Evaluation of a deer-activated bio-acoustic frightening device for reducing deer damage in cornfields

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Abstract Deer (*Odocoileus* spp.) can cause substantial damage to agricultural crops, resulting in economic losses for producers. We developed a deer-activated bio-acoustic frightening device to reduce white-tailed deer (*O. virginianus*) damage in agricultural fields. The device consisted of an infrared detection system that activated an audio component which broadcast recorded distress and alarm calls of deer. We tested the device against unprotected controls in cornfields during the silking–tasseling stage of growth in July 2001. The device was not effective in reducing damage: track-count indices ($F_{1,4}$=0.02, P=0.892), corn yield ($F_{1,9}$=1.27, P=0.289), and estimated damage levels ($F_{1,10}$=0.87, P=0.374) did not differ between experimental and control fields. The size ($F_{2,26}$=1.00, P=0.380), location ($F_{2,25}$=0.39, P=0.684), and percent overlap ($F_{2,25}$=0.20, P=0.818) of use-areas of radiomarked female deer did not differ between during- and after-treatment periods. We concluded that the deer-activated bio-acoustic device was not effective in protecting cornfields in this study; however, the device may be more effective in small areas such as gardens or for high-value crops that do not grow tall enough to offer protective cover.

Key words animal damage control, bio-acoustics, corn, distress calls, frightening devices, *Odocoileus virginianus*, white-tailed deer, wildlife damage management

Damage to agricultural crops can be a problem in areas with high densities of deer (*Odocoileus* spp.). 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 producers from wildlife depredation was estimated to be as high as $4.5 billion (Conover 2002). In 1993 over $30 million worth of corn was lost to deer just in the 10 largest corn-producing states (Wywialowski 1996).

Use of corn by deer peaks in late June–early July during the silking–tasseling stage of growth (Hygnstrom et al. 1992). At this stage silk-producing ears emerge from the nodes and pollen-producing tassels emerge from the meristem of the corn plant. Cornfields are highly susceptible to deer damage at the silking–tasseling stage because use by deer is high and this is the most critical period for damage that reduces yield (Eldredge 1935, Shapiro et al. 1986, Vorst 1986). Damaged ears of corn are not replaced and often will become infected with fungus. Producers may be able to reduce expenses and the amount of damage to crops by implementing control methods, such as frightening devices, when corn plants are most susceptible to deer damage.

The duration of protection and efficacy often limits the cost-effectiveness of frightening devices.

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Propane exploders, Electronic Guards, and other visual 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, Gilsdorf et al. 2004). A major limitation of nonlethal frightening devices is that animals habituate to the stimuli (Bomford and O'Brien 1990, Koehler et al. 1990, Craven and Hygnstrom 1994, Nolte 1999). Methods to delay habituation include changing the location of frightening devices and altering the periodicity of stimuli (Koehler et al. 1990, Nolte 1999). Belant et al. (1996) reported that periodically fired propane exploders were effective in frightening deer for ≤2 days, while deer-activated propane exploders were effective for 1–2 weeks. A deer-activated scarecrow device also was effective in reducing deer damage in soybeans for up to 6 weeks (Beringer et al. 2003). Few studies have been published about animal-activated devices.

Use of bio-acoustics as a frightening device is relatively unstudied. Bio-acoustics 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 from a deer that has sensed 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 bio-acoustics have been conducted on birds (Thompson et al. 1968, Mott and Timbrook 1988, Aguilera et al. 1991, Gorenzel and Salmon 1993), and knowledge of the potential use of mammalian communication signals for depredation control is scarce (Frings 1964, Koehler et al. 1990). Two potential advantages of bio-acoustics over other acoustic frightening devices (e.g., propane exploders) are that 1) animals may not habituate to them as readily because calls are meaningful to members of the same species and 2) calls may be effective on animals at low intensities; therefore, it is not necessary to produce loud alarm or distress calls that could be disturbing to neighbors or nontarget animals (Frings 1964, Sprock et al. 1967).

Our objective was to design and test a deer-activated bio-acoustic frightening device to reduce white-tailed deer (*O. virginianus*) damage in cornfields. An extensive literature review (Gilsdorf et al. 2002) prompted us to design a device that incorporated new technology with stimuli that have not been tested. We combined an animal-activation system with a frightening device that emitted deer distress and alarm calls. We conducted our study in an actual field situation to more accurately test the effectiveness of the device in reducing deer damage.

Study area

We conducted the study during the summer of 2001 at the DeSoto National Wildlife Refuge (DNWR), located 30 km north of Omaha, Nebraska in the Missouri River valley. The DNWR was a 3,166-ha mosaic of forest, grassland, wetland, and agricultural fields. The density of deer at DNWR was approximately 19/km^2, based on previous estimates (VerCauteren 1998) and consistent subsequent harvest rates (DNWR, unpublished data). Corn (156 ha), soybeans (292 ha), grain sorghum, alfalfa, and a wheat/clover mix were cultivated on a 3-year rotation. Approximately 10–16% of the corn was left standing as food plots for wildlife.

We used cornfields on DNWR as test fields for this study. We located and paired test fields of similar size, shape, and location on the refuge. We used 12 test fields (6 pairs) for the study and assigned treatments randomly to each of the fields in a pair. Fields containing the deer-activated bio-acoustic device are referred to as "experimental" while fields with no frightening device are referred to as "control." The average size of the experimental and control fields was 10.9 ha (range = 5.5–19.7 ha) and 10.7 ha (range = 5.9–15.9 ha), respectively. The average distance between experimental and control fields was 0.9 km (range = 0.5–2.9 km). The fields were a minimum of 0.5 km apart to minimize the potential for dependence among the fields. The dimension and shape of the cornfields allowed the frightening devices to protect an average of 30% (range 21–48%) of the total perimeter of each experimental cornfield.

Methods

The deer-activated bio-acoustic 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, Calif.) to detect the presence of deer entering a cornfield. Each system consisted of an infrared transmitting and receiving unit (Figure 1). Four infrared beams were emitted from 4 lenses on the transmitter. We positioned transmitters and receivers horizontally on wooden posts

50–200 m apart, aiming the transmitter so that the receiver collected all 4 beams of infrared light. All 4 beams had to be broken simultaneously to activate the audio system. We set the infrared beams 71 cm aboveground, the height of an average adult deer midway between the top of the back and bottom of the chest (Sauer 1984).

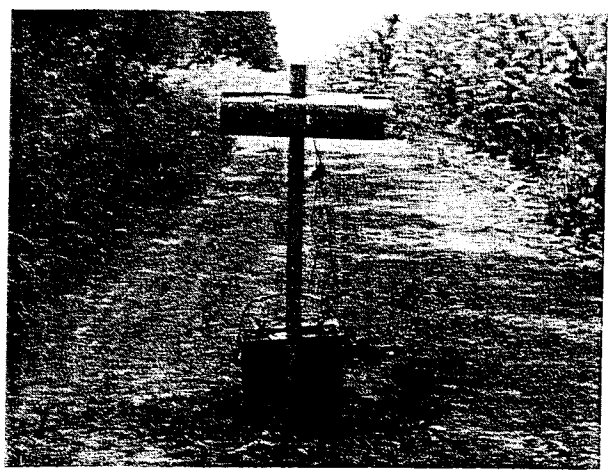
The audio system included a compact disk (CD) player (model CDC-X217, Aiwa, Tokyo, Japan), 30-second time delay, relay, counter, and weatherproof 13-cm horn speaker. We suspended each speaker on the edge of a cornfield 2.4 m above ground with a metal rod. The time-delay device provided power to the CD player for 30 seconds, after which the system reset itself. 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. Twelve-volt marine batteries powered the frightening devices.

We recorded distress and alarm calls from live-captured deer with a Sony Digital Handycam (model DCR-TRV320, Sony, Tokyo, Japan). Deer were captured in the study area in netted cage traps and restrained by hand for 1–4 minutes while being equipped with radiocollars. We extracted distress and alarm calls using Video Wave III SE software (MGI Software Corp., Richmond Hill, Ont.), and copied them onto CDs.

We placed 2 frightening devices on the perimeter of each experimental field adjacent to wooded areas where the highest levels of damage were expected. The infrared systems were situated to protect as much field perimeter as possible (50–200 m).

We positioned frightening devices at the first sign of silking-tasseling in the cornfields (6 July 2001) and operated them for 18 days, which was sufficient time for the ears of corn to mature past the silking-tasseling phase and become less attractive and susceptible to deer (Hygnstrom et al. 1992). After the ninth night, devices in each test field were repositioned about 100 m along the field perimeter to reduce habituation (Koehler et al. 1990, Nolte 1999). We calculated costs of equipment and labor (at $10/hr) required to operate the deer-activated bio-acoustic devices.

We used indices of track counts, corn yields, damage assessments, and use-areas of radiomarked deer to evaluate the efficacy of the frightening devices. A tractor-mounted 2-m-wide drag was used to establish and maintain a smooth dragline around the perimeter of each field. We counted tracks of deer entering and leaving cornfields in the 1 m of dragline nearest the corn about every 6 days. A single observer counted tracks on all fields to eliminate observer bias. We recorded 1 track count



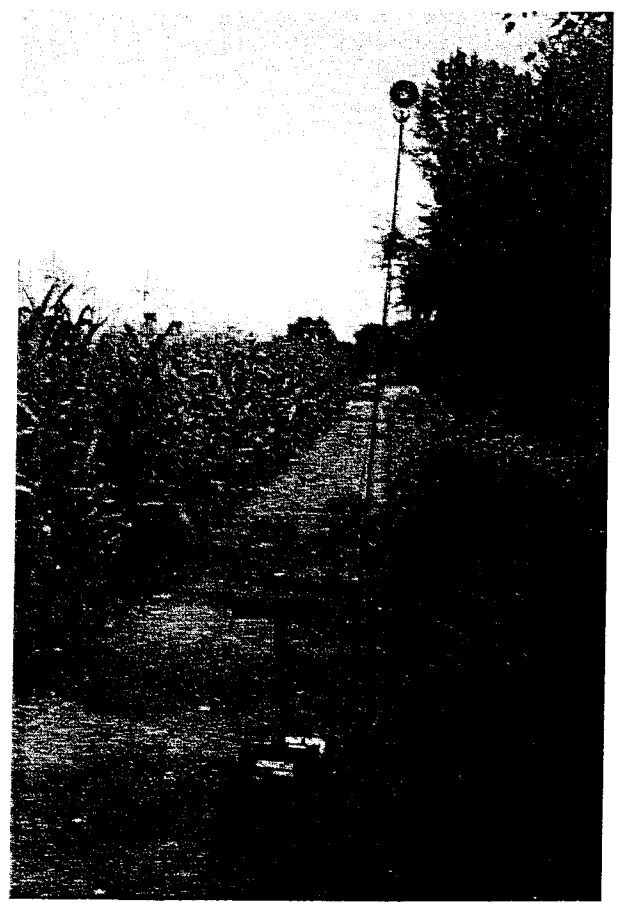


Figure 1. Infrared transmitting unit (left) and receiving unit (right) of the deer-activated bio-acoustic frightening device along the edge of a cornfield.

before frightening-device application, 2 during the 18-day treatment period, and 3 after the treatment.

We obtained data on corn yield for the 12 test fields from farmers when the corn was delivered to grain elevators or directly from yield monitors linked to Global Positioning Systems (GPS) on their harvesting equipment that calculated yields once every second during harvest. We compared corn yield from experimental fields with those fields that served as controls.

We used a variable-area-transect sampling method (Engeman and Sugihara 1998, Engeman and Sterner 2002) to assess the amount of damage caused by deer in the experimental and control fields immediately following the treatment period. 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 we inspected a row of corn, counting the total number of ears including damaged and undamaged ears. When 5 deer-damaged ears were tallied, we recorded distance traveled and total number of ears in the row sampled. If 5 deer-damaged ears were not tallied in 100 m, the observer recorded total number of ears and any deer-damaged ears observed in that 100 m of row. We estimated and compared the average percentage of damage/plot [damaged ears/(damaged ears+ undamaged ears)] among fields.

We used chronologically sequenced use-areas of radiomarked female deer associated with the frightening devices to further ascertain effectiveness of the devices. Use-areas were spaces that the radiomarked deer occupied during 2 18-day study periods. We chose to use the term "use-area" rather than "home range" because of the limited time period in which we collected the data. A home range should include all normal activities associated with feeding, resting, mating, and rearing young (Shivik and Gese 2000). We monitored 23 radiomarked deer in the vicinity of the test fields from June–September 2001. Telemetry locations were distributed equally throughout the day and night. We generated use-areas with the Spatial Ecology Analysis System (SEAS), and harmonic mean method (Dixon and Chapman 1980) using a Geographic Information System (TNTmips®, MicroImages, Lincoln, Nebr.). Use-areas were defined by the 95% isopleth, 20% isopleth core area, and arithmetic center. If the core area was ≤0.5 km from an experimental field or control field, we assigned the deer to the respective treatment.

We produced use-areas with location data from 18-day periods during treatment ("During") and after treatment ("After"). We could not calculate a use-area for the "before treatment" period because of the insufficient number of locations (2–5) recorded per animal. We determined "During" and "After" use-areas with an average of 27 (range = 23–29) and 20 (range = 19–22) locations, respectively, for each deer in each period. We evaluated the impact of the frightening device by comparing size, location of center, and percentage overlap of use-areas between during- and after-treatment periods.

We collected data for track-count indices and use-areas over time and analyzed them as repeated measures. We used a randomized complete block design and analyzed the data using a mixed linear model (e.g., McLean et al. 1991), implemented in SAS Proc Mixed (Littell et al. 1996, SAS Institute Inc. 2000) with means estimated as least-squares means. We used Akaike's Information Criterion (AIC) to select the covariance structure that provided the best-fit model for the repeated measures analyses (Littell et al. 1996), and the Kenward-Roger adjustment for denominator degrees of freedom.

All procedures involving animals were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee (IACUC # 99-03-014) and United States Department of Agriculture/ Animal and Plant Health Inspection Service/ Wildlife Services/National Wildlife Research Center Institutional Animal Care and Use Committee (QA-726).

Results

Materials for each deer-activated bio-acoustic device cost about $600. The devices we built were prototypes that, to our knowledge, had never been built or tested before. The deer-activated bio-acoustic devices needed little maintenance and were functional 24 hours a day during the treatment period. Each device required about one hour to construct and one hour to erect in the field. We estimate it cost $40–$50/field to deploy the devices.

Analysis of data on track counts showed no differences among the treatment effects ($F_{1,4}=0.02$, $P=0.892$) and treatment-by-time interaction ($F_{5,19}=1.52$, $P=0.232$). Differences were detected, however, among time periods ($F_{5,19}=77.06$, $P\leq 0.001$). Use of cornfields by deer tended to decrease similarly in experimental and control fields across the time periods (Figure 2).

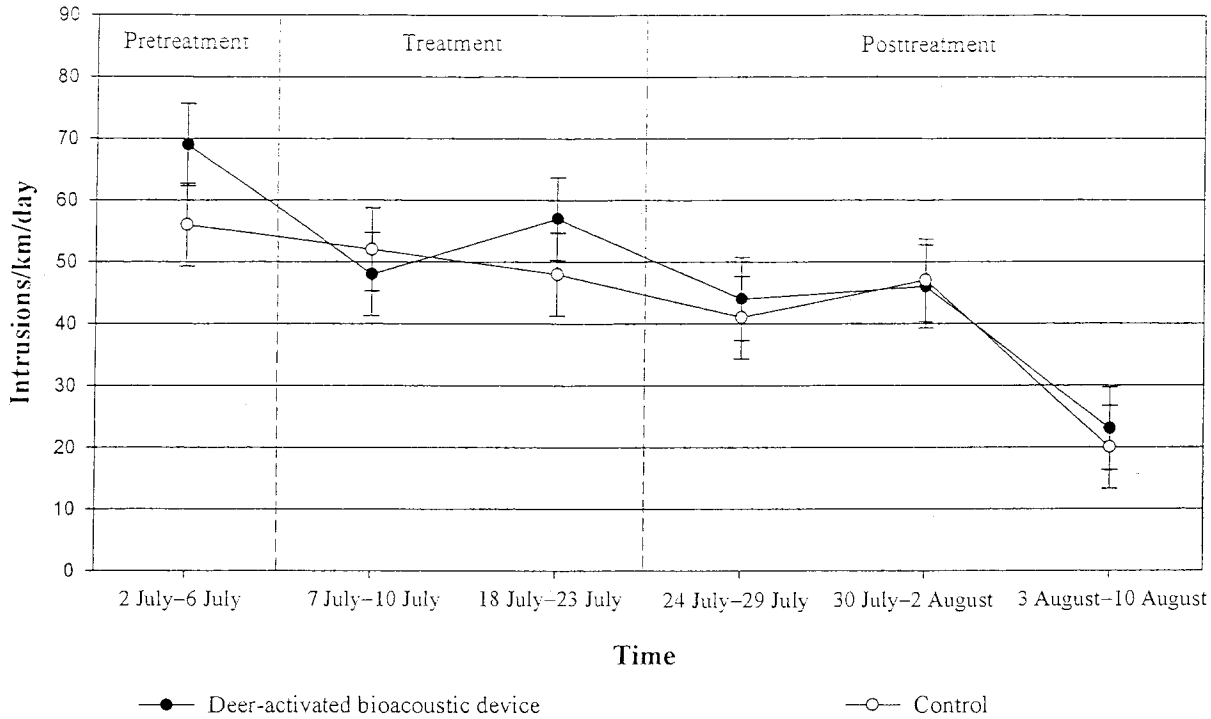


Figure 2. Deer-track counts from perimeters of cornfields protected by deer-activated bio-acoustic frightening device and unprotected (control) fields on DeSoto National Wildlife Refuge, Missouri Valley, Iowa, 2001.

The mean yields of corn (kg/ha) for control ($\bar{x}$= 5,614, SE=481, n=6) and experimental fields ($\bar{x}$= 6,381, SE=481, n=6) did not differ ($F_{1,9}$=1.27, P= 0.289). The size of test fields tended to slightly influence the amount of corn produced/hectare ($F_{1,9}$=3.89, P=0.080) in that as field size increased, yield (kg/ha) increased.

We found no differences in levels of damage by deer between experimental fields and control fields. The average percentage of damage/plot was not different among experimental ($\bar{x}$=20%, SE=4.7, n=6) and control fields ($\bar{x}$=14%, SE=4.7, n=6) ($F_{1,10}$=0.87, P=0.374).

Frightening devices had no effect on the use-areas of radiomarked deer (Table 1). The mean size of use-areas of radiomarked deer exposed to experimental or control fields did not differ throughout the study. Thirteen radiomarked deer used experimental fields and 10 used control fields. Size of the use-areas was not influenced by treatment ($F_{2,26}$= 1.00, P=0.380), time ($F_{1,25}$=2.08, P=0.161), and treatment-by-time interactions ($F_{2,25}$=1.49, P= 0.245). Deer continued to use cornfields even if they contained frightening devices. Location of the centers of the use-areas of radiomarked deer exposed to the experimental or control fields did not differ throughout the study ($F_{2,25}$=0.39, P=0.684). Regarding use-areas of the 13 radiomarked deer exposed to the deer-activated bio-acoustic device, 7 shifted their use-areas closer to the experimental field, 5 moved away from the field, and 1 did not move toward or away from the field. Regarding use-areas of the 10 deer exposed to control fields, 7 moved toward the control field, 2 moved away, and 1 moved neither away nor toward the control.

Table 1. Size and shift of 18-day use-areas of female radiomarked deer exposed to a deer-activated bio-acoustic frightening device on DeSoto National Wildlife Refuge, Missouri Valley, Iowa, 2001.

		$\bar{x}$ size (ha)				$\bar{x}$ center shift (m)[a]		$\bar{x}$ % overlap[b]	
Trt[c]	n	During[d]	SE	After[e]	SE	D–A	SE	D–A	SE
Experimental	13	37	19	62	44	332	126	65	8
Control	10	69	22	54	53	195	152	65	10

[a] D–A = "During to After" shift.
[b] D–A = "During to After" overlap.
[c] Deer exposed to frightening device (experimental) or control.
[d] During = 6 July 2001–23 July 2001.
[e] After = 24 July 2001–11 August 2001.

Deer did not alter their use-areas to avoid cornfields that contained frightening devices. Overlaps of chronologically sequenced use-areas for radiomarked deer exposed to the different treatments were not significantly different ($F_{2,25}=0.20$, $P=0.818$). Deer continued to use all cornfields regardless of the treatment.

Discussion

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

We expected that track counts associated with control fields would increase from the "Pretreatment" period to the "Treatment" period as the corn plants grew and produced ears, then decrease over time in the "Post-treatment" period after the ears of corn became less attractive to deer. We also expected that track counts would be lower in experimental fields than control fields during the treatment. This was not the case, however, as track counts in general decreased throughout the study period in experimental and control fields (Figure 2). Use of fields by deer may have been influenced by the fact that mature cornfields also provided cover that deer would continue to use even after the silking-tasseling stage. The average track-count indices for experimental fields decreased at a higher rate than for control fields from pretreatment to treatment period, which may show an initial response to the devices.

In similar research, Gilsdorf et al. (2004) reported that track-count indices tended to increase throughout the study period. Results here showed a tendency for track count indices to decrease throughout the study period. Such results may be due to drought conditions that occurred during the summer of 2001. Dry soil contributed to observer difficulty in identifying deer tracks entering or leaving cornfields. In addition, drought may have caused the ears of corn to senesce earlier; therefore, fiber content increased, palatability decreased, and ultimately use by deer decreased.

Although not significantly different, the experimental fields sustained slightly more damage by deer than control fields. The average percentage of damage/plot was 6% higher in experimental fields than control. One field that was assigned a frightening device sustained intense deer damage before the silking-tasseling stage and before the frightening devices were applied. The elevated use of some experimental fields by deer during the "Pretreatment" period may have contributed to higher levels of damage (Figure 2). It may be difficult to break the feeding pattern of deer once it is established or to evaluate a frightening device used for a short time based on damage that occurred between planting and the silking-tasseling stage.

Another possible confounding factor in our study is that the frightening devices protected only portions of 2 sides of the test fields rather than the entire perimeter. Deer that did not walk between the infrared transmitter and receiver could have entered a cornfield without activating the frightening devices. Although we placed the devices in areas we felt would receive the greatest amount of pressure by deer, the devices may have provided more protection if the entire perimeters were protected. The device also may be more effective in small areas of concern such as gardens or high-value plantings.

The frightening device did not appear to alter use-areas of radiomarked deer enough to deter them from using protected cornfields. Use-areas of deer exposed to a frightening device increased slightly in size ($\bar{x}=44$ ha, range of 8–84) and centers shifted little ($\bar{x}=158$ m, range of 66–455 m). Each deer used ≤ 1 cornfield in their use-area and did not move to another cornfield after the devices were installed (Table 1). The mean "After" size and shift in location of use-areas of deer exposed to the frightening devices was inflated due to one individual that temporarily moved 2,414 m, resulting in a use-area of 280 ha.

On 5 occasions we saw deer trigger the device, which resulted in deer fleeing from the area. Deer would turn toward the distress calls, listen for 3–5 seconds, then flee from the cornfield or run into the field for protection, suggesting that the sounds frightened them.

When selecting a home-range estimator, researchers should consider the behavior of subject animals, landscape of the study area, and statistical capabilities of the estimator since there is no single "best" estimator for all circumstances (Worton 1995, Shivik and Gese 2000). An optimal sample size for number of locations to estimate a home range is about 50 per animal but may vary from as few as 20 to as many as 200 locations depending on the home-range estimator used (Kernohan et al.

2001, Leban et al. 2001). In our study we evaluated use-areas over 18-day periods and were concerned with spatial relationships rather than comparing estimator accuracy for inliers and outliers. We used the harmonic mean home-range estimator because it is less sensitive to small sample sizes than are other estimators. The harmonic mean is a special case of the kernel methods (Larkin and Halkin 1994). We believe we selected the most applicable estimator to achieve our objectives.

Animals often react physiologically to alarm and distress calls. Thompson et al. (1968) reported that some starlings (*Sturnus vulgaris*) exposed to starling distress calls had heart rates over 700 beats/min, which was 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. Numbers of Canada geese (*Branta canadensis*) in campgrounds were reduced an average of 71% with alarm and distress calls (Mott and Timbrook 1988). In another study Canada geese became alert and moved up to 100 m away from alarm and distress calls but never left the area (Aguilera et al. 1991). Knowledge of potential use of mammalian communication signals is limited. Sprock et al. (1967) reported that a Norway rat (*Rattus norvegicus*) exposed to rat distress calls spent fewer hours in a sound chamber in which the calls were emitted. Similar reactions may be evident in other mammals (Frings 1964, Sprock et al. 1967, Koehler et al. 1990). We chose deer alarm and distress calls to serve as the innovative stimuli for our frightening device because research using mammalian bio-acoustics is scarce and we felt they had the most potential to deter deer with limited habituation.

Advancements in technology have allowed for improvements in activation systems for frightening devices. Infrared and lasers beams can be used to activate frightening devices, making them operable only in the presence of offending animals. Animal-activated frightening devices are thought to reduce habituation to the stimuli, thus rendering the animal-activated devices more effective than systematic devices over time (Belant et al. 1996).

A similar study was conducted during the same year in Missouri, using a similar frightening device, except that acoustic stimuli included a visual effigy and a variety of sounds rather than strictly alarm and distress calls. The frightening device was effective in reducing deer damage to small (0.4 ha) plots of soybeans for up to 6 weeks (Beringer et al. 2003).

Management implications

We suggest additional testing of the deer-activated bio-acoustic device under other conditions, such as high-value crops including fruits and vegetables and in smaller areas that allow for the protection of the entire perimeter of the area. Placing speakers inside the area to be protected rather than on the perimeter may result in the deer leaving the field. The device could also be modified to include a visual stimulus and a variety of acoustic stimuli, which may increase effectiveness. Agricultural producers typically tolerate damage levels of ≤10% of the crop value (Craven et al. 1992). Considering that the prototype devices cost $600 to construct and $40–50 to operate, they may provide limited but cost-effective protection from deer damage, especially in high-value crops. An animal-activated device that incorporates as many stimuli (i.e. acoustic and visual) as possible and one that is inexpensive and relatively maintenance-free may prove to be most applicable for controlling wildlife damage (Koehler et al. 1990, Belant et al. 1996).

Methods for controlling deer damage are limited by proximity to urban areas. Controlled hunting and sharpshooting can be effective but may be difficult to justify in urban areas due to local ordinances and concerns about human health and safety (Jones and Witham 1995, Kuser 1995, Mayer et al. 1995, Kilpatrick et al. 1997). The public supports management, especially nonlethal techniques, to control wildlife causing damage to personal property (Green et al. 1997, Loker et al. 1999, Reiter et al. 1999). Nonlethal devices such as the deer-activated bio-acoustic device may be useful in some rural and urban environments.

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