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Original Article

Efficacy of an Acoustic Hailing Device as an Avian Dispersal Tool

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ABSTRACT Bird strikes are a major safety and financial concern for modern aviation. Audible stimuli are common bird dispersal techniques, but their effectiveness is limited by the saliency and relevance of the stimulus. Furthermore, high ambient sound levels present at airfields might require that effective audible stimuli rely more on total volume (i.e., exceeding physiological tolerances) than ecological relevance. Acoustic hailing devices (AHD) are capable of sound output with a narrow beam width and at volumes high enough to cause physical discomfort at long distances. We tested the effectiveness of an AHD as a dispersal tool on free-ranging birds recognized as hazardous to aviation safety at the Savannah River Site and Phinizy Swamp Nature Park in South Carolina and Georgia, USA, respectively, between October 2013 and March 2015. Our study design included experimental trials with timed-interval counts of birds directly before and after AHD treatment. For most species, counts of birds associated with treatment periods (use of AHD) and control periods (no use of AHD) occurred on different days. Sound treatments yielded variable success at dispersing birds. Specifically, AHD treatment was effective for dispersing vultures (*Coragyps atratus* and *Cathartes aura*) and gulls (Laridae), but ineffective for dispersing blackbirds (Icteridae), diving ducks (*Aythya* spp., *Bucephala* spp., *Oxyura* spp.), and coots (*Fulica americana*). Trials were conducted in a relatively quiet environment with birds that were unhabituated to excessive noise; thus, we cannot unequivocally recommend an AHD as a universally effective avian dispersing tool. However, future research should consider AHD testing integrated with other methods, as well as investigation of treatments that might be salient to specific target species. © 2017 The Wildlife Society.

KEY WORDS AHD, airport safety, bird strikes, long-range acoustic device.

Bird collisions with aircraft (i.e., bird strikes) are common and involve safety risks to the public, substantial monetary losses, and deaths of individual birds involved (Allen 2000, Dolbeer et al. 2015). Many of the species most consequential to aviation safety have been increasing over the past few decades and generally include those with large body mass or that exhibit flocking behavior (Dolbeer and Eschenfelder 2003; DeVault et al. 2011, 2016). From 1990 through 2014, 156,114 wildlife collisions with aircraft were reported to the Federal Aviation Administration (FAA), and 96.9% of these incidents involved birds (Dolbeer et al. 2015). The costs of bird strikes to civil aviation worldwide exceed US$1.2 billion annually (Allen 2000). Furthermore, because liability for bird strikes occurring within the air-operations area increasingly rests with airports, management efforts to reduce bird strikes have become a top priority for operators of civilian airfields (Dale 2009). The air-operations area refers to areas on the airport designated for takeoff, landing, and surface maneuvers of aircraft (FAA, Title 14, Code of Federal Regulations, Part 139, Subpart D) and within FAA siting criteria for certificated airports (i.e., within 1.5 km of a runway for airports servicing piston-powered aircraft only and within 3.0 km of a runway for airports servicing turbine-powered aircraft).

In airport environments, effective wildlife management to reduce hazards to aviation requires the integration of methods to reduce availability of resources vital to wildlife

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populations, enhanced perceived risk of predation, and dispersal of animals near flight paths (Blackwell et al. 2009, 2013; DeVault et al. 2013). Ideally, such methods would be nonlethal, noninjurious, and have no negative environmental effects. Many nonlethal approaches exploit an animal's sensory ecology, including visual, tactile, or auditory stimuli (Engeman et al. 2002, Blackwell and Fernández-Juricic 2013, Seamans et al. 2013).

In particular, a variety of sounds have been employed to repel birds from airports. These sounds are typically generated by firearms, pyrotechnics, propane cannon exploders, "audible" radar, etc. (Seamans et al. 2013). Generally, birds hear at frequencies between 1 and 5 kHz, with greater sensitivity (at $\leq$10 db SPL [sound pressure level]) in the range of 2–4 kHz (Dooling 2002). However, the ability of a bird to hear a sound depends on multiple properties including frequency, frequency modulation, amplitude, amplitude modulation, and ambient noise.

Frequency and frequency modulation are 2 separate properties of sound that are processed by the auditory system in different ways (Henry and Lucas 2009, 2010). Additionally, some bird species specialize in the processing of pure tones, whereas others specialize in the processing of frequency sweeps (Henry and Lucas 2010). This distinction is relevant because the saliency of a sound in eliciting detection should be affected by the filtering properties of the species-specific auditory physiology. Further, subsequent behavioral response to a stimulus hinges on whether an ecologically salient cue is detectable under ambient conditions and contextually relevant (Beason 2004, Miksis-Olds et al. 2007). In the context of using sound as a tool for dispersing birds, effectiveness can thus be limited simply by the saliency of the stimulus locally or behaviorally, and its relevance. The level of auditory resolution and saliency of particular frequencies necessary to elicit avoidance or dispersal responses across bird species and in different environmental or experimental contexts are unclear.

Birds commonly habituate to specific sound properties (e.g., regular explosions), decreasing the efficacy of deterrents involving repetitive sounds (Seamans et al. 2013). Further, a negative experience (e.g., hearing an alarm or distress call, or pain associated with the intensity of the sound) associated with an invisible stimulus could be difficult for an animal to relate to a specific area or object. A negative experience also might not outweigh the potential benefit of resources within the environment (Clark and Avery 2013).

Furthermore, effects of some auditory repellents that incorporate avian distress or alarm calls may be confounded by ambient noise in the airport environment. For example, the sound spectrum of some aircraft engines lies in the same frequency range as distress calls of some bird species (e.g., Short et al. 2000), possibly decreasing the effectiveness (via interference) of biosonic deterrents (e.g., acoustic stimuli intended to interfere with bird communication; see Swaddle et al. 2016). Similarly, because wind and other ambient noises around an airport tend to occur at relatively low frequencies (e.g., 1–2 kHz), the addition of salient cues in the anticipated best auditory range for birds (e.g., 2–4 kHz) likely would not add to the overall sound pressure level (i.e., the summation of energy within this frequency range; *sensu* Dooling's [2002] application to deterring birds from wind turbines). Thus, the efficacy of an auditory repellent used in the airport environment might be reliant more on the summation of energy within a particular frequency range, or intensity producing discomfort, than on its ecological saliency.

Acoustical hailing devices (AHD), also called long-range acoustic devices, are hailing and warning devices originally developed for long-distance communication that can project intelligible messages up to 2 km (Davidson 2009). These devices are also capable of sound output at volumes high enough to cause physical discomfort at long distances and project within a narrow beam width that allows for targeting of specific individuals (Davidson 2009). Because of this, they have been promoted as a crowd-dispersing tool and nonlethal deterrent for wildlife by device manufacturers (McNab and Scott 2009).

Acoustic hailing might be a promising tool for use at airports for several reasons. The devices can emit tones that far exceed bird sensitivity to sound pressure (up to 156 SPL) and potentially elicit flight responses, despite considerable ambient noise at airports. Acoustic hailing devices also are nonlethal and when properly used should not interfere with airport activities. Efficiency of AHDs as an avian dispersal tool has not, however, been rigorously tested and species-specific effects are not well-understood.

We evaluated the efficacy of an AHD as a dispersal tool for use on free-ranging birds commonly recognized as hazardous to aviation safety (DeVault et al. 2011, 2016). We field tested the AHD in natural settings, with the potential advantage of allowing observation of a more complete range of behavioral responses by birds than might be possible under tightly controlled experimental conditions using sequestered individual or small aggregations of birds. The use of natural settings not associated with an airfield provided an optimal scenario for AHD testing because of relatively low ambient noise as compared with that typically found on airfields. We sought to identify species-specific responses to AHD treatments at known flocking-bird roosts, bait sites, or other areas where natural aggregations of target species occurred. We predicted that AHD would be more effective at dispersing larger birds and those species that tend to flock.

STUDY AREA

We conducted our experimental trials at sites in South Carolina and Georgia, USA, between October 2013 and March 2015. The Savannah River Site (SRS), located near Aiken, South Carolina (33.344088, −81.741207), was an 800-km^2, limited-access nuclear production and research facility owned and operated by the U.S. Department of Energy. The SRS was large, off-limits to the public, and harbored large populations of each of the bird species targeted in this research (White and Gaines 2000). Our targeted species included blackbirds (Icteridae), diving ducks (Aythya, Bucephala, Oxyura), American coots (*Fulica americana*), gulls (Laridae), black vultures (*Coragyps atratus*), and turkey vultures (*Cathartes aura*). Additional trials on blackbirds were conducted at constructed wetland habitats of the Phinizy Swamp Nature Park in Augusta, Georgia.

Phinizy Swamp Nature Park wetland cells were built between 1997 and 2002 as a natural, tertiary treatment alternative for municipal wastewater effluent for Augusta, Georgia, and dominated by giant cutgrass (*Zizaniopsis miliacea*). The SRS A-01 wetlands were constructed in 2000 and consisted of a retention pond and 4 pairs of 0.4-ha wetland cells. These wetlands were created to remove heavy metals from processed wastewater and storm water runoff, and planted with giant bulrush (*Schoenoplectus californicus*). Large population of roosting blackbirds, mainly redwing blackbirds (*Agelaius phoeniceus*), occurred regularly at both Phinizy Swamp (~50,000–100,000 birds) and SRS A-01 (~10,000–25,000 birds) in the autumn and winter periods. Phinizy Swamp Nature Park was adjacent to the Augusta Bush Field Airport where roosting blackbirds were known to represent a bird-strike hazard (Kennamer et al. 2013).

We conducted trials for the remaining species on several sites at the SRS. We conducted duck, coot, and gull trials on L-Lake, a 405-ha reservoir originally built in the early 1980s as a cooling reservoir for a national defense nuclear reactor that was no longer operational. Vulture trial sites ($n = 6$) included multiple locations baited with wild pig (*Sus scrofa*) carcasses, as well as the Three Rivers Solid Waste Authority Regional Landfill where vultures aggregated and frequently were observed foraging and loafing. This landfill had a 120-ha footprint and received solid waste from 9 counties in South Carolina. Baited sites were located on a cleared powerline right of way ($n = 1$), along dirt or gravel roads ($n = 3$), and in a clearcut ($n = 1$) on the SRS. These sites were relatively open habitats, and allowed for a 100–300-m distance from the bait site to the AHD.

METHODS

We used a Hyperspike HS-18 (Ultra Electronics, Columbia City, IN, USA) for all avian dispersal trials. According to manufacturer specifications, the HS-18 can produce a peak of 156 dB SPL and can be used for communication at an effective distance up to 2 km with a sound beam width of 5°. We did not develop tones having characteristics uniquely proficient at dispersing any particular bird species. Active treatment periods consisted of 4 preprogrammed (1.3kHz Cascade02 Alert Tone, 1.3kHz Cascade05 Alert Tone, 1.3kHz Combo01 Alert Tone, 1.3kHz Sine Alert Tone04) tones repeatedly projected by the AHD in 15-sec bursts followed by 5 sec of silence. We qualitatively selected tones from the 25 tones provided by Ultra Electronics that exhibited multiple frequencies, frequency modulations, and saliencies that we perceived as being well above the ambient acoustic environments of our study sites, with the characteristics thought to potentially influence bird behavior (Henry and Lucas 2009, 2010). All trials followed protocols approved by the University of Georgia's Institutional Animal Care and Use Committee (A2013: 02-004-Y3-A).

We included a wide range of avian species in the study, along with their corresponding specific behaviors and habitat requirements; therefore, it was not possible to use standardized methods across all species. However, the basic design of our study included experimental trials with timed-interval counts of birds. For all species of birds studied, bird counts were conducted by one of several trained observers to minimize observer effects or detection bias. With the limited number of sites available for use, treatment sites also served as their own control sites; we relaxed strict assumptions of independence of our counts for statistical analyses (Seamans et al. 2016). For most species, bird counts associated with treatment (use of AHD) and control (no use of AHD) occurred on different days (see specific details below). We opted for nonparametric analyses because of the frequency of zeroes in counts for some species, nonnormal count distributions, and our inability to transform count data in many instances. We describe treatment methods used for each species or group and associated analyses below.

Blackbirds

We conducted the trials of AHD effectiveness for blackbirds at 2 constructed wetlands—Phinizy Swamp Nature Park Wetlands (Cell #4, 12 ha) and SRS A-01 Wetlands (3.6 ha)—from October to December in 2013 and 2014. Each AHD trial for blackbirds consisted of evening counts of birds landing in the constructed wetland vegetation conducted on 2 consecutive evenings, including a pretreatment day (Pretreatment—Day 1; no AHD in use) and a treatment day (Treatment—Day 2; with AHD in use). We attempted trials once every 1–2 weeks over a 2-month period each year and cancelled planned trials when weather forecasts included possible afternoon–evening precipitation events during any of the 2 consecutive days. Single observers made evening counts of blackbirds landing in emergent vegetation lasting for a 1-hr period, extending from 45 min before sunset to 15 min after sunset during the peak period of blackbird entry to roost sites. We recorded temperature, humidity, barometric pressure, and cloud cover immediately prior to initiating 1-hr counts.

On treatment evenings (Day 2), we operated the AHD within the 1-hr count period at intervals of 10 min active (15-sec bursts followed by 5 sec of rest) followed by 2 min inactive. The AHD was aimed at flocks of blackbirds approaching the wetlands. When no flocks were observed, the AHD was aimed at the roosting site and swept back and forth until the next incoming flock was observed. Projection—count distances to all points in both study-site wetlands was 50–500 m from the AHD. The AHD was mounted on a tripod in the back of a truck with no attempt to conceal the truck or AHD. We conducted 20 1-hr counts, representing 10 complete trials. We analyzed count data using a nonparametric Wilcoxon signed-rank test to test for potential differences in blackbird numbers using the roost site between our Pretreatment—Day 1 and Treatment—Day 2.

Ducks and Coots

We evaluated the effect of AHD treatment on ducks and coots on L-Lake at the SRS in February 2014 and January 2015. We conducted counts within the southern portion (~26 ha) of the lake. We baited waterfowl to the area with 68-kg bags of whole-kernel corn centered 500 m from the AHD on a shoal at a depth of approximately 1 m the night before trials commenced.

We collected data during pretreatment days (Pretreatment—Day 1; no AHD in use), treatment days (Treatment—Day 2; with AHD in use), and post-treatment days (Post-treatment—Day 3; no AHD in use). We made paired 30-min counts directly before (initial count) and after (final count) a 30-min AHD active (treatment) or inactive (control) period. We repeated these counts 4 times during each treatment day to assess the potential for habituation to or a cumulative effect of the AHD treatments (see Bejder et al. 2009). We performed treatments or controls at 0800–0930, 1000–1130, 1200–1330, and 1400–1530 hr to test for a possible within-day order effect, which would be evident if duck or coot numbers increased (potential habituation effect) or decreased (cumulative effect) throughout the course of an individual day. During all counting periods, we recorded waterfowl species and numbers observed within the 26-ha portion of L-Lake.

Although we observed numerous species of waterfowl–waterbirds over the course of the study, diving ducks and coots were the predominant species recorded. Thus, we limited our analyses to these groups. Furthermore, we found that combining counts from all diving duck species yielded data that minimized the presence of zeroes as counts. American coots were numerous enough so that count values of zero did not occur. Our paired-count approach allowed us to account for variability in numbers of birds that were initially present when we began periods of AHD activity or inactivity. We used analysis of covariance (ANCOVA) to evaluate the response of diving ducks to ADH treatments, with final waterfowl counts being the response variable, initial counts serving as a covariate, day (1, 2, or 3) as a categorical effect, and within-day ordering of treatments as a categorical effect. We included all 2- and 3-way interactions of the main effects in the tested models. We tested all count data for normality using Shapiro–Wilk tests, and natural-log–transformed data as necessary.

Gulls

We conducted gull trials on the southern approximately 26 ha of L-lake during February 2014 and January–March 2015 that consisted of paired 30-min counts made directly before (i.e., the initial count) and after (i.e., the final count) a 30-min active (AHD treatment) or inactive (control) period. We categorized days simply as treatment or nontreatment days with no distinction between pre- and post-treatment. A minimum of 10 gulls was required to be present to initiate a trial to ensure a measureable effect was possible. We used ANCOVA to evaluate the response of gulls to ADH treatments, with final counts of gulls (after active or inactive AHD periods) as the response variable, initial counts used as a covariate, and day (AHD active or inactive) as a categorical effect. The model included an interaction of 2 main effects, (initial count and treatment or control). We tested counts for normality using a Shapiro–Wilk test, and natural-log–transformed data as necessary.

Vultures

We tested the effectiveness of the AHD in dispersing vultures from sites on the SRS between July and September 2014. Our AHD trials for vultures consisted of 15 min of initial observations (counting vultures), 15 min of active treatment or control, and 15 min of final observations (counting vultures). Our treatments consisted of a 7-min active AHD period, a 1-min inactive period, and an additional 7-min active AHD period. Inactive periods were necessary to prevent damage to the AHD speakers. We initiated trials between 0900 and 1615. We tested for statistical differences between initial and final counts for both treatment and control vulture trials using a Wilcoxon signed-rank test for all trials.

We were also interested in determining how long AHD treatments dispersed target species. Vulture trials were the only species where an attractant was localized enough to measure the time to return. We placed motion-activated trail cameras on baited sites prior to AHD treatments to determine the amount of time that sound treatments displaced vultures (length of time between the end of the treatment and the first arrival of a vulture post-treatment). We initiated trials between 1005 and 1540 with sunset during this period occurring between 2004 and 2023.

RESULTS

Blackbirds

We did not detect an effect of use of the AHD on numbers of blackbirds landing in the constructed wetlands ($n = 20$, Wilcoxon signed-rank test: $S = 97$, $P = 0.57$). This lack of effect occurred despite that average numbers of landing birds varied among days in a manner consistent with a treatment effect, with a 26.5% decrease between Day 1 and Day 2 (Table 1).

Ducks and Coots

We used 87 paired counts of diving ducks and coots to evaluate AHD effects. Our counts of diving ducks were not distributed normally, so we transformed them via the natural log. The full model explained >60% of the variation in the final counts of diving ducks ($F_{23,63} = 6.74$, $P < 0.001$); however, none of the model effects involving AHD treatments differed (i.e., day effect or its interaction with any of the other main effects; all $P > 0.25$). No more

Table 1. Acoustic hailing device trial result for blackbirds landing on constructed wetlands at the Savannah River Site and Phinizy Swamp Nature Park in October to December 2013-2014. Trial counts took place for an hour including 45 min before sunset and 15 min after sunset. Trials were split into pretreatment (Day 1), treatment (Day 2) days. Counts are averaged across trial days and sample size (*n*), minimum counts (Min.), and maximum counts (Max.) are included.

Trial	*n*	Mean landing/hr	Min.	Max.
Day 1	10	9,088.9 ± 2,181.4	1,229	22,880
Day 2	10	6,683.7 ± 2,888.7	690	15,784

than an approximately 10% reduction in diving duck counts could be attributed to use of the AHD (Table 2). Given the experimental protocol and level of variability in counts, a 10% reduction in counts could not be demonstrated as being statistically or biologically significant. Our effect tests showed that the initial counts (also natural log transformed) of diving ducks (covariate effect: $F_{1,63} = 86.55$, $P < 0.001$) and interaction of within-day order and initial counts ($F_{3,63} = 2.94$, $P = 0.04$) both influenced final counts. There was an overall, strong positive effect of the initial counts on the final counts, with an overall slope estimated as $\beta = 0.838 \pm 0.072$ SE. Strong positive relationships between initial and final treatment counts were also evident for sequential within-day orderings, but only the early afternoon ($\beta = 1.203 \pm 0.137$ SE) and late afternoon ($\beta = 0.584 \pm 0.105$ SE) slopes differed from the overall slope (Fig. 1).

Our raw counts of coots ($n = 87$) approximated a normal distribution and our overall model explained a substantial amount of the variation in counts ($F_{23,63} = 21.36$, $P < 0.001$; $R^2 = 0.84$) and indicated that final counts of coots were positively influenced by initial counts (covariate effect: $F_{1,63} = 375.8$, $P < 0.001$); no other effects were evident. Post-treatment Day 3 counts (least squares $= 720.60 \pm 25.44$ SE; Table 2) were approximately 8.1% and 10.4% greater that Treatment Day 2 counts, respectively.

Gulls

Our untransformed gull counts ($n = 37$ pairs) were highly variable and deviated from a normal distribution (Table 2). We transformed counts via natural log (after adding 1 to prevent transformation of values of 0). The full ANCOVA model was significant ($F_{3,33} = 3.27$, $P = 0.03$), but explanatory effects described relatively little of the overall variation in final counts (<20%). Both the initial counts and treatment or nontreatment day affected final counts (covariate effect: $F_{1,33} = 5.20$, $P = 0.03$; categorical treatment effect: $F_{1,33} = 6.00$, $P = 0.02$), but the interaction did not ($P = 0.93$). Final counts from AHD treatment days (geometric mean = 8.67, 95% CI = 3.35–31.65) were 76.4% lower than counts from days when the AHD was not actively used (Fig. 2; geometric mean = 37.67, 95% CI = 17.97–78.98).

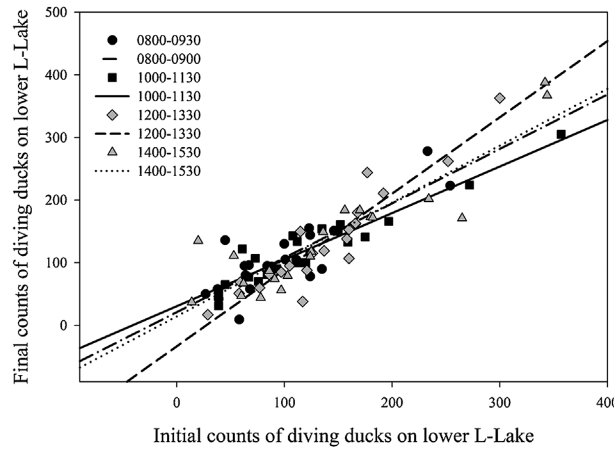

Figure 1. Untransformed initial versus final counts of diving ducks treated with an acoustic hailing device on lower L-Lake of the Savannah River Site in February 2014 and January 2015. Effects tests indicated that initial counts and within-day order effect influenced final counts. Counts were divided by sampling periods (0800–0930, 1000–1130, 1200–1330, 1400–1530) to evaluate within-day order effect. The biological relevance of within-day effect was unclear.

Vultures

We conducted 26 sound trials and 21 control counts on vultures at the SRS. Post-treatment vulture numbers were lower than pretreatment numbers (Wilcoxon signed-rank test, $S = 174.5$, $P < 0.001$; Table 2). Small within-site samples sizes generally prevented among-site comparisons, but post-treatment counts at all sites were reduced. Final control counts ($n = 21$) were not different from initial counts (Wilcoxon signed-rank test, $S = 28$, $P = 0.34$; Fig. 3). Using motion cameras, we documented elapsed time for vultures to return to bait sites for 12 treatment events. The elapsed time for vultures to return to bait piles ranged from 26 min to 48 hr with an average of 12.3 ± 4.3 (SE) hours. In 4 trials, the time to return included nighttime hours when vultures are unlikely to be active. When nighttime hours were removed, the average time to return decreased to 7.9 ± 2.3 hours.

DISCUSSION

Our study represents the first effort to evaluate the efficacy of acoustic hailing devices for dispersing birds commonly

Table 2. Acoustic hailing device (AHD) trial results for ducks, coots, gulls, and vultures on the Savannah River Site between October 2013 and March 2015. Initial and final counts are averaged across trial day or treatment or control where appropriate. Counts are split by day (Day 1 = pretreatment, no AHD in use; Day 2 = treatment, AHD in use; Day 3 = posttreatment, no AHD in use) for ducks and coots and into treatment and control for gulls and vultures. Sample size, initial minimum count, initial maximum count, final minimum count, and final maximum count are included.

Species	Trial	n	Mean initial count	Mean final count	Initial min. count	Initial max. count	Final min. count	Final max. count
Ducks	Day 1	28	169.6 ± 17.4	$1,71.7 \pm 18.4$	14	357	37	388
	Day 2	32	103.7 ± 9.4	103.8 ± 8.9	27	265	9	244
	Day 3	27	104.1 ± 10.2	105.8 ± 9.5	30	234	17	202
Coots	Day 1	28	681.5 ± 56.8	721.4 ± 56.1	110	1,135	119	1,190
	Day 2	32	615.3 ± 55.8	606.3 ± 56.5	123	1,009	103	1,064
	Day 3	27	705.2 ± 49.5	752.1 ± 54.4	126	1,175	118	1,219
Gulls	Treatment	17	130.4 ± 41.7	37.7 ± 13.3	10	546	0	169
	Control	20	62.5 ± 15.6	95.4 ± 31.9	11	255	1	419
Vultures	Treatment	26	18.8 ± 2.2	2.4 ± 1.0	4	44	0	25
	Control	21	24.3 ± 3.2	22.2 ± 3.5	8	67	0	58

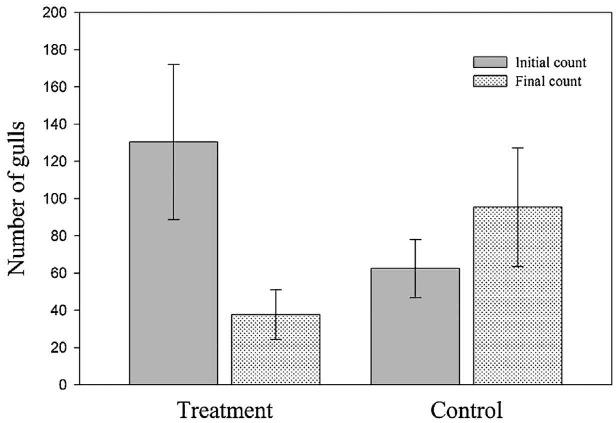

Figure 2. Mean (±SE) initial versus final counts of gulls during acoustic hailing device (AHD) trials on lower L-Lake of the Savannah River Site in February 2014 and January 2015. Initial counts and treatment effects influenced final counts, and control trials displayed no significant effect ($P > 0.05$) in gulls.

involved in bird strikes. The ambient noise conditions under which we conducted this study represented an optimal environment of eliciting a flight response. The lack of response by several groups (blackbirds, ducks, and coots) indicated that an AHD would not be effective in areas where these species are the primary bird-strike concern. Qualitatively, the AHD tended to work best in open environments and even natural structures produced considerable signal bounce. Generally, the larger the species, the more effective the AHD was at dispersing them; vultures were the most responsive to treatments. Flocking behavior, however, did not increase the likelihood of dispersal in our focal species and the most social species (blackbirds) did not disperse. Treatments had varying success at dispersing birds in this study and responses were species-specific and discussed below.

For blackbirds, the AHD decreased average counts of individuals coming into roosts, though average counts still

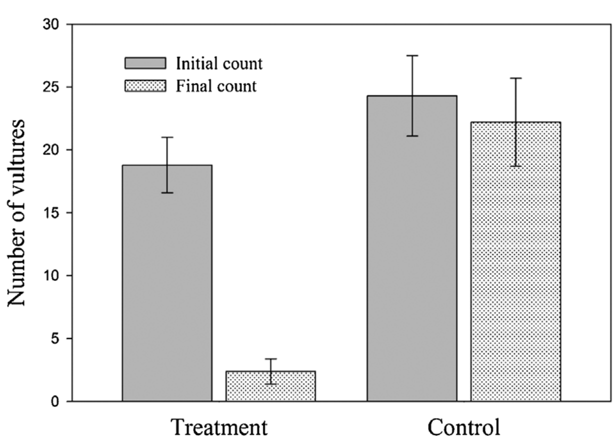

Figure 3. Mean (±SE) initial versus final counts of vultures during acoustic hailing device (AHD) trials at the Savanah River Site between July and September 2014. AHD treatment significantly decreased vulture counts. Initial and final counts during control trials did not differ ($P > 0.05$).

remained relatively high (>6,000). At a large blackbird roost encompassing several hundred ha (Phinizy Swamp Nature Park Wetlands), treatment of one 12-ha vegetation cell was ineffective. Specifically, when some birds (~26.5%) were dispersed by the AHD treatment, they used adjacent wetland cells as alternative roosts. Thus, a mobile AHD platform or strategy for treating the entire Phinizy wetlands might have been more effective. However, wetland size and bird mobility would remain a challenge.

Alternatively, at the SRS A-01 wetlands, wetland size was smaller (3.6 ha), and no suitable, similar alternative roost wetlands were known to be located nearby. The ultimate roosting location of displaced blackbirds at the SRS A-01 wetlands was unclear, but we observed late-arriving individuals (after AHD treatments ended) and it is possible that birds initially dispersed by the AHD simply returned later. The AHD treatments were not effective for dispersing blackbirds to substantially reduce the risk of bird strikes. In situations with limited roosting habitat, AHD treatments may be effective if conducted both during and after typical roost-flight periods. Other methods, such as the removal of roosting habitat, are likely more effective at reducing blackbird use of roosting areas (Conover 1984, Kennamer et al. 2013).

Waterfowl and coots similarly showed a limited response to AHD treatments. Pretreatment counts best predicted the number of waterfowl and coots after treatment, indicating that AHD poorly dispersed these species. Treatment days had the lowest average counts for both diving ducks and coots. Several factors may have contributed to the limited effectiveness of AHD treatment on waterfowl. Waterfowl were baited to our AHD treatment locations. The baiting may have increased the incentive to remain within the study site. Additionally, maintenance of bait on the site may not have been consistent through time and we have no knowledge of other resources in the study area. However, we do not believe bait alone explained much variance in the response of diving ducks to AHD treatment because a similar response was observed for coots, which, as consumers of algae, should not have been attracted to the bait (corn) used in this study.

Previous research on the response of waterfowl to hazing systems has shown greater response by ducks using remote detection and multiple hazing tactics. Stevens et al. (2000) used multiple hazing tactics (auditory, chemical, and visual) and waterfowl were 4.2 times less likely to land on ponds with hazing devices. Ronconi and St. Clair (2006) reported significant reductions in waterfowl landings using a radar-activated hazing system. Waterfowl appear to have strong aversion to multiple hazing tactics (Stevens et al. 2000, Ronconi and St. Clair 2006). A future experimental design might consider effects of AHD treatments integrated with other visual or tactile stimuli.

Gulls responded negatively to AHD treatments and dispersed from the treatment area. However, there was high variation in gull counts, and the final count from one trial resulted in a greater number of birds present. Nontreatment days also exhibited large changes in gull numbers between initial and final counts (e.g., initial count = 55, final count = 350). Only 4 of 17 trials completely removed gulls from the southern portion of L-Lake. Gulls were not expected to use the bait present in the southern section of L-Lake; thus, we did not consider baiting as an incentive to remain in the area. Previous research on gull dispersal indicated that various dispersal techniques are effective on gulls, but they tend to habituate quickly to hazing devices when not coupled with lethal control (Bomford and O'Brien 1990, Dolbeer et al. 2003, Baxter and Allan 2008, Soldatini et al. 2008).

The AHD treatment was effective at dispersing vultures from bait sites, although vultures were not completely dispersed in all treatments. Vultures typically left within minutes of the initiation of treatment, although vultures flushing from adjacent forest habitat occasionally required additional time to leave. The AHD was more effective in more open than forested or rugged terrain; however, between-site comparisons were not possible because of small sample sizes. Trials at the Three Rivers Landfill resulted in the largest post-treatment counts and no trial completely dispersed vultures.

The availability of anthropogenic food at the landfill may be incentive enough to reduce effectiveness of dispersal methods used against vultures. Treatments did not permanently disperse vultures from any bait sites (not including the landfill) and birds returned shortly following dispersal. The SRS harbors large populations of vultures and the long-term effectiveness of AHD treatments may be mitigated by the presence of naïve birds that are drawn to feeding or loafing locations (Holland 2015). To our knowledge, there are no other studies on the effectiveness of dispersing any vulture species with hazing devices other than hanging effigies or handheld lasers (Seamans 2004, Avery et al. 2006). Our data suggested that AHD treatments could be effective for removing the majority of vultures from around airports in conjunction with limiting access to food resources (landfills and bait piles) and loafing structures.

The research was carried out under field conditions, so we encountered several limitations that highlight the need for future research on use of AHDs as a wildlife dispersal tool. For example, although we focused on the loudest sounds possible to determine whether summation of energy within a particular frequency range would illicit flight response even without ecological saliency, we suggest that future research should more systematically determine the most effective sounds and frequency ranges for each species, especially for species that did not disperse during AHD treatments.

We did not detect a cumulative within-day effect for the waterfowl species that were subjected to multiple treatments, but daily AHD use over longer temporal periods or multiple days may or may not illicit desired responses. Extending AHD treatments over longer temporal periods, however, requires increased labor and logistical costs. To save cost, airport managers may be inclined to use a remotely activated device that can operate without constant human input. Another consideration for implementation of this technology is that AHD treatments produce excessive sound in a human environment (e.g., airports, industrial facilities, etc.) and thus may conflict with ongoing human activities in treatment zones.

MANAGEMENT IMPLICATIONS

Of the species we experimentally exposed to AHD treatments, gulls and vultures were the most sensitive to the sound stimulus provided. Our data suggest that use of AHD for dispersal of blackbirds, diving ducks, or coots would be unsuccessful without further exploration of specific sound profiles, which may or may not illicit a response. The mixed response of the avian species tested with the AHD treatments indicated that without further experimentation, this tool would not be useful across a range of applications requiring dispersal of mixed communities of birds for management purposes, but rather for specific targeted applications involving vultures, gulls, or other potential species not tested in this project. Although our results do not rule out the efficacy of AHD methods for dispersal of birds, they do suggest that more research should be conducted if this tool is to be used for broad applications involving multiple species.

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