to 2 August 1999. Excessive moisture for 14 days allowed for only one "After" track count.

A 2-m drag mounted on the three-point hitch of a tractor (International Harvester 284, Chicago, Illinois, USA) was used to establish and maintain a smooth dragline. Deer tracks entering and leaving the cornfields were counted in the 1-m width of the dragline nearest the corn. A single observer counted tracks on all fields to eliminate observer bias. Stem-and-leaf plots revealed that the data were approximately normally distributed. The plot of the residuals showed equal variances. We used the unstructured covariance structure, and the Kenward-Roger adjustment for denominator degrees of freedom in our analysis.

Corn yield data were available for 10 of the 12 test fields on DNWR. Farmers reported yield data obtained from grain elevators when the corn was delivered, or directly from Global Positioning System (GPS) linked yield monitors on harvesting equipment. A stem-and-leaf plot revealed that the data were approximately normally distributed and a plot of the residuals showed equal variances.

We used a variable area transect sampling method (Engeman et al. 1994, Engeman and Sugihara 1998, Engeman and Sterner 2002) to assess the amount of deer damage in all treatment and control fields immediately following the 18th night of deployment of the frightening devices. The field dimensions were estimated and a grid was applied to the field. We used a numbered grid to randomly locate 10 test plots in fields ≤4.0 ha (*n* = 12), 20 test plots in fields 4.4-12.1 ha (*n* = 9), and 30 test plots in fields > 12.1 ha (*n* = 3). At each test plot, a 100-m tape was staked into the ground in a cornrow. The observer walked down the cornrow counting the total number of ears of corn, including undamaged and damaged ears. When five deer-damaged ears were tallied, the observer stopped and recorded the distance traveled and the total number of ears. If 5 deer-damaged ears were not tallied in 100 m, the observer recorded the total number of ears and any deer-damaged ears observed in that 100 m. While rewinding the tape, the observer counted the number of corn plants in the distance traveled back to the beginning of the tape. Four calculations were used to determine the amount of damage in the test fields: 1) average damage per plot, 2) average percent damage per plot, 3) total estimated damage per field, and 4) total estimated percent damage per field.

We used a multilocation trial to test for any differences in damage assessments between DNWR and LHSF test fields. Stem-and-leaf plots revealed that the data were approximately normally distributed. Residual plots showed equal variance of data for all assessment methods except for "average percent damage per plot." We used the Box-Cox analysis to determine the correct data transformation and the arcsine square-root data transformation ($\sin^{-1}(x^{1/2})$) to restore equal variance to the binomial data (Kuehl 2000).

We used the chronologically-sequenced use-areas of associated radio-collared female deer as supporting data to determine the effectiveness of the treatments on DNWR. Twelve radio-collared deer were monitored from June 1999 to September 1999. Locations were collected with equal distribution throughout day and nighttime hours. Telemetry locations were solved using the Spatial Ecology Analysis System (SEAS).

Use-areas were computed using the harmonic mean (Dixon and Chapman 1980) in a Geographical Information System (GIS; Map and Image Processing System (TNTmips®), MicroImages, Lincoln, Nebraska, USA). We determined the area using the 95% isopleth, center, and aerial distribution of each use-areas. Core areas of deer were plotted using the 20% isopleth. Deer were assigned as "propane cannon," "electronic guard," or "control" deer if their core area was ≤1 km from the respective treatment or control field.

Telemetry locations were subdivided into "before treatment," "during treatment," and "after treatment" categories. Use-areas were produced using location data from an 18-night period for each subdivision. The "Before" use-area consisted of an average of 18 locations for each deer (range =15-20) collected from 24 June 1999 to 11 July 1999. The "During" use-area consisted of an average of 20 locations for each deer (range =18-21) collected from 12 July 1999 to 30 July 1999. The "After" use-area was plotted using an average of 11 locations for each deer (range = 9-12) collected from 31 July 1999 to 17 August 1999.

We evaluated the effectiveness of the frightening devices by comparing: 1) size of the use-areas, 2) distance of the use-area center shift, and 3) percent of overlap of subsequent use-areas, from the periods before, during, and after the application of the frightening devices. Stem-and-leaf plots revealed that the data were approximately normally distributed and plots of the residuals showed equal variance. We used the heterogeneous first-order autoregressive covariance structure for the analysis of use-area size and the unstructured covariance structure for the remaining use-area analysis. We used the Kenward-Roger adjustment for denominator degrees of freedom for all use-area analyses.

Affect of propane cannons on radio-collared deer

We also conducted a supplemental study on DNWR using only propane cannons to determine the effect the devices would have on the use-areas of radio-collared deer. We placed propane cannons on the edges of cornfields that were being used by radio-collared deer using the same technique as previously stated. The propane cannons were active for a period of 18 nights from 19 September 1999 to 3 October 1999. In this supplemental study, all available radio-collared deer were exposed to propane cannons.

We calculated use-areas for 12 radio-collared deer exposed to the propane cannons. Use-areas were subdivided into "Before," "During," and "After" subdivisions, with each subdivision consisting of an 18-night monitoring period. The "Before" use-area consisted of an average of 23 locations for each deer (range = 21-24). The "During" use-area consisted of an average of 43 locations for each deer (range = 42-46). The "After" use-area was plotted using an average of 20 locations for each deer (range = 20-21).

We analyzed: 1) size of the use-area, 2) distance of the use-area center shift, and 3) percent of overlap of subsequent use-areas, from the periods before, during, and after application of the frightening device. Stem-and-leaf plots revealed that the data were approximately normally distributed and plots of the residuals showed equal variance. We used the heterogeneous compound symmetry covariance structure for use-area size, the compound symmetry covariance structure for the use-area center shift, and the unstructured covariance structure for the use-area overlap analysis. We used the Kenward-Roger adjustment for denominator degrees of freedom for all use-area analyses.

All procedures used on animals were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee (IACUC # 99-03-014). United States Department of Agriculture research protocol was QA-726.

Results

Efficacy of propane cannons and electronic guards

Track count indices

Track counts depicted no evidence that the devices deterred deer from using cornfields (Figure 9). We found no significant affect of treatment-by-time interactions ($F_{6,8} = 0.84$, $P = 0.575$) on track count indices and no difference between treatment effects ($F_{2,7} = 0.70$, $P = 0.532$). Time was a significant effect in the analysis ($F_{3,7} = 20.48$, $P \leq 0.001$). Average (least square mean) deer use (tracks/km/night) of cornfields while the electronic guards were active (lsmean = 42) was about twice as much as the "Before" period (lsmean = 24). The average deer use of fields protected by electronic guards remained about constant from "During" (lsmean = 41) to "After" (lsmean = 47). Average deer use of cornfields while propane cannons were active (lsmean = 34) was twice as much as the "Before" period (lsmean = 17, Table 3). The average deer use of propane cannon fields remained about constant from "During" (lsmean = 34) to "After" (lsmean = 37). Deer use of control fields was over twice as much in the "During" period (lsmean = 48) as the "Before" (lsmean = 21) period. The average deer use of control fields remained about constant from "During" (lsmean = 48) to "After" (lsmean = 53).

Corn yield

The average yields of corn (kg/ha) for fields with electronic guards (lsmean = 7,511, SE = 1,371, $n = 3$), propane cannons (lsmean = 6,930, SE = 1,218, $n = 4$), and control fields (lsmean = 7,915, SE = 1,390, $n = 3$) did not differ statistically ($F_{2,6} = 0.14$, $P = 0.873$, Table 4). The field size (ha) was also not a factor in corn yield ($F_{1,6} = 0.01$, $P = 0.911$).

Damage assessment

The multilocation trial showed that location had no significant effect on the average damage per plot ($F_{2,12} = 0.16$, $P = 0.857$), average percent damage per plot ($F_{2,12} = 0.59$, $P = 0.571$), total estimated damage per field ($F_{2,12} = 1.06$, $P = 0.378$), and total estimated percent damage per field ($F_{2,12} = 0.88$, $P = 0.442$) between DNWR and LHSF fields. Therefore, we pooled our data from the two locations.

We found no significant differences in levels of deer damage among fields containing frightening devices and control fields. The average level of damage per plot (damaged ears/m^2) did not differ ($F_{2,12} = 0.17$, $P = 0.843$) among electronic guard (lsmean = 1.8, SE = 0.450, $n = 8$), propane cannon (lsmean = 1.6, SE = 0.450, $n = 8$), and control (lsmean = 1.7, SE = 0.450, $n = 8$) fields (Table 5). The average percentage of damage per plot (damaged ears/(damaged ears + undamaged ears)) was not different ($F_{2,12} = 1.45$ $P = 0.272$) among electronic guard (lsmean = 19%, SE = 0.030, $n = 8$), propane cannon (lsmean = 16%, SE = 0.030, $n = 8$), and control (lsmean = 15%, SE = 0.030, $n = 8$) fields. The total estimated damage per field (total damaged ears/total area sampled) was not different ($F_{2,12} = 0.96$, $P = 0.412$) among electronic guard (lsmean = 0.2, SE = 0.263, $n = 8$) , propane cannon (lsmean = 0.6, SE = 0.263, $n = 8$), and control (lsmean = 0.2, SE = 0.263, $n = 8$) fields. Finally, the total estimated percent damage per field (total damaged ears/(total ears damaged + total undamaged ears)) also did not differ ($F_{2,12} = 1.03$, $P = 0.386$) between electronic guard (lsmean = 5%, SE = 0.025, $n = 8$), propane cannon (lsmean = 7%, SE = 0.025, $n = 8$), and control (lsmean = 3%, SE = 0.025, $n = 8$) fields.

Use-areas of deer

Use-area size. The size of use-areas of radio-collared deer exposed to the different treatments did not differ throughout the study (Table 6). The effects of treatment-by-time ($F_{4,13} = 0.86$, $P = 0.513$), time ($F_{2,12} = 0.69$, $P = 0.521$), and treatment ($F_{2,11} = 0.08$, $P = 0.924$) did not significantly influence the size of use-areas. Deer exposed to electronic guards ($n = 2$) had an lsmean "Before" use-area of 11 ha (range = 10-12 ha), "During" use-area of 42 ha (range = 29-54 ha), and "After" use-area of 31 ha (range = 24-38 ha). Deer exposed to propane cannons ($n = 5$) had an lsmean "Before" use-area of 24 ha (range = 10-45 ha), "During" use-area of 21 ha (range = 10-47 ha), and "After" use-area of 63 ha (range = 12-238 ha). Deer that were not exposed to frightening devices ($n = 5$) had an lsmean "Before" use-area of 33 ha (range = 3-98 ha), "During" use-area of 37 ha (range = 28-42 ha), and "After" use-area of 30 ha (range = 11-53 ha).

Use-area center shift. The location of the use-areas of radio-collared deer did not differ throughout the study (Table 6). The effects of treatment-by-time ($F_{4,9} = 0.97$, $P = 0.471$), time ($F_{2,8} = 1.10$, $P = 0.379$), and treatment ($F_{2,9} = 0.30$, $P = 0.750$) were not significant. Deer exposed to electronic guards had an lsmean "Before to During" center shift of 195 m (range = 115-275 m), "During to After" center shift of 174 m (range = 91-256 m), and "Before to After" center shift of 164 m (range = 110-218 m). Deer exposed to propane cannons had an lsmean "Before to During" center shift of 71 m (range = 18-138 m), "During to After" center shift of 198 m (range = 42-499 m), and "Before to After" center shift of 225 m (range = 97-479 m). Deer exposed to control fields had an lsmean "Before to During" center shift of 135 m (range = 87-238 m), "During to After" center shift of 100 m (range = 42-248 m), and "Before to After" center shift of 177 m (range = 147-249 m).

Use-area overlap. The overlap of chronologically sequenced use-areas of radio-collared deer exposed to the different treatments did not differ throughout the study (Table 6). The effects of treatment-by-time ($F_{4,9} = 1.86$, $P = 0.203$), time ($F_{2,8} = 3.00$, $P = 0.107$), and treatment ($F_{2,9} = 0.46$, $P = 0.644$) were not significant. Deer exposed to electronic guards had an lsmean "Before to During" overlap of 27% (range = 20-34%), "During to After" overlap of 76% (range = 68-83%), and "Before to After" overlap of 32 % (range = 26-38 %). Deer exposed to propane cannons had an lsmean "Before to During" overlap of 78% (range = 43-100%), "During to After" overlap of 47% (range = 9-85%), and "Before to After" overlap of 47% (range = 4-100%). Deer exposed to control fields had an lsmean "Before to During" overlap of 51% (range = 7-100%), "During to After" overlap of 82% (range = 53-100%), and "Before to After" overlap of 55% (range = 18-88%).

Affect of propane cannons on radio-collared deer

Use-area size. The size of the use-area did not differ ($F_{2,17} = 0.08$, $P = 0.921$) in the additional study testing the effects of propane cannons on the use-areas of 12 radio-collared female deer (Table 7). The lsmean "Before" use-area size was 42 ha (range = 8-

155 ha), "During" use-area was 38 ha (range = 17-62 ha), and "After" use-area size was 38 ha (range = 6-73 ha).

Use-area center shift. The shift in the use-area center of 12 radio-collared deer exposed to propane cannons did not differ ($F_{2,22} = 1.37$, $P = 0.275$) among periods (Table 7). The lsmean "Before to During" center shift was 95 m (range = 40-281 m), "During to After" center shift was 108 m (range = 45-231 m), and "Before to After" center shift was 130 m (range = 36-324 m).

Use-area overlap. The overlap of use-areas for the radio-collared deer did not differ ($F_{2,10} = 0.47$, $P = 0.636$) among periods. The lsmean "Before to During" overlap was 72% (range = 47-100%), "During to After" overlap was 76% (range = 36-100%), and "Before to After" overlap was 70% (range = 18-100%).

Discussion

The data we collected did not support the hypothesis that treatment fields protected with frightening devices would experience less deer-use and damage than control fields. The 4 response variables we measured showed no significant differences among protected fields and control fields.

Track count indices

Predictions for the track count indices were correct except for the "After" period. Track counts increased from "Before" to "During 1" periods, decreased while the devices were active from "During 1" to "During 2," and increased from "During 2" to "After" periods (Figure 9). The increase in deer use from "Before" to "During 1" was most likely due to the development of new ears of corn. The appearance of this favored food source attracted deer to the cornfields. Track indices in cornfields with frightening devices increased at a lower rate than control fields. The lower rate of increase may suggest the frightening devices were initially effective at reducing deer intrusions, however not to a significant degree.

The decrease in deer intrusions throughout the "During" period may have been due to the growth of the ears of corn beyond the preferred size and stage of development. At the end of the 18-night treatment period, most of the ears of corn exceeded 20 cm in length. The ears may have been too large at this time, making them less palatable.

A factor responsible for the increased deer use of cornfields from "Before" to "After" may be the overall growth of the corn plants. The dense cornfields may offer shelter from predators and environmental conditions. Deer may not be feeding on the corn as heavily, however they may remain in the cornfields throughout the day rather than returning to forest habitat.

We conducted track counts on 6-day intervals, weather permitting. With the occurrence of a rain event, tracks were washed out following a significant rainfall (≥1.27 cm) making it impossible to conduct an accurate count. Rainfall of such an amount also made operating the tractor and drag impossible due to wet soil conditions. Track counts were converted to tracks/night during analysis to better represent deer-use in the test fields.

Corn yield

The prediction that the corn yield would be higher in protected fields than control fields was rejected. On average, control fields produced 7,946 kg/ha, which was 1,051 kg/ha and 419 kg/ha more than fields containing propane cannons and electronic guards, respectively. Fields containing electronic guards produced, on average, 632 kg/ha more that fields with propane cannons. If propane cannons and electronic guards were effective in reducing deer damage, one would expect the fields containing the devices to have had higher corn yields than control fields. Deer using cornfields before the devices were activated, may have allowed for damage to occur before protection, reducing corn yield. We observed deer damage to corn plants before the silking-tasseling stage. The damage was such that the plant could not reach maturity and thus produce ears or corn. Other factors such as soil type, hybrid, etc. may have also affected corn yield. The lack of significance in yield was probably due to the relatively small number of observations (10 fields) of corn yield data.

Damage assessment

The prediction that the protected fields would sustain less damage than control fields was rejected. In general, fields containing propane cannons sustained more damage than fields containing electronic guards and control fields. Fields containing electronic guards contained more damage than control fields. If the frightening devices were effective, fields containing propane cannons and electronic guards would have been exposed to less damage because the deer were frightened from the fields.

Fields containing electronic guards, on average had 0.1 damaged ears/m^2 per plot more than control fields, control fields had 0.1 damaged ears/m^2 per plot more than fields containing propane cannons, and fields containing electronic guards had 0.2 damaged ears/m^2 per plot more than fields containing propane cannons. The average percent damage per plot was 4% higher in fields with electronic guards than in control fields, 1% higher in fields with propane cannons than in control fields, and 3% higher in fields with electronic guards than in fields with propane cannons. Average estimated damage per field was similar between control fields and electronic guard fields, 0.4 damaged ears/m^2 higher in propane cannon fields than in control fields, and 0.4 damaged ears/m^2 higher in propane cannon fields than in electronic guard fields. On average, fields containing electronic guards sustained an estimated 2% more damage than control fields, fields containing propane cannons sustained an estimated 4% more damage than control fields, and fields containing propane cannons sustained an estimated 2% more damage than electronic guard fields.

Explanations for inconsistent damage between fields are difficult to explain, however several possibilities are evident. It may be difficult to break a feeding pattern once established. Frightening devices should be employed at the first sign of damage before feeding or use patterns have been established (Koehler et al. 1990, Craven and Hygnstrom 1994, Nolte 1999). Another possibility for the insignificance in damage assessments is that the frightening devices only protected two sides of the test fields. Deer may not have been frightened from the acoustic stimuli if they could not see the flashing strobe of the electronic guard, or without seeing the propane cannon in the environment. Finally, habituation to the devices may have allowed deer to quickly disregard the stimuli and continue feeding unaffected.

An interesting observation we made while conducting damage assessments to one particular field was the height of the ears on the corn plant. In this particular field, ears were about 1.4 m above the ground as opposed to other fields in which ears were about 1 m above the ground. The field sustained <1% total estimated damage for the entire field, making it one of the least damaged fields sampled. Cultivating a hybrid of corn that contains this characteristic may help reduce deer damage to the ears of corn because the ears are not as easily accessible to the deer.

Use-areas of deer

The prediction that the radio-collared deer in the vicinity of the frightening devices would shift their use-areas to avoid the disturbance was rejected. The area, location, and overlap of use-areas showed that deer continued to use cornfields whether protected by frightening devices or unprotected.

Efficacy of propane cannons and electronic guards

Regarding the "Before to During" period, of the 5 deer exposed to propane cannons, 4 of the deer shifted their use-areas closer to the treatment field. The 2 deer exposed to electronic guards also moved closer to the treatment fields. The "During to After" use-area shift revealed deer once again moved closer to the cornfields. The frightening device did not appear to alter radio-collared deer's use-areas enough to deter them from using cornfields.

Affect of propane cannons on radio-collared deer

The radio-collared deer for the supplemental study were also not deterred from using cornfields protected by propane cannons. Six of the 12 deer shifted their home ranges closer to the field with the propane cannon. Four of the 12 moved away from the propane cannons. Two of the 12 deer neither moved away or towards the fields with the propane cannon, but shifted their home range only slightly and parallel to the field with the propane cannon.

The use-areas of all deer were solved using all locations recorded in the 18-night tracking periods. The number of locations needed per animal to produce an accurate home range estimate is a debatable topic. An optimal sample size for the number of locations is often about 50 locations per animal but may vary from as few as 20 to 200 locations, depending on the home range estimator used (Kernohan et al. 2001, Leban et al. 2001). Sample sizes of such intensity were impossible for our research due to time, personnel constraints, and the potential for autocorrelation in the data. Therefore we referred to the area used by a radio-collared deer as the "use-area" rather than a "home range."

We conducted this study to the best of our abilities given the time, personnel, and financial constraints placed upon us. The lack of significance among all variables was most likely due to the small sample sizes available for this study. Power analysis showed that we needed over 100 test fields for each treatment to obtain a 90% power of detecting differences among treatments. A sample size of such intensity would have been impossible given our abilities. Propane cannons and electronic guards were not effective in reducing deer use of cornfields during the silking-tasseling stage. The devices may be applicable in other situations however with varying results.

Cost effectiveness

Propane cannons. The propane cannons used for this study were manually operated and had to be turned on and off by personnel. Propane cannons can be purchased for $200 to $500 from several commercial sources (Craven and Hygnstrom 1994, Hygnstrom and Hafer 1994). Systematic propane cannons for this study were set to fire about every 15 minutes. About 1 hour was required to calibrate each propane cannon to fire at the proper interval. To maintain the 12 propane cannons on DNWR throughout the study, it required about 2-4 hours per day to visit all the devices in the test fields. One 9.1 kg propane fuel canister for each cannon provided sufficient fuel to operate the devices for the 18-night test period. Each propane cannon consumed approximately 4.5 kg of fuel during the 18-night period. The fuel canisters were rented for $12.50 apiece, which included delivery and fuel. Expenses required to operate the propane cannons for this study would suggest they would be cost-effective for protecting high-value crops only. Motion-activated propane cannons (Belant et al. 1996) are available and may be more cost effective.

Electronic guard. The electronic guard is a self-operating frightening device that requires little operative maintenance. Once the device is turned on, the photoelectric sensor activates and deactivates the device. The electronic guard is available for $250 (not including battery) from Pocatello Supply Depot (Pocatello, ID). One 12-volt lantern battery in each device provided sufficient power to the unit throughout the 18-night test period. Additional costs involved with each electronic guard device included the battery ($12.99), a 3.7-m piece of 1.3-cm re bar ($2.35), approximately 0.5 hours to install the device in the field, and about 0.5 hours to move the device after the 9th night of activation. A relatively maintenance free frightening device will increase the cost-effectiveness of a wildlife damage control technique.

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Table 3. Indices of deer track counts from perimeters of cornfields protected by propane cannons, electronic guards, and unprotected (control) fields on DeSoto National Wildlife Refuge, Missouri Valley, IA, USA, 1999.

	# of	Electronic guard		Propane cannon		Control	
Time	fields	lsmean[a]	SE	lsmean[a]	SE	lsmean[a]	SE
Before[b]	4	24	0.004	17	0.004	21	0.004
During 1[c]	4	46	0.009	36	0.009	56	0.009
During 2[d]	4	38	0.009	31	0.009	40	0.009
After[e]	4	47	0.009	37	0.009	53	0.009

[a] Tracks/km/night

[b] 27 June 1999 to 4 July 1999

[c] 17 July 1999 to 20 July 1999

[d] 22 July 1999 to 26 July 1999

[e] 30 July 1999 to 2 August 1999

Table 4. Comparison of corn yields for fields protected by propane cannons, electronic guards, and unprotected (control) fields on DeSoto National Wildlife Refuge, Missouri Valley, IA, USA, 1999.

		Corn yield (kg/ha)			Field size (ha)	
Treatment	n	lsmean	Range	SE	$\bar{x}$	Range
Electronic Guard	3	7,511	5,912 – 9,183	1,371	9.3	4.5 – 15.2
Propane Cannon	4	6,930	3,019 – 9,120	1,218	7.9	4.1 – 14.0
Control	3	7,915	6,290 – 9,309	1,390	9.5	5.8 – 13.8

Table 5. Estimates of deer damage in cornfields protected by propane cannons, electronic guards, and unprotected (control) fields on DeSoto National Wildlife Refuge, Missouri Valley, IA, USA and Loess Hills State Forest, Pisgah, IA, USA, 1999.

		Damage[a]	% Damage[b]	Total Damage[c]	Total % Damage[d]
Treatment	n	lsmean	lsmean	lsmean	lsmean
Electronic Guard	8	1.8	19	0.2	5
Propane Cannon	8	1.6	16	0.6	7
Control	8	1.7	15	0.2	3

[a] damaged ears/m^2 per plot

[b] damaged ears/(damaged ears + undamaged ears) per plot (using nontransformed data)

[c] total damaged ears/total area sampled (damaged ears/m^2) per field

[d] total damaged ears/(total ears damaged + total undamaged ears) per field

Table 6. Use-areas of radio-collared female deer exposed to propane cannons and electronic guards on DeSoto National Wildlife Refuge, Missouri Valley, IA, USA, 1999.

		lsmean Size (ha)			lsmean Center shift (m)[a]			lsmean % Overlap[b]		
Treatment[c]	n	Before[d]	During[e]	After[f]	B-D	D-A	B-A	B-D	D-A	B-A
E. Guard	2	11	42	31	195	174	164	27	76	32
P. Cannon	5	24	21	63	71	198	225	78	47	47
Control	5	33	37	30	135	100	177	51	82	55

[a] B-D = "Before to During" shift, D-A = "During to After" shift, B-A = "Before to After" shift

[b] B-D = "Before to During" overlap, D-A = "During to After" overlap, B-A = "Before to After" overlap

[c] Deer exposed to corresponding frightening device or control

[d] Before = 24 June 1999 to 11 July 1999

[e] During = 12 July 1999 to 30 July 1999

[f] After = 31 July 1999 to 17 August 1999

Table 7. Use-areas of radio-collared female deer with propane cannons placed in their home ranges on DeSoto National Wildlife Refuge, Missouri Valley, IA, USA, 1999.

		lsmean Size (ha)			lsmean Center shift (m)[a]			lsmean % Overlap[b]		
Treatment[c]	n	Before[d]	During[e]	After[f]	B-D	D-A	B-A	B-D	D-A	B-A
P. Cannon	12	42	38	38	95	108	130	72	76	70

[a] B-D = "Before to During" shift, D-A = "During to After" shift, B-A = "Before to After" shift

[b] B-D = "Before to During" overlap, D-A = "During to After" overlap, B-A = "Before to After" overlap

[c] Deer exposed to corresponding frightening device or control

[d] Before = 5 September 1999 to 18 September 1999

[e] During = 19 September 1999 to 3 October 1999

[f] After = 4 October 1999 to 17 October 1999

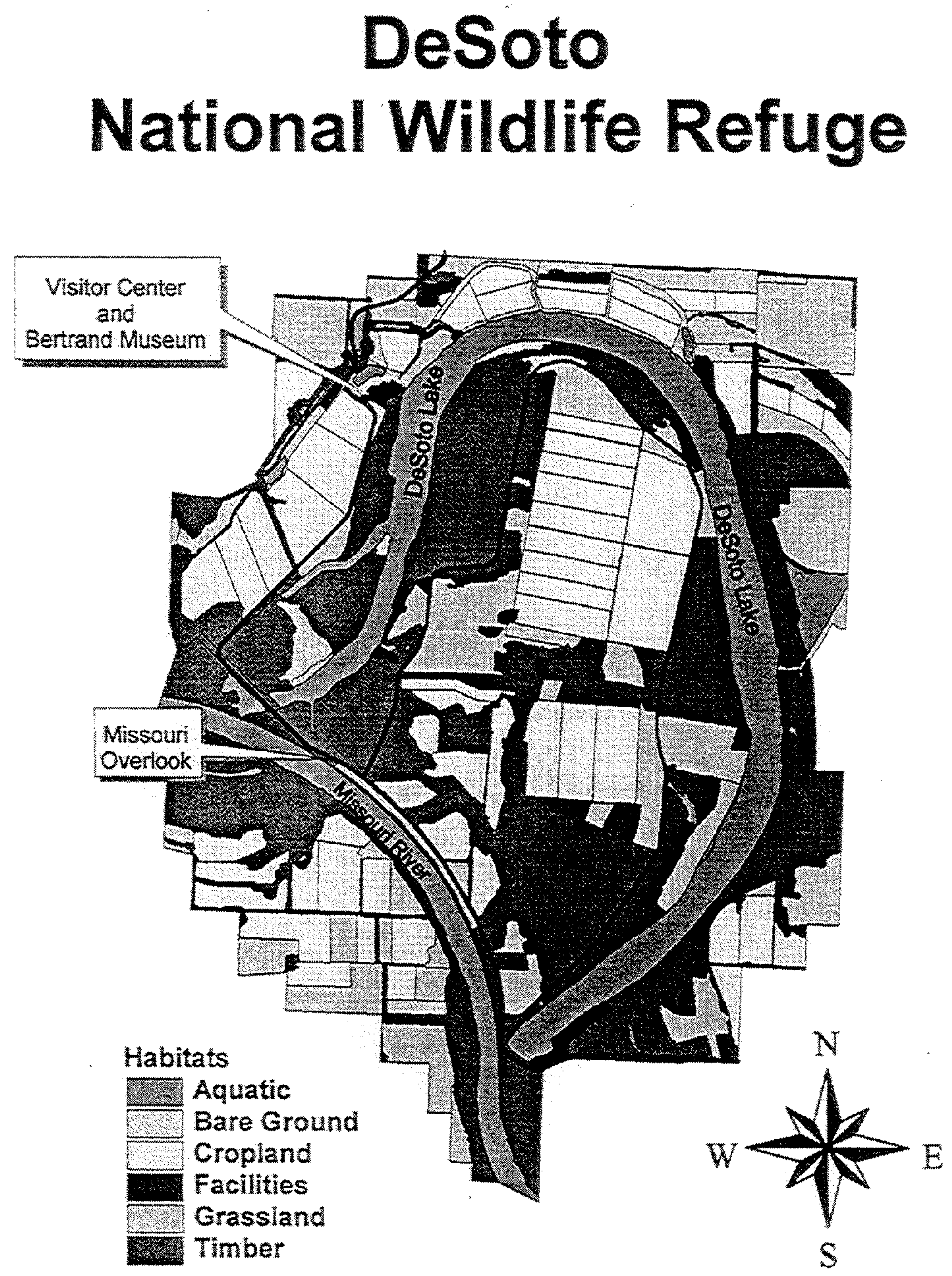


Figure 5. Map of DeSoto National Wildlife Refuge showing field layout.

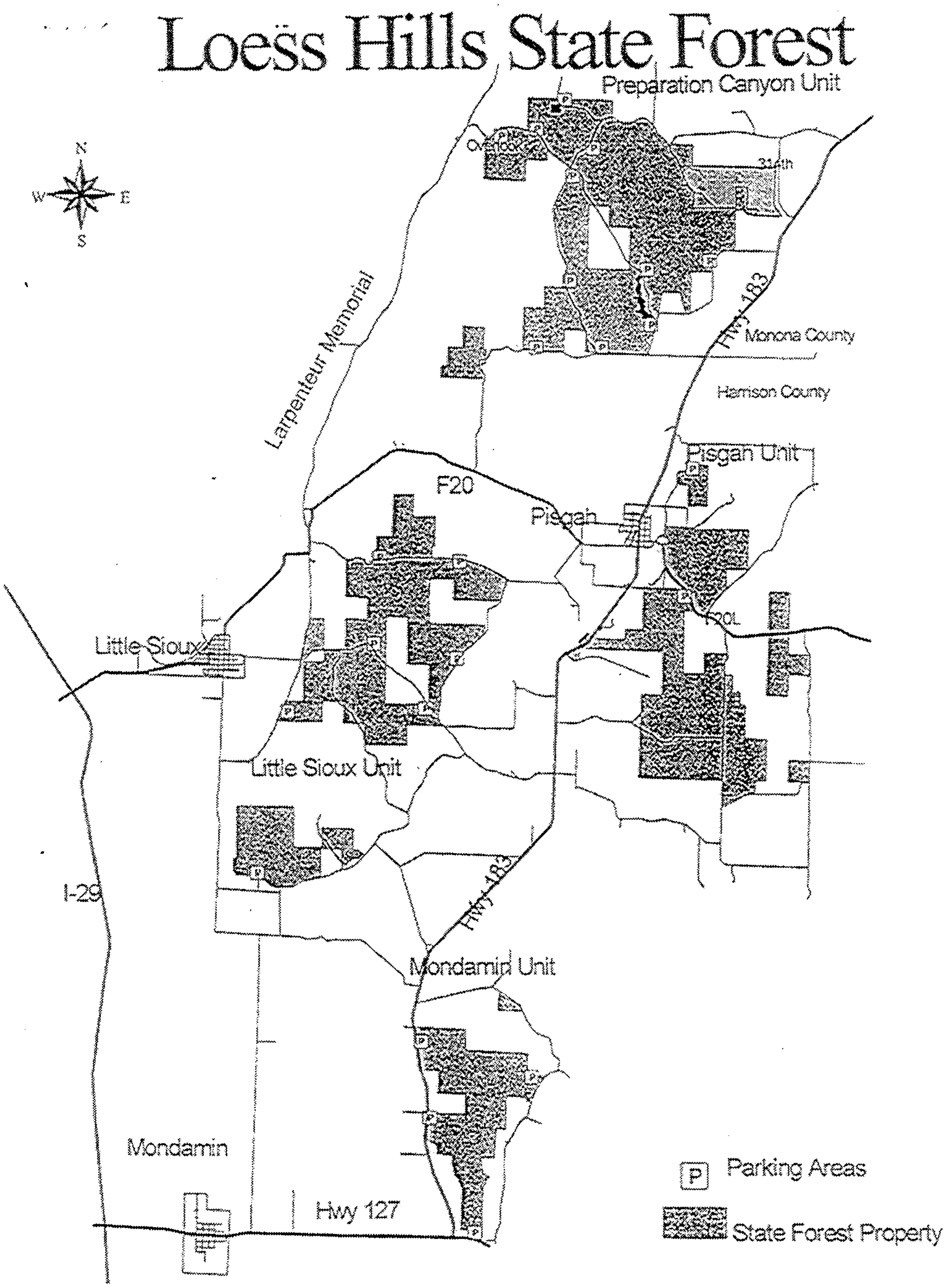


Figure 6. Map of the Loess Hills State Forest showing the four units that comprise the study area.

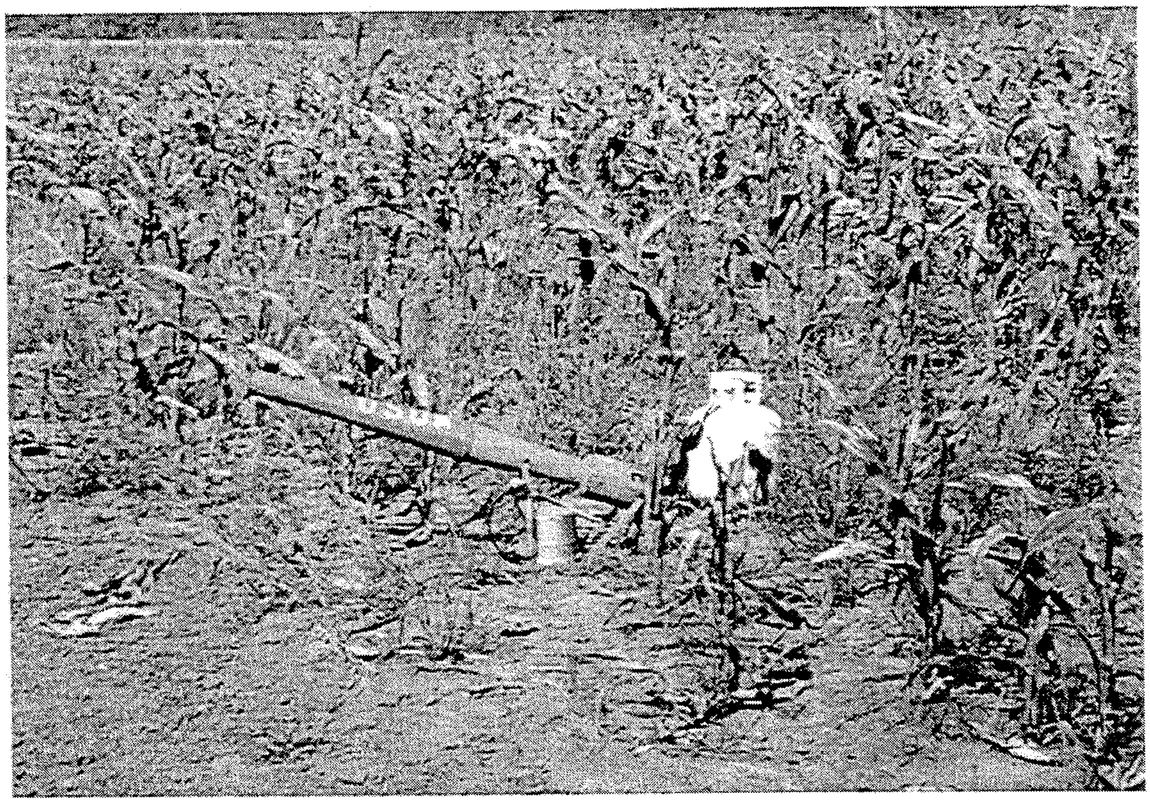
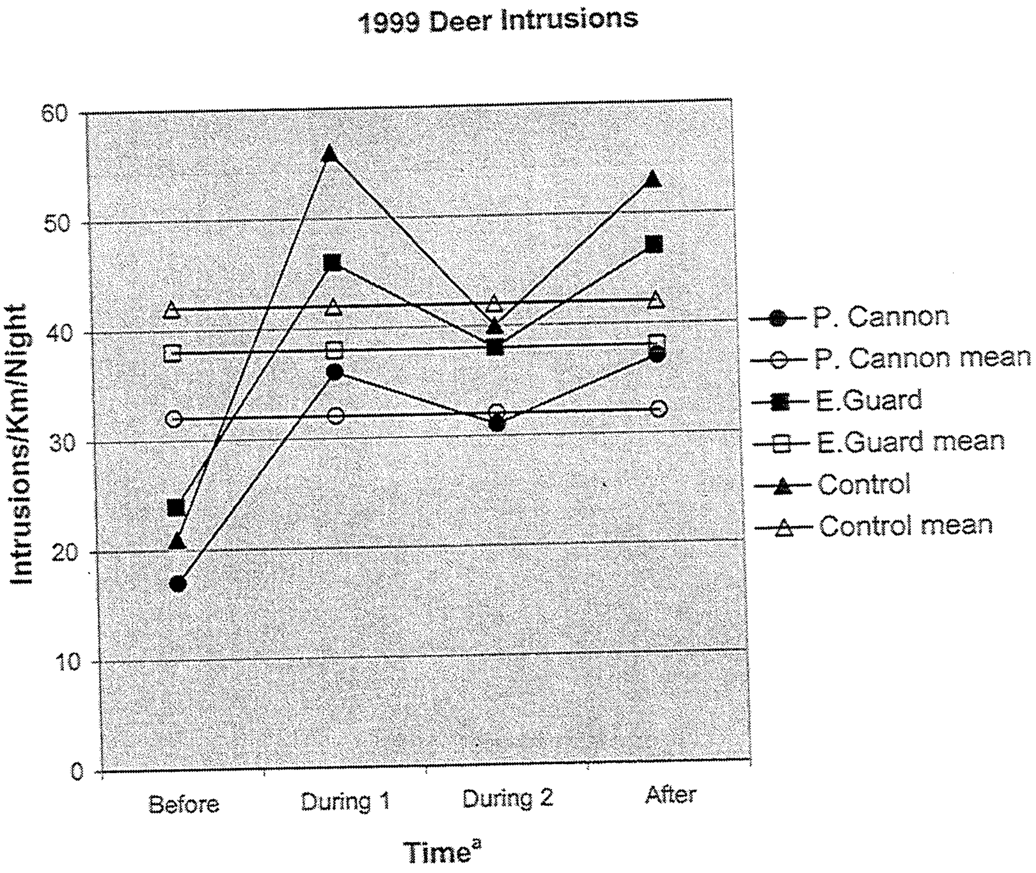


Figure 7. Propane cannon on the edge of a cornfield.

Figure 8. Electronic guard suspended from a metal rod on the edge of a cornfield.



[a] Before = 27 June 1999 to 4 July 1999

During 1 = 17 July 1999 to 20 July 1999

During 2 = 22 July 1999 to 26 July 1999

After = 30 July 1999 to 2 August 1999

Figure 9. Indices of deer track counts from perimeters of cornfields protected by propane cannons, electronic guards, and unprotected (control) fields on DeSoto National Wildlife Refuge, 1999.

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Chapter 3.

Evaluation of a Deer-Activated Bioacoustic Frightening Device to Reduce Deer Damage in Cornfields.

***Abstract*:** We developed a deer-activated bioacoustic frightening device for reducing deer damage in crop fields. The device consisted of an infrared detection system, which activated an audio component that broadcast deer distress calls. We tested the device against unprotected controls in cornfields during the silking-tasseling stage of growth. The device was not effective in reducing damage as track count indices ($F_{5,19} = 1.52$, $P = 0.232$), corn yield ($F_{1,9} = 1.27$, $P = 0.289$), and estimated damage per field ($F_{1,10} = 1.66$, $P = 0.227$) did not differ between treatment and control fields. The size ($F_{2,25} = 1.49$, $P = 0.245$), location ($F_{2,25} = 0.39$, $P = 0.684$), and percent overlap ($F_{2,25} = 0.20$, $P = 0.818$) of use-areas of radio-collared female deer did not differ among before, during, and after treatment periods.

Introduction

Damage to agricultural crops by deer (*Odocoileus* spp.) can be a problem in areas with high deer densities. Deer are responsible for causing more damage to agricultural products than any other species of wildlife (Conover and Decker 1991, Wywialowski and Beach 1992). In the United States, annual economic loss to agricultural crops from wildlife depredation can be as high as $316 million (Fagerstone and Clay 1997). In 1993, over $30 million of corn was lost to deer damage in the 10 largest corn-producing states alone (Wywialowski 1996).

Hygnstrom et al. (1992) reported that use of corn by deer peaks in late June/early July during the silking-tasseling stage at which developing ears first emerge from the corn plants with silk. Cornfields are highly susceptible to deer damage at the silking-tasseling stage because deer use of cornfields is high, more plants are necessary to satiate a deer's appetite, and the corn plants are more vulnerable to physical damage at this time. Hygnstrom et al. (1992) concluded that landowners may be able to reduce the amount of damage and the cost of control by implementing control methods, such as frightening devices, at the silking-tasseling stage.

Methods for controlling deer damage consist of lethal and/or nonlethal tactics that are limited by proximity to urban areas. Controlled hunting and sharpshooting can be effective, but may be difficult to justify in some settings such as urban areas, due to local ordinances and human health and safety concerns (Jones and Witham 1995, Kuser 1995, Mayer et al. 1995, Kilpatrick et al. 1997). The public supports management, especially nonlethal techniques, to control wildlife that are causing damage to personal property (Green et al. 1997, Loker et al. 1999, Reiter et al. 1999). Nonlethal devices that do not pose a threat to humans or nontarget animals may be applicable to rural and urban environments.

Duration of protection, habituation, and efficacy often limits the cost effectiveness of frightening devices. Propane cannons, electronic guards, and other visual and/or acoustic devices have been used to control deer damage with variable success (Belant et al. 1996, Curtis et al. 1997, Belant et al. 1998, Chapter 2). A major limitation of using nonlethal frightening devices is that animals habituate to the stimuli (Bombford and O'Brien 1990, Koehler et al. 1990, Cravēn and Hygnstrom 1994, Nolte 1999). Habituation is the process by which animals adjust to and ignore new sights, sounds, and smells over time (Bombford and O'Brien 1990). Methods to delay habituation include altering the location of the frightening devices, or altering the periodicity of stimuli (Koehler et al. 1990, Nolte 1999). Belant et al. (1996) reported that periodically (8-10 minutes) fired cannons were effective in frightening deer for only 2 days, while deer-activated propane cannons were effective for one to two weeks. The motion-activated cannons seemed to delay habituation, which would make them more effective in reducing damage.

The stimuli used in a frightening device may be visual and/or acoustic. Some animals fear new unfamiliar objects in their environment (neophobia) and may avoid the area for a short time (Koehler et al. 1990). Propane cannons produce a loud explosion when they fire, frightening nearby animals. An Electronic Guard (Linhart et al. 1992) contains a siren and a flashing strobe light. Loud noises associated with some frightening devices may be disturbing to humans and nontarget wildlife (Frings 1964).

A relatively unstudied area in frightening devices is the use of 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, such as the snort of a deer that senses a predator (Sauer 1984). A distress call is emitted when an animal is being physically traumatized or restrained (Sprock et al. 1967, Marchinton and Hirth 1984). Most studies using bioacoustics have been conducted on birds (Frings 1964, Thompson et al. 1968a, b; Mott and Timbrook 1988, Aguilera et al. 1991). Knowledge of the potential use of mammalian communication signals is limited (Frings 1964, Koehler et al. 1990). An advantage of bioacoustics over other acoustic frightening devices is that the 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, which could be disturbing to neighbors or nontarget animals.

The objective of this research was to design and test a deer-activated bioacoustic frightening device to reduce deer damage in cornfields. An extensive literature review prompted us to design a device that incorporated new technology with stimuli that has never been tested. To our knowledge, combining an animal-activation system to a frightening device that emits mammalian bioacoustics has never been studied. The study was conducted in an actual field situation to more accurately test the effectiveness of such a device for potential use in controlling deer damage. Koehler et al. (1990) suggested that testing devices in field conditions rather than in constructed artificial feeding sites may provide more applicable results. Development of an effective frightening device may protect personal property from wildlife damage, ultimately saving millions of dollars in damage.

We hypothesized that treatment fields protected with deer-activated bioacoustic frightening devices would experience less use and damage by deer than control fields. We predicted that the frightening devices would repel deer and that: 1) track counts would increase from the "Before" period to the "During" period, then decrease over time in the "After" period with fewer tracks in treatment fields than in control fields, 2) corn yield would be higher in treatment fields than in control fields 3) treatment fields would sustain less damage than control fields, and 4) radio-collared deer in the vicinity of the frightening device would shift their use-areas to avoid the devices.

Study area

The study was conducted during the summer of 2001 at the DeSoto National Wildlife Refuge (DNWR, Figure 10), which is located about 32 km north of Omaha, NE in the Missouri River valley. The DNWR consists of 3,166 ha comprised of a patchwork of forest, grassland, wetland, and cropland. The density of the deer herd at DNWR was about 19 deer/km^2 during the study (VerCauteren 1998). Corn (155.7 ha), soybeans (291.7 ha), grain sorghum, alfalfa, and a wheat/clover mix are cultivated on a 3-year rotation. Approximately 10-16% of the corn is left standing as food plots for wildlife.

Methods

The deer-activated bioacoustic device consisted of an infrared detection system and an audio system. We used an outdoor quad-beam infrared security system (model PB-IN200HF, PULNiX Security Sensors Inc., Sunnyvale, CA) to detect the presence of deer entering or leaving a cornfield. Each system consisted of an infrared transmitting and receiving unit (Figure 11). Four infrared beams were emitted from four transmitting mirrors on the transmitter. The transmitters and receivers were positioned horizontally on wood posts 50-200 m apart. The transmitter was aimed so that the receiver collected all four beams of infrared light. All four beams of infrared light had to be broken simultaneously to activate the audio system.

The audio system included a CD player (Aiwa CDC-X217), 30-second time delay, relay, counter, and weatherproof 12.7-cm horn speaker. Each speaker was suspended on the edge of a cornfield 2.4 m above the ground with a metal rod. A deer entering the cornfield would break the four infrared beams, which would activate the audio system, and a disk containing deer distress calls. The time delay device provided power to the CD player for 30 seconds. After 30 seconds, the system reset itself. When activated again, the CD played from where it stopped the previous time. The counter confirmed that the device was functioning, and enumerated the activations. The CD player and other electrical components were contained in a sealed plastic container.

Distress calls were recorded from live-captured deer with a Sony Digital Handycam (model DCR-TRV320). The deer were captured to be equipped with radio collars for other aspects of our research. The digital audio component was extracted using Video Wave III SE, MGI Software Corp. software and copied on compact disks.

Two 12-volt deep-cycle batteries powered each frightening device (one powered the transmitting unit and one the receiving unit) for the 18-night test period. We monitored the battery charge with a voltmeter about once every 6 days to ensure sufficient power was being supplied to the device.

Two frightening devices were placed on opposite sides of each treatment field to protect that portion of the field perimeter. If applicable, the devices were placed along forest-field edges that experienced the highest levels of damage. The infrared systems were situated to protect as much field perimeter as possible (50-200 m). The infrared beams were situated 71 cm above the ground, the height of the average adult deer midway between the top of the back and bottom of the chest (Sauer 1984). The height of the infrared beams eliminated false triggering by other wildlife such as raccoons (*Procyon lotor*), opossums (*Didelphis virginiana*), wild turkeys (*Meleagris gallopavo*), and coyotes (*Canis latrans*).

Cornfields on DNWR were used as test fields for this study. We located and grouped test fields with similar size, shape, and location. A group of similar fields was considered a block. Twelve test fields (6 pairs fields) were used for the study. The average size of the test fields was 10.8 ha (range = 5.5-19.7ha). The test fields were a minimum of 0.5 km apart to maintain independence among fields. The average distance between pairs of protected (treatment) and unprotected (control) fields was 0.9 km (range = 0.05-2.9 km). Treatments were assigned randomly to each of the fields in each group. Treatments consisted of a deer-activated bioacoustic frightening device and a control with no device.

The frightening devices were applied at the first sign of silking-tasseling to all cornfields (6 July 2001) and were active for 18 nights. We found that 18 nights is sufficient time for the ears of corn to mature past the silking-tasseling phase after which, deer-use declined (Hygnstrom et al. 1992). The ears may have been too large at this time (most ears of corn exceeded 20 cm), making them less palatable. The devices in each test field were repositioned along the field perimeter once after the 9th night to minimize habituation to the devices (Koehler et al. 1990, Nolte 1999).

We used track count indices, corn yield data, damage assessments and use-areas of radio-collared deer to determine the efficacy of the frightening devices. Use-areas were the area radio-collared deer used during the study. Given the time permitted to collect telemetry locations for radio-collared deer, it was impossible to collect enough locations to consider the area a "home range" (Kernohan et al. 2001, Leban et al. 2001).

A randomized complete block design was used for this study, with blocks considered random. We used analysis of variance (ANOVA) in SAS (SAS Institute Inc. 2000) to analyze all data to determine significant differences between control and treatment fields. Assumptions of ANOVA include 1) independence between treatments, 2) normal distribution of data, and 3) equal variances (Dowdy and Wearden 1991).

The data collected before, during, and after treatment is from a repeated measures experiment and we used Akaike's information criteria (AIC) to determine which covariance structure provided the best-fit model for those analyses. Potential covariance structures included compound symmetry (CS), first-order autoregressive (AR(1)), toeplitz (TOEP), unstructured (UN), heterogeneous compound symmetry (CSH), and heterogeneous first-order autoregressive (ARH (1)). We selected the model that yielded the smallest AIC value because this model is estimated to be the closest to the unknown reality that produced the data from all models considered (Burnham and Anderson 1998). We used the Kenward-Roger adjustment for denominator degrees of freedom when repeated measures analysis was appropriate.

We recorded track counts before treatment application, during the 18-night treatment period, and after treatment application. Track counts were conducted around the perimeters of all test fields on DNWR every 6 days, weather permitting. The 18-

night before, during, and after subdivisions would allow for 3 track count assessments to be conducted per subdivision, however time constraints and rainfall events prevented this for all periods. The "Before" period included tracks counted from 2 July 2001 to 6 July 2001. We were unable to collect track count data for a period of 13 days for the "Before" period due to time limitations, which allowed for only 1 "Before" track count. The "During 1" period was from 7 July 2001 to 10 July 2001,and the "During 2" was from 18 July 2001 to 23 July 2001. Excessive moisture for 8 days permitted only two "During" track counts. The "After 1" period was from 24 July 2001 to 29 July 2001, "After 2" was from 30 July 2001 to 2 August 2001, and "After 3" was from 3 August 2001 to 10 August 2001.

A 2-m drag mounted on the three-point hitch of a tractor (International Harvester 284, Chicago, Illinois, USA) was used to establish and maintain a smooth dragline. Deer tracks entering and leaving the cornfields were counted in the 1 m of the dragline nearest the corn. A single observer was used to count tracks on all fields to minimize observer bias. Stem-and-leaf plots showed that the data were approximately normally distributed. A plot of the residuals revealed unequal variance of the track count data. We used the Box-Cox method to determine that the reciprocal square root transformation ($x^{-1/2}$) was appropriate to restore equal variance (Kuehl 2000). We used the Toeplitz covariance structure, and the Kenward-Roger adjustment for denominator degrees of freedom in our analysis.

Corn yield data were available for the 12 test fields. Farmers reported yield data obtained from grain elevators when the corn was delivered or directly from Global Positioning System (GPS) linked yield monitors on harvesting equipment. A stem-and-leaf plot showed that the data were approximately normally distributed and a plot of the residuals showed equal variances for the treatment groups.

We used the Variable Area Transect sampling method (Engeman et al. 1994, Engeman and Sugihara 1998, Engeman and Sterner 2002) to assess the amount of deer damage in all treatment and control fields immediately following the 18th night of employment of the frightening devices. The field dimensions were estimated and a grid was applied to the field. We randomly located 20 test plots in fields <12.1 ha and 30 test plots in fields >12.1 ha with a numbered grid. At each test plot, a 100-m tape was staked into the ground in a cornrow. The observer walked down the cornrow counting the total number of ears of corn (deer-damaged and not damaged). When five deer-damaged ears were tallied, the observer stopped and recorded the distance traveled and the total number of ears. If 5 deer-damaged ears were not tallied in 100 m, the observer recorded the total number of ears and any deer-damaged ears observed in that 100-m. While rewinding the tape, the observer counted the number of corn plants in the distance traveled back to the beginning of the tape. Four calculations were used to determine the amount of damage in the test fields: 1) average damage per plot, 2) average percent damage per plot, 3) total estimated damage per field, and 4) total estimated percent damage per field. Stem-and-leaf plots showed that the data were approximately normally distributed and plot of the residuals showed equal variances for the treatment groups.

We used the chronologically-sequenced use-areas of associated radio-collared female deer as supporting data to determine the effectiveness of the devices. Twenty-nine radio-collared deer were monitored on DNWR from June 2001 to September 2001. We accumulated telemetry locations with equal distribution throughout day and nighttime hours to give a representation of all animal movements. Telemetry locations were solved using the Spatial Ecology Analysis System (SEAS). Use-areas were computed using the harmonic mean (Dixon and Chapman 1980) in a Geographical Information System (GIS; Map and Image Processing System (TNTmips®), MicroImages, Lincoln, Nebraska, USA). We determined the area using the 95% isopleth, center, and aerial distribution of each use-areas. Core areas of deer were plotted using the 20% isopleth. If the core area was ≤0.5 km from a treatment or control field, the deer was assigned the respective treatment.

Telemetry locations were subdivided into during treatment, ("During") and after treatment ("After") categories. We determined the area, center, and aerial distribution of each use-area for the subdivided periods. Use-areas were produced using location data from an 18-night period for each subdivision. We could not calculate a use-are for the "before treatment" period because of the small number of locations (2-5) recorded per animal. The "During" use-area consisted of an average of 27 locations for each deer (range =23-29) collected from 6 July 2001 to 23 July 2001. The "After" use-area was plotted using an average of 20 locations for each deer (range = 19-22) collected from 24 July 2001 to 11 August 2001.

We evaluated the effectiveness of the frightening device by comparing the: 1) size of the use-areas, 2) distance of the use-area center shift, and 3) percent of overlap of subsequent use-areas, from the periods during and after the application of the frightening device. Stem-and-leaf plots showed that the data were approximately normally distributed and plots of the residuals showed equal variance. We used the unstructured covariance structure, and Kenward-Roger adjustment for denominator degrees of freedom for use-area analysis.

The procedures used on animals were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee (IACUC # 99-03-014). United States Department of Agriculture research protocol was QA-726.

Results

Track count indices

Analysis of track count data showed no significant effect of treatment-by-time interactions ($F_{5,19} = 1.52$, $P = 0.232$) and no difference between treatment effects ($F_{1,4} = 0.02$, $P = 0.892$). Time was a significant effect in the analysis ($F_{5,19} = 77.06$, $P \leq 0.001$). Use of treatment fields by deer (tracks/km/night) decreased 29% from "Before" (lsmean = 69) to the average "During" (lsmean = 53) and continued to decrease 30% from the average "During" (lsmean = 53) to the average "After" (lsmean = 38) periods (Table 8). Use of control fields by deer decreased 11% from "Before" (lsmean = 56) to the average "During" (lsmean = 50) and continued to decrease 27% from the average "During" (lsmean = 50) to the average "After" (lsmean = 36) periods.

Corn yield

The least square mean (lsmean) of corn yield (kg/ha) for control (lsmean = 5,614, SE = 481, $n = 6$) and treatment (lsmean = 6,381, SE = 481, $n = 6$) fields did not differ statistically ($F_{1,9} = 1.27$, $P = 0.289$, Table 9). The size of test fields (ha) did not influence ($F_{1,9} = 3.89$, $P = 0.080$) the amount of corn produced per hectare.

Damage assessments

We found no significant differences in deer damage levels between fields with frightening devices and control fields. The lsmean level of damage per plot (damaged ears/m^2) did not differ ($F_{1,10} = 0.85$, $P = 0.378$) between treatment (lsmean = 1.4, SE = 0.405, $n = 6$) and control fields (lsmean = 0.9, SE = 0.405, $n = 6$, Table 10). The average percentage of damage per plot (damaged ears/(damaged ears + undamaged ears)) was not different ($F_{1,10} = 0.87$ $P = 0.374$) among treatment (lsmean = 20%, SE = 0.047, $n = 6$) and control fields (lsmean = 14%, SE = 0.047, $n = 6$). The total estimated damage per field (total damaged ears/total area sampled) was not different ($F_{1,10} = 1.66$, $P = 0.227$) among treatment (lsmean = 0.4, SE = 0.110, $n = 6$) and control (lsmean = 0.2, SE = 0.110, $n = 6$) fields. Finally, the total estimated percent damage per field (total damaged ears/(total ears damaged + total undamaged ears)) also did not differ ($F_{1,10} = 1.30$, $P = 0.280$) between treatment (lsmean = 5%, SE = 0.016, $n = 6$) and control (lsmean = 3%, SE = 0.016, $n = 6$) fields.

Use-areas of deer

Thirteen radio-collared deer were exposed to the deer-activated bioacoustic device and 10 used control fields. Six were not exposed to any frightening device or control, so we considered them as exposed to "neither" treatment.

Use-area size. The lsmean use-area size of radio-collared deer exposed to the different treatments did not differ throughout the study. Treatment-by-time ($F_{2,25} = 1.49$, $P = 0.245$), time ($F_{1,25} = 2.08$, $P = 0.161$), and treatment ($F_{2,26} = 1.00$, $P = 0.380$) effects did not influence use-area size. Deer exposed to the frightening device had an lsmean "During" use-area of 37 ha (range = 4-75 ha), and "After" use-area of 62 ha (range = 8-

280 ha, Table 11). Deer that used control fields had an lsmean "During" use-area of 69 ha (range = 8-382 ha), and "After" use-area of 54 ha (range = 8-102 ha). Deer exposed to neither treatment or control fields had an lsmean "During" use-area of 43 ha (range = 4-89 ha), and "After" use-area of 178 ha (range = 7-861 ha).

Use-area center shift. The shift in centers of use-areas of radio-collared deer "During to After" relative to the different treatments did not differ ($F_{2,25} = 0.39$, $P = 0.684$) throughout the study (Table 11). Deer exposed to the frightening device had an lsmean "During to After" center shift of 332 m (range = 66-2,414m). Deer that used control fields had an lsmean "During to After" center shift of 195 m (range = 54-640m). Deer exposed to neither treatment or control fields had an lsmean "During to After" center shift of 163 m (range = 29-383m).

Use-area overlap. The overlaps of chronologically-sequenced use-areas for radio-collared deer exposed to the different treatments were not significantly different ($F_{2,25} = 0.20$, $P = 0.818$, Table 11). Deer exposed to the frightening device had an lsmean "During to After" overlap of 65% (range = 0-100%). Deer that used control fields had an lsmean "During to After" overlap of 65% (range = 30-100%). Deer exposed to neither treatment or control fields had an lsmean "During to After" overlap of 56% (range = 6-99%).

Discussion

The data we collected did not support the hypothesis that treatment fields protected with frightening devices would experience less deer-use and damage than control fields. The 4 response variables we measured showed no significant differences among protected fields and control fields.

Track count indices

We predicted that track counts would increase from the "Before" period to the "During" period, then decrease over time in the "After" period with fewer tracks in treatment fields than in control fields, however this was not the case. In general, the track counts decreased throughout the study period. Track counts decreased from "Before" to "During 1" periods for both treatment and control. Counts decreased through "After 1" for control fields while counts for treatment fields increased from "During 1" to "During 2," then decreased in "After 1." Counts increased from "After 1" to After 2" then decreased to "After 3" periods for both treatment and control fields (Figure 12).

As the corn plants grow and develop ears, one would expect the deer to increase their use of cornfield, which would be depicted by an increase in track counts from "Before" to "During." Deer-use would then decrease or remain constant after the ears of corn have fully developed past the point when they become less attractive to deer. The cover provided by mature corn plants also offers shelter, in which deer would continue to use cornfields for reasons other than for feeding.

The trends in deer intrusions on test fields are not what would be expected. The average track count indices for treatment fields decreased at a higher rate than control fields from "Before" to "During 1." Deer use of treatment fields was higher than control fields for the "Before" period. The reason for this difference is unclear. Weather trends had some influence on the ability to conduct the track counts. Two rainfall events of over 2.5 cm that occurred in the "During" periods may have washed out deer tracks.

We conducted track counts on 6-day intervals, weather permitting. Weather events may have had an affect on the variability in the track count indices. With the occurrence of a rain event (≥1.3 cm), tracks were washed out, making it impossible to conduct an accurate count or to operate the tractor and drag. Track counts were converted to tracks/night during analysis to better represent deer-use in the test fields.

Corn yield

We predicted that corn yield would be higher in treatment fields than in control fields. Our prediction was correct. On average, cornfields that were protected by the frightening devices produced 767 kg/ha more than control fields, supporting the hypothesis that the deer-activated bioacoustic frightening device may have been deterring deer from entering cornfields. The lack of significance in corn yield data is probably due to the relatively small number of observations (12 test fields) available for the study.

Loss of yield results in lower incomes for agricultural producers. If one considers that the average price for corn is about $0.08/kg, then significant economic loss can occur to fields that sustain high levels of damage by deer. We recorded that on average, fields containing the deer-activated bioacoustic frightening device produced about 767 kg/ha more than control fields, which translates to an economic loss of about $60/ha for unprotected cornfields. Agricultural producers may not tolerate such a loss of income, making frightening devices an acceptable damage management tool. The economic savings would be even greater on high value crops.

Damage assessment

We predicted that treatment fields would sustain less damage than control fields, however our data did not support this prediction. Surprisingly, the treatment fields sustained slightly more damage by deer than control fields. On average, fields containing the frightening device had 0.5 damaged ears/m^2 per plot more than control fields. The average percent damage per plot was 6% higher in treatment fields than control. Average estimated damage per field was 0.2 damaged ears/m^2 higher in fields with the device than in control fields. On average, fields containing the frightening device sustained an estimated 2% more damage than control fields. The amount of damage experienced increases the yield loss and ultimately a loss of income, as previously noted.

Explanations for slightly higher damage to fields containing the deer-activated bioacoustic frightening device are evident. In one case, a field that was assigned a frightening device had sustained intense deer damage before the silking-tasseling stage, hence before the frightening device was applied. A goal of wildlife damage management is to reduce wildlife depredation to a tolerable level. When implementing a damage management plan, frightening devices should be before feeding or use patterns become established (Koehler et al. 1990, Nolte 1999, DeNicola et al. 2000). It may be difficult to break a feeding pattern once established.

Another possibility for the insignificance in damage assessments is that the frightening devices only protected a portion of two sides of the test fields. The device did not protect the entire perimeter. Deer that did not walk between the infrared transmitter and receiver could enter the cornfield without activating the frightening devices. A device of such a design may provide more protection if the entire perimeter could be protected. The device may be applicable to small areas of concern such as gardens or high value plantings.

Use-areas of deer

We predicted that radio-collared deer in the vicinity of the deer-activated bioacoustic frightening device would shift their use-areas to avoid the devices, however this was not the case. The distance that radio-collared deer shifted their use-area was not significant for all treatments. Regarding the 13 deer exposed to the deer-activated bioacoustic device, 7 of the deer shifted their use-areas closer to the treatment field, 5 moved away from the field, and 1 did not move towards or away from the field. One deer that moved 2,414 m from the treatment field increased the mean distance (332 m) that treatment deer shifted their home range. In regards to the 10 deer exposed to control fields, 7 deer moved toward the control field, 2 moved away, and 1 moved neither away or towards the control. Six deer were not exposed to neither the device nor control, of which 4 moved towards cornfields and 2 moved away from cornfields. The frightening device did not appear to alter the use-areas of radio-collared deer enough to deter them from using cornfields.

The use-areas of deer were solved using all locations recorded in the 18-night tracking periods. The number of locations needed to produce an accurate home range estimate is debatable. An optimal sample size for the number of locations is often about 50 locations per animal but may vary from as few as 20 to 200 locations depending on the home range estimator used (Kernohan et al. 2001, Leban et al. 2001). Large sample sizes were impossible in our research due to time, personnel constraints, and the potential for autocorrelation in the data. Therefore we referred to the area used by a radio-collared deer as the "use-area" rather than a "home range." We used use-areas of radio-collared deer as supporting data for our assessment of the effectiveness of the frightening device.

We conducted this study to the best of our abilities given the time, personnel, and financial constraints placed upon us. The lack of significance among all variables was most likely due to the small sample sizes available for this study. Power analysis showed that we would have needed over 50 test fields for each treatment to obtain a 90% power of detecting differences among treatments. A sample size of such intensity would have been impossible given our abilities.

Use of bioacoustics and animal-activated devices

Most evaluations of bioacoustic devices have been conducted on birds (Thompson et al. 1968a, b, Mott and Timbrook 1988, Aguilera et al. 1991, Gorenzel and Salmon, 1993). Animals often react physiologically to alarm and distress calls. Thompson et al. (1968b) reported that some starlings (*Sturnus vulgaris*) exposed to the distress calls had heart rates over 700 beats/min, which is 130% above the normal heart rate. Gorenzel and Salmon (1993) reported that crows (*Corvus brachyrhynchos*) responded to tape-recorded crow distress and alarm calls by taking flight and circling overhead while giving assembly and scolding calls. The crows stopped vocalizing and flew away after the tape was played, leaving the roost empty. Mott and Timbrook (1988) tested alarm and distress calls on Canada geese (*Branta canadensis*). Goose numbers were reduced an average of 71% with alarm and distress calls. 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). Sprock et al. (1967) reported that one rat (*Rattus norvegicus*) exposed to rat distress calls spent fewer hours in a sound chamber in which the calls were emitted. Knowledge of the potential use of mammalian communication signals is limited, however similar reactions may be evident in other mammals (Frings 1964, Sprock et al. 1967, Koehler et al. 1990).

Advancements in technology have allowed for improvements in activation systems for frightening devices. Infrared and lasers beams can be used to activate frightening devices. Animal-activated frightening devices are thought to reduce habituation to the stimuli, thus rendering the devices more effective over time. Motion-activated propane cannons were effective for up to 6 weeks while periodically-firing cannons were effective for only 2 days (Belant et al. 1996). Research using animal-activated devices is limited.

Deer-activated bioacoustic frightening device

The deer-activated bioacoustic devices needed little maintenance during the test period. Each device required about 1 hour to construct. Approximately 0.5 hour was needed to erect each device in the field. We altered the position of the frightening devices following the 9th night of activation, which required about 1 hour per test field.

We encountered no environmental or mechanical limitations to the devices. The devices were functional 24 hours a day during the 18-night test period. A larger battery was used to power the receiver and audio systems because of the extra voltage needed to operate the additional components. Battery life may vary depending on the initial charge of the battery, the number of activations to the system, and environmental conditions such as temperature. The manufacturers of the infrared devices warn that intense reflection from the sun or fog may impede infrared transmission. Even during nights of dense fog, the devices remained operational up to 200 m.

On one occasion, a badger (*Taxidia taxus*) disturbed a transmitter post, causing it to fall. The receiver could no longer detect the infrared beams and thus activated the audio system, causing it to play continuously. We discovered the problem the same night it occurred and resolved it by moving the frightening device farther down the field edge.

Each deer-activated bioacoustic device cost about $600 in materials to build. The devices we built were prototypes that, to our knowledge, have never been built or tested before. The advanced technological equipment used in this device contributed to the high costs for development.

We suggest additional testing of the deer-activated bioacoustic device under other conditions, for example high-value crops such as fruits and vegetables, and smaller areas that allow for the protection of the entire perimeter of the area. On several occasions we observed deer triggering the device, which resulted in the deer fleeing from the area. The deer would turn towards the deer distress calls, listen for several seconds, then flee from the cornfield or enter the field for protection, suggesting that the sounds were frightening the deer. The device could be modified to include a visual stimulus and a variety of acoustic stimuli, which may also increase the effectiveness. Implementing an integrated management system that incorporates frightening devices may also be most effective in controlling damage (Chapter 1). An animal activated device that incorporates as much stimuli as possible, and one that is relatively maintenance free may prove to be most effective in reducing habituation and overall protection of property (Koehler et al. 1990, Belant et al. 1996).

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Table 8. Indices of deer track counts from perimeters of cornfields protected by a deer-activated bioacoustic frightening device, and unprotected (control) fields on DeSoto National Wildlife Refuge, Missouri Valley, IA, USA, 2001.

		Transformed data				Nontransformed data[a]			
	# of	Control		Treatment		Control		Treatment	
Time	fields	lsmean	SE	lsmean	SE	lsmean	SE	lsmean	SE
Before[b]	6	4.5	0.367	4.1	0.367	56	0.007	69	0.007
During 1[c]	6	4.5	0.337	4.7	0.367	52	0.007	48	0.007
During 2[d]	6	4.6	0.367	4.4	0.367	48	0.007	57	0.007
After 1[e]	6	5.0	0.367	4.9	0.367	41	0.007	44	0.007
After 2[f]	6	4.7	0.367	4.7	0.367	47	0.007	46	0.007
After 3[g]	6	7.0	0.367	7.0	0.367	20	0.007	23	0.007

[a] Tracks/km/night

[b] 2 July 2001 to 6 July 2001

[c] 7 July 2001 to 10 July 2001

[d] 18 July 2001 to 23 July 2001

[e] 24 July 2001 to 29 July 2001

[f] 30 July 2001 to 2 August 2001

[g] 3 August 2001 to 10 August 2001

Table 9. Comparison of corn yields for fields protected by a deer-activated bioacoustic frightening device, and unprotected (control) fields on DeSoto National Wildlife Refuge, Missouri Valley, IA, USA, 2001.

	Corn yield (kg/ha)			Field size (ha)		
Treatment	lsmean	Range	SE	lsmean	Range	n
Bioacoustic Device	6,381	3,900 – 7,938	481	10.9	5.5 – 19.7	6
Control	5,614	4,994 – 6,724	481	10.7	5.9 – 15.9	6

Table 10. Estimates of deer damage in cornfields protected by a deer-activated bioacoustic frightening device and unprotected (control) fields on DeSoto National Wildlife Refuge, Missouri Valley, IA, USA, 2001.

		Damage[a]	% Damage[b]	Total Damage[c]	Total % Damage[d]
Treatment	n	lsmean	lsmean	lsmean	lsmean
Bioacoustic Device	6	1.4	20	0.4	5
Control	6	0.9	14	0.2	3

[a] damaged ears/m^2 per plot

[b] damaged ears/(damaged ears + undamaged ears) per plot

[c] total damaged ears/total area sampled (damaged ears/m^2) per field

[d] total damaged ears/(total ears damaged + total undamaged ears) per field

Table 11. Use-area summary statistics for female radio-collared deer exposed to a deer-activated bioacoustic frightening device on DeSoto National Wildlife Refuge, Missouri Valley, IA, USA, 2001.

		lsmean Size (ha)				lsmean Center shift (m)[a]		lsmean % Overlap[b]	
Trt[c]	n	During[d]	SE	After[e]	SE	D-A	SE	D-A	SE
Device	13	37	19	62	44	332	126	65	8
Control	10	69	22	54	53	195	152	65	10
Neither	6	43	28	178	65	163	186	56	12

[a] D-A = "During to After" shift

[b] D-A = "During to After" overlap

[c] Deer exposed to corresponding frightening device, control, or neither

[d] During = 6 July 2001 to 23 July 2001

[e] After = 24 July 2001 to 11 August 2001

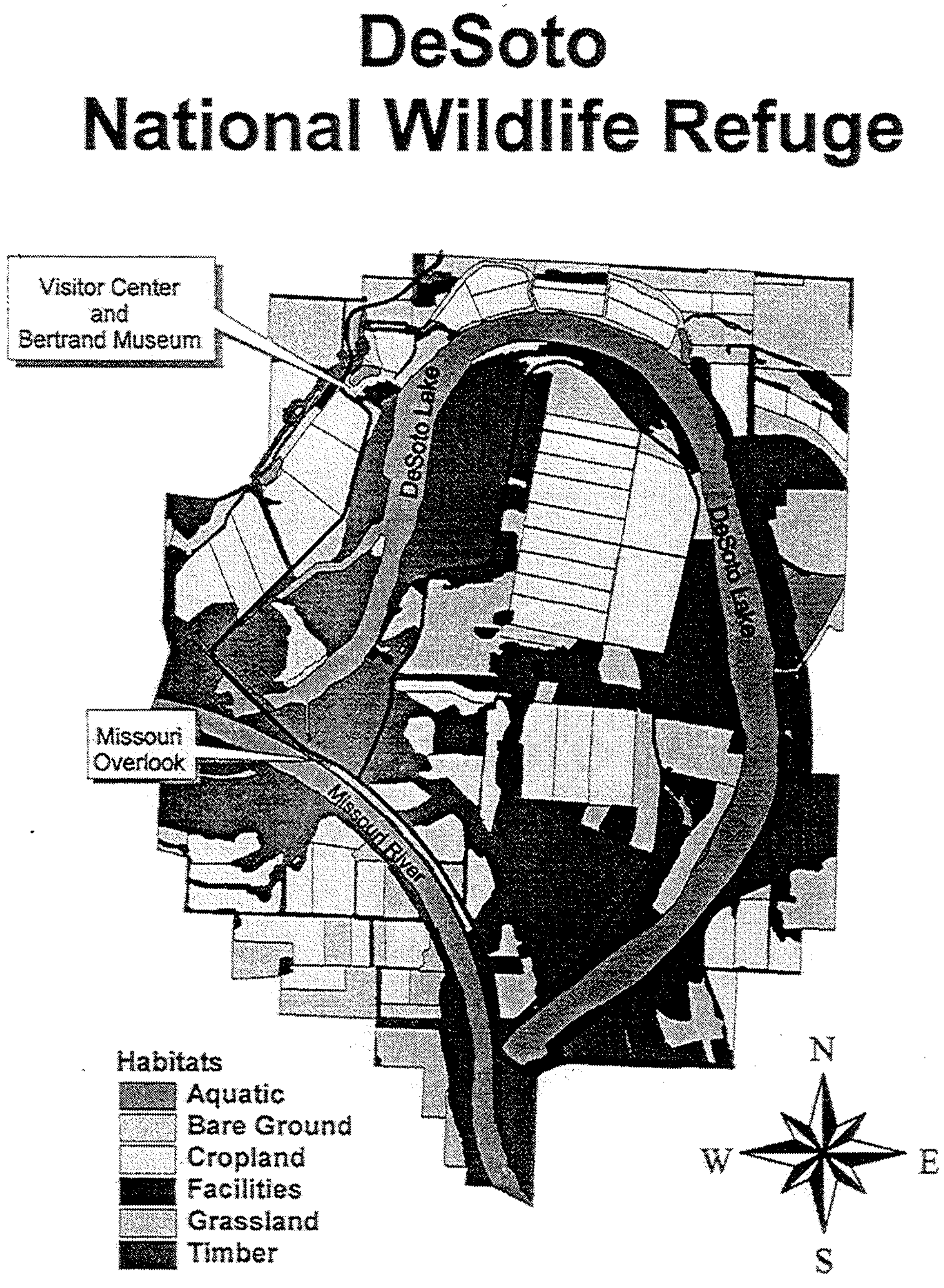


Figure 10. Map of DeSoto National Wildlife Refuge showing field layout.

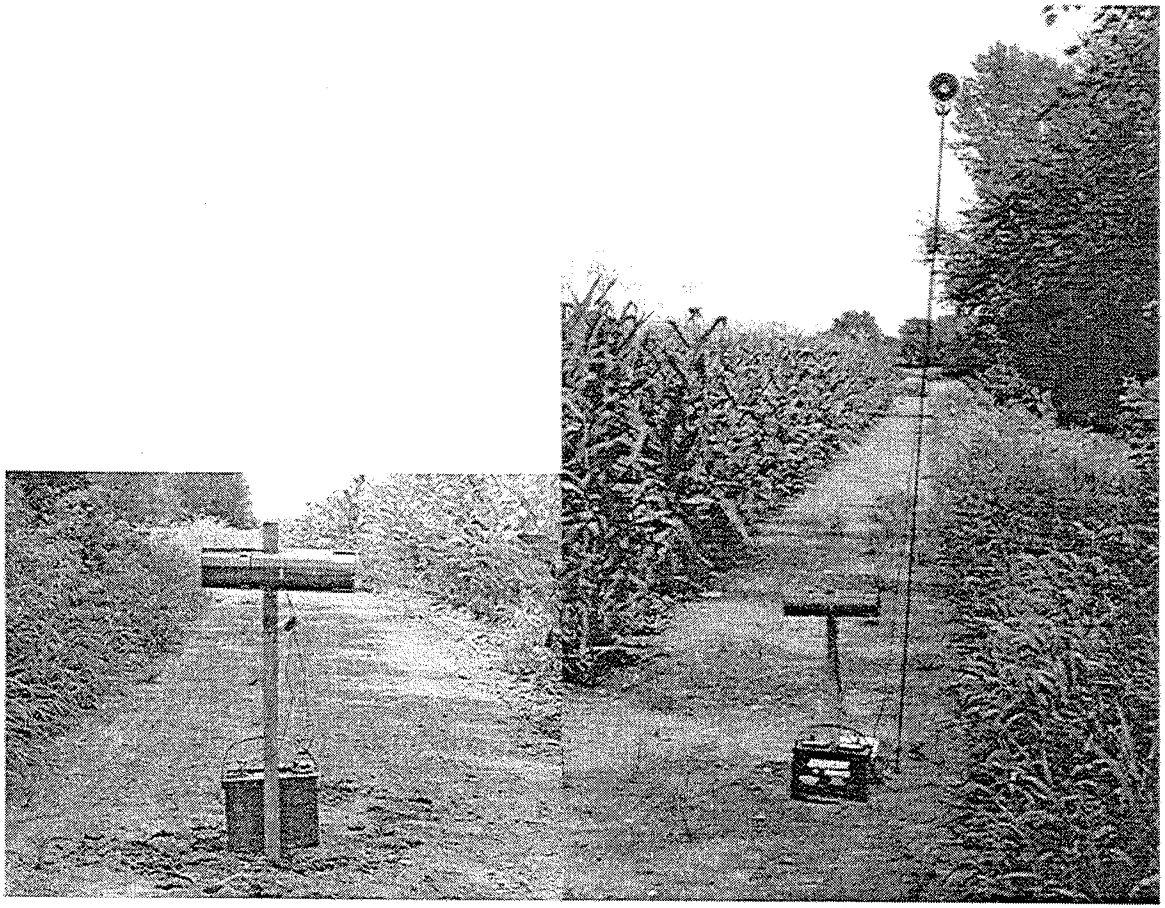
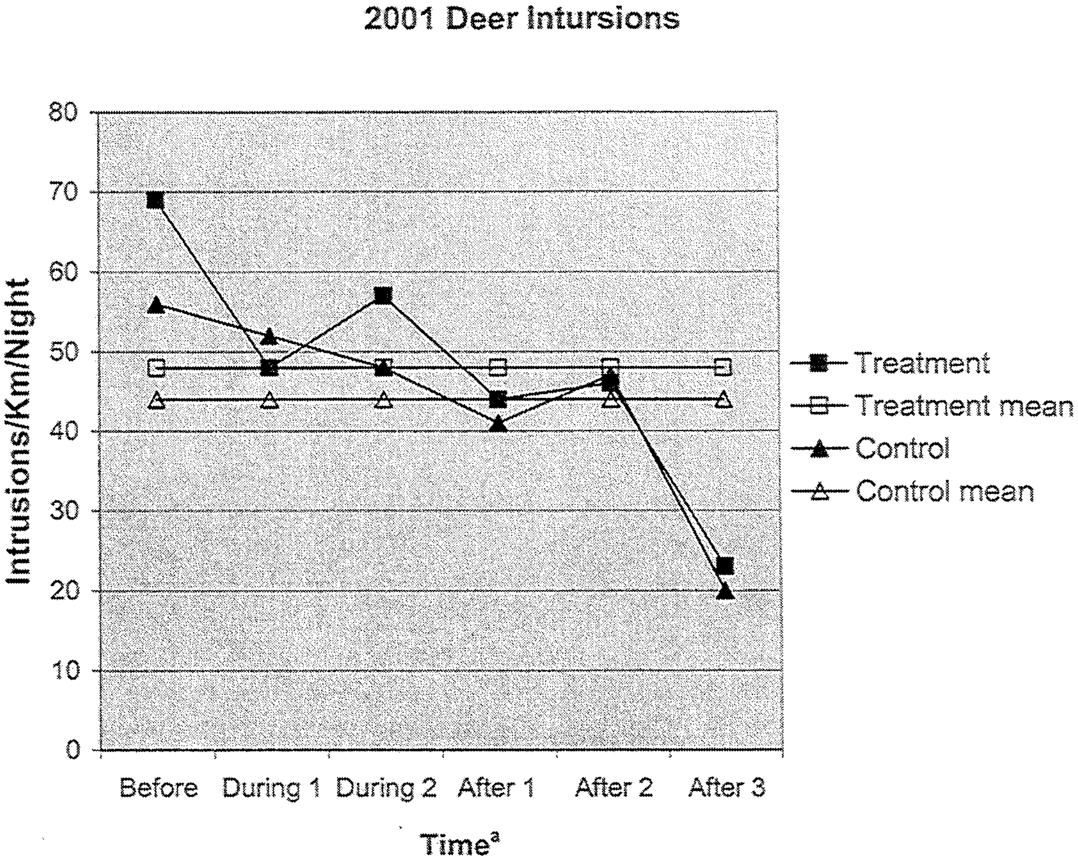


Figure 11. Infrared transmitting unit (left) and receiving unit (right) of the deer-activated bioacoustic frightening device along the edge of a cornfield.



[a] Before = 2 July 2001 to 6 July 2001

During 1 = 7 July 2001 to 10 July 2001

During 2 = 18 July 2001 to 23 July 2001

After 1 = 24 July 2001 to 29 July 2001

After 2 = 30 July 2001 to 2 August 2001

After 3 = 3 August 2001 to 10 August 2001

Figure 12. Indices of deer track counts from perimeters of cornfields protected by deer-activated bioacoustic frightening device and unprotected (control) fields on DeSoto National Wildlife Refuge, 2001.

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Appendix A.

Related publications and presentations.

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Gilsdorf, J. M. 2001. Nebraska deer struck by lightning. Deer & Deer Hunting Magazine. Vol. 24, Issue 7.

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(Appendix A cont.)

Presentations

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Gilsdorf, J. M. 2000. Effectiveness of frightening devices to reduce deer damage in cornfields. Nebraska Bowhunters Association. Kearney, NE.

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Gilsdorf, J. M. 2001. Radio Telemetry. DeSoto Refuge Fest. Missouri Valley, IA.

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Appendix B. Estimates of corn yields for fields protected by propane cannons, electronic guards, and unprotected (control) fields on DeSoto National Wildlife Refuge, 1999.

Treatment	Area (ha)	Yield (kg/ha)
Propane cannon	4.1	3,019
	6.6	9,120
	7.1	6,667
	14.0	8,774
Electronic guard	4.5	9,183
	10.5	5,912
	15.2	7,485
Control	6.7	9,309
	11.7	8,240
	13.8	6,290

Appendix C. Estimates of deer damage in cornfields protected by propane cannons, electronic guards, and unprotected (control) fields on DeSoto National Wildlife Refuge (DNWR) and Loess Hills State Forest (LHSF), 1999.

Treatment	Study Area	# of plots	Damage per plot [a]	% Damage per plot [b]	Total damage [c]	Total % damage [d]
Propane cannon	DNWR	20	0.4	9	0.1	2
		20	1.8	19	0.2	5
		20	1.1	11	0.1	1
		30	1.1	14	0.1	1
	LHSF	10	1.2	16	0.3	6
		10	0.8	19	0.2	4
		10	0.2	3	0.1	1
		10	5.9	38	3.7	34
Electronic guard	DNWR	20	1.3	14	0.1	2
		20	2.1	21	0.3	5
		20	1.4	16	0.2	3
		30	1.6	21	0.1	2
	LHSF	10	2.9	28	0.4	12
		10	2.5	18	0.1	3
		10	0.3	4	0.1	1
		10	2.7	25	0.3	11

(Appendix C cont.)

Treatment	Study Area	# of plots	Damage per plot [a]	% Damage per plot [b]	Total damage [c]	Total % damage [d]
Control	DNWR	20	1.5	14	0.1	2
		20	2.3	14	0.1	2
		20	0.9	11	0.1	2
		30	1.1	10	0.1	1
	LHSF	10	2.0	16	0.1	2
		10	2.4	19	0.1	3
		10	0.8	8	0.1	1
		10	2.6	24	0.9	14

[a] damaged ears/m^2

[b] damaged ears/(damaged ears + undamaged ears)

[c] total damaged ears/total area sampled (damaged ears/m^2)

[d] total damaged ears/(total ears damaged + total undamaged ears)

Appendix D. Use-areas of radio-collared female white-tailed deer exposed to propane cannons and electronic guards on DeSoto National Wildlife Refuge, 1999.

		Area (ha)			Center Shift (m)[d]			% Overlap[e]		
Treatment	Deer ID	Before[a]	During[b]	After[c]	B-D	D-A	B-A	B-D	D-A	B-A
Propane cannon	015	10	21	238	78	145	204	43	9	4
	137	10	12	17	67	143	97	67	47	41
	188	40	37	43	52	159	169	79	85	73
	190	45	16	17	138	42	177	100	76	100
	200	14	10	12	18	499	479	100	17	17
Electronic guard	198	12	54	24	275	256	110	20	83	38
	202	10	29	38	115	91	218	34	68	26

(Appendix D cont.)

		Area (ha)			Center Shift (m)[d]			% Overlap[e]		
Treatment	Deer ID	Before[a]	During[b]	After[c]	B-D	D-A	B-A	B-D	D-A	B-A
Control	149	28	28	17	238	104	156	54	82	88
	150	3	42	11	140	55	185	7	100	18
	154	24	31	23	103	53	147	61	96	61
	205	98	40	53	87	248	249	100	53	79
	208	14	42	48	107	42	147	33	81	29

[a] Before = before devices were employed, 24 June 1999 to 11 July 1999

[b] During = devices active, 12 July 1999 to 30 July 1999

[c] After = devices removed, 31 July 1999 to 17 August 1999

[d] B-D = "Before to During" shift, D-A = "During to After" shift, B-A = "Before to After" shift

[e] B-D = "Before to During" overlap, D-A = "During to After" overlap, B-A = "Before to After" overlap

Appendix E. Use-areas of radio-collared female white-tailed deer with propane cannons placed in their home ranges on DeSoto National Wildlife Refuge, 1999.

	Area (ha)			Center Shift (m)[d]			% Overlap[e]		
Deer ID	Before[a]	During[b]	After[c]	B-D	D-A	B-A	B-D	D-A	B-A
015	15	18	32	54	74	70	78	56	47
137	28	24	67	85	106	53	88	36	42
149	8	17	6	40	75	109	47	100	67
150	38	47	24	75	56	103	77	100	92
154	155	43	73	125	231	324	100	49	100
188	39	45	52	281	111	182	51	71	60
190	10	18	56	47	204	179	50	32	18
198	39	62	37	72	123	52	63	97	86

(Appendix E cont.)

	Area (ha)			Center Shift (m)[d]			% Overlap[e]		
Deer ID	Before[a]	During[b]	After[c]	B-D	D-A	B-A	B-D	D-A	B-A
200	45	39	29	85	101	95	90	93	93
202	71	58	28	95	61	152	95	100	96
205	34	53	27	104	104	207	60	100	67
208	19	26	21	77	45	36	69	76	76

[a] Before = before devices were employed, 5 September 1999 to 18 September 1999

[b] During = devices active, 19 September 1999 to 3 October 1999

[c] After = devices removed, October 1999 to 17 October 1999

[b] B-D = “Before to During” shift, D-A = “During to After” shift, B-A = “Before to After” shift

[c] B-D = “Before to During” overlap, D-A = “During to After” overlap, B-A = “Before to After” overlap

Appendix F. Estimates of corn yields for fields protected by a deer-activated bioacoustic frightening device, and unprotected (control) fields on DeSoto National Wildlife Refuge, 2001.

Treatment	Area (ha)	Yield (kg/ha)
Bioacoustic device	5.54	3,900
	5.91	5,101
	6.43	7,919
	9.23	5,661
	18.62	7,862
	19.67	7,938
Control	5.87	6,724
	8.42	5,032
	8.70	5,019
	10.20	4,994
	14.85	5,661
	15.94	6,158

Appendix G. Estimates of deer damage in cornfields protected by a deer-activated bioacoustic frightening device and unprotected (control) fields on DeSoto National Wildlife Refuge,2001.

Treatment	# of plots	Damage per plot [a]	% Damage per plot [b]	Total damage [c]	Total % damage [d]
Bioacoustic device	20	0.48	8	0.11	2
	20	2.88	38	1.00	15
	20	2.21	31	0.52	8
	20	2.02	28	0.28	4
	30	0.45	10	0.12	7
	30	0.27	4	0.09	1
Control	20	0.22	5	0.07	2
	20	0.47	11	0.13	2
	20	0.88	12	0.20	3
	20	0.25	9	0.05	1
	30	2.48	28	0.40	7
	30	0.84	16	0.05	1

[a] damaged ears/m^2

[b] damaged ears/(damaged ears + undamaged ears)

[c] total damaged ears/total area sampled

[d] total damaged ears/(total ears damaged + total undamaged ears)

Appendix H. Use-areas for female radio-collared white-tailed deer exposed to a deer-activated bioacoustic device, control (no device), or neither (neither device or control) on DeSoto National Wildlife Refuge 2001.

Treatment	Deer ID	During[a] area (ha)	After[b] area (ha)	Center Shift (m)	% Overlap (During to After)
Bioacoustic Device	137	46	23	154	96
	149	25	56	74	45
	150	29	26	85	81
	154	7	58	148	12
	205	75	84	336	70
	208	42	70	127	57
	214	46	52	71	83
	219	23	10	101	100
	244	44	36	455	81
	258	48	46	98	83
	259	51	280	2414	0
	261	11	8	183	75
	262	35	58	66	60
Control	198	33	100	120	33
	211	51	47	90	89
	212	36	-	-	-
	230	8	8	54	75
	234	382	54	640	100

(Appendix H cont.)

Treatment	Deer ID	During[a] area (ha)	After[b] area (ha)	Center Shift (m)	% Overlap (During to After)
(Control cont.)	235	15	27	147	52
	243	38	102	162	37
	250	43	18	101	100
	251	72	90	176	71
	255	15	44	265	30
Neither	188	25	30	230	50
	190	4	7	103	43
	200	22	40	29	55
	213	89	71	96	99
	224	68	61	134	84
	225	51	861	383	6

[a] During = 6 July 2001 to 23 July 2001

[b] After = 24 July 2001 to 11 August 2001