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A Sonic Net Excludes Birds from an Airfield: Implications for Reducing Bird Strike and Crop Losses

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A sonic net excludes birds from an airfield: implications for reducing bird strike and crop losses

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Abstract. Collisions between birds and aircraft cause billions of dollars of damages annually to civil, commercial, and military aviation. Yet technology to reduce bird strike is not generally effective, especially over longer time periods. Previous information from our lab indicated that filling an area with acoustic noise, which masks important communication channels for birds, can displace European Starlings (*Sturnus vulgaris*) from food sources. Here we deployed a spatially controlled noise (termed a "sonic net"), designed to overlap with the frequency range of bird vocalizations, at an airfield. By conducting point counts, we monitored the presence of birds for four weeks before deployment of our sonic net, and for four weeks during deployment. We found an 82% reduction in bird presence in the sonic net area compared with change in the reference areas. This effect was as strong in the fourth week of exposure as in the first week. We also calculated the potential costs avoided resulting from this exclusion. We propose that spatially controlled acoustic manipulations that mask auditory communication for birds may be an effective long term and fairly benign way of excluding problem birds from areas of socioeconomic importance, such as airfields, agricultural sites, and commercial properties.

Key words: acoustic deterrent; acoustics; airport; bird strike; communication; European Starling (Sturnus vulgaris); *noise pollution; predation risk; sensory ecology.*

Introduction

Collisions between birds and aircraft have serious negative impacts for birds and humans. Wildlife strikes may cost the United States civil aviation industry as much as $937 million (all dollar amounts shown in US$) annually and have caused 255 fatalities worldwide from 1988–2013 (Richardson and West 2000, Cleary et al. 2006, Thorpe 2012, Dolbeer et al. 2014). As air travel increases (Dolbeer 2013) in tandem with growing populations of birds in airport environments, there is a pressing need for developing measures to protect against bird strikes (Cleary and Dolbeer 2005, Lambertucci et al. 2015). The majority of these strikes occur at the level of the airfield, primarily during take-off and landing, which points to the airfield as a key location to be targeted by preventative measures (Dolbeer 2006).

Techniques to deter birds from airports include shooting, poisoning, live-capture and relocation, and the use of scare-technologies (Seamans et al. 2013). Capture and fatal methods are expensive and labor intensive and, thus, have not been considered sustainable methods of deterring birds (DeVault et al. 2013). Most technologies used to scare birds have not been successful at consistently keeping birds away because species tend to habituate to devices, such as propane-powered cannons, that produce loud noises (Washburn et al. 2006, Belant and Martin 2011). Similarly, it has been proposed that birds quickly learn that playback of predator vocalizations, or conspecific alarm or distress calls, do not pose a real threat if there is no negative reinforcement paired with the stimuli (Baxter and Allan 2008, Cook et al. 2008).

From the perspective of avian conservation, collisions with aircraft can pose a threat to migratory and resident birds. This threat is increasing because airports are often surrounded by habitat that attracts and supports birds, such as wetlands and open fields, and the availability of such suitable habitat is generally declining, thus potentially concentrating bird populations to the available habitat in and near airports (DeVault et al. 2013). Substantially changing the habitat around airports to

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support fewer birds would have significant environmental and economic costs and, thus, may not be a sustainable solution to limiting bird strike (Blackwell et al. 2009, 2013). Ideally, efforts to minimize the risk of bird strikes would also benefit bird species.

Birds' ability to habituate to current nonlethal tactics of biosonic playback (alarm, distress, predators' calls) demonstrates the need for the development of other techniques that birds are less likely to ignore. Though visual animals, most birds employ acoustic communication to determine many aspects of their ecology, including foraging, social structure, territoriality, and mating (Marler and Slabbekoorn 2004). Notably, human-generated noise, such as traffic noise or noise from machinery, results in the displacement of some bird species from localities, especially when birds' communication overlaps in frequency range with the anthropogenic noise (Francis et al. 2009, 2011, Goodwin and Shriver 2011). Additionally, environmental noise appears to decrease the fitness of many avian species (Klump 1996, Barber et al. 2010, Kight et al. 2012) and some bird species appear to select habitat to maximize transmission and reception of acoustic signals (Wiley and Richards 1982, Wiley 2006).

By integrating knowledge of previous research assessing the effects of human-generated noise on birds (Kight and Swaddle 2011, Francis and Barber 2013) and of birds' sensory ecology, we hypothesized that deliberately introduced noise, which overlaps with the frequency range of avian communication, could be used to deter birds from airports and other socioeconomically important areas (Mahjoub et al. 2015). We used a sports stadium directional speaker to broadcast pink noise from 2 to 10 kHz (which we term a "sonic net"), thus overlapping largely with the acoustic space in which most birds vocalize (Marler and Slabbekoorn 2004), over an airfield site and monitored changes in avian abundance and species richness for four weeks. These changes were compared to four weeks of pre-noise baseline observations, and point counts from two neighboring reference areas that did not receive the noise treatment.

Previously our group explored the efficacy of the same type of sound to deter European Starlings (*Sturnus vulgaris*) from food patches in a large aviary (Mahjoub et al. 2015). The European Starling ranks in the top five problem species for aircraft collisions (Dolbeer et al. 2014) and is also a major crop-consuming pest species for agriculture (Pimentel et al. 2005, Linz et al. 2007). In our previous study, deployment of a sonic net reduced foraging by almost 50%, over several days. Moreover, starlings experiencing the sonic net showed reduced responses to playback of alarm calls in the sonic net treatment as compared to control treatments, suggesting that the sonic net masks the signaling space of starlings and diminishes their ability to gather acoustic information from the environment (Mahjoub et al. 2015).

Given that our previous study showed displacement of starlings in captivity, in the current study we sought to determine the sonic net's efficacy at displacing and deterring wild birds from an airfield. We predicted that the noise treatment would reduce bird abundance and species richness at the affected sites. By reducing bird abundance, our sonic net technology could reduce the potential risk to passengers and aircraft, and further reduce the costs of repair and maintenance to aircraft. Using a database from 24 years of bird strikes on aircraft, we estimated the sonic net's effective cost reduction in terms of avoided damage, calibrated to the species we observed in our sites. We predicted that our sonic net treatment would lead to a reduction in this cost calculation.

Methods

Study site

We performed the study at three sites of approximately equal size, each ~0.5 ha, at an active airfield near Newport News, Virginia, USA (37°08′09″ N, 76°36′41″ W). All sites were within 100 m of the nearest neighbor and contained short mown grass close to a runway and service road. There was no other vegetation on these sites and little topography, which is typical of habitats close to runways at many airports. The middle of these three sites received a long-term sound manipulation, whereas the other two sites were designated as reference sites (Fig. 1).

Bird point counts

We conducted four 30 min bird point counts per week at each site, for eight consecutive weeks. Within a single week, two of the four point counts were conducted in the morning (07:00–09:00) and two in the afternoon (15:00–17:30). The order of site point counts was randomized each day and no point counts were performed on days of heavy rain. Prior to each point count we recorded wind speed, wind direction, and air temperature with a handheld weather station (Kestrel 3000; Kestrel, Birmingham, Michigan, USA). During a point count, a single observer continuously scanned a site, with the aid of binoculars, and recorded the species identity and location of every bird that landed in or flew over (within 20 m of the ground) the focal site for the 30-min period. We counted birds that flew over each site because flying birds pose risks to aircraft and our noise field spread vertically as well as horizontally (see following sections). As the habitat was completely open and flat, with no visual barriers, we are confident we observed almost all birds that were present during each point count. The observer was standing still at least 25 m from the closest part of a site and so was unlikely to have significantly disturbed the birds in the focal site. From the point count observations we generated metrics of total bird abundance

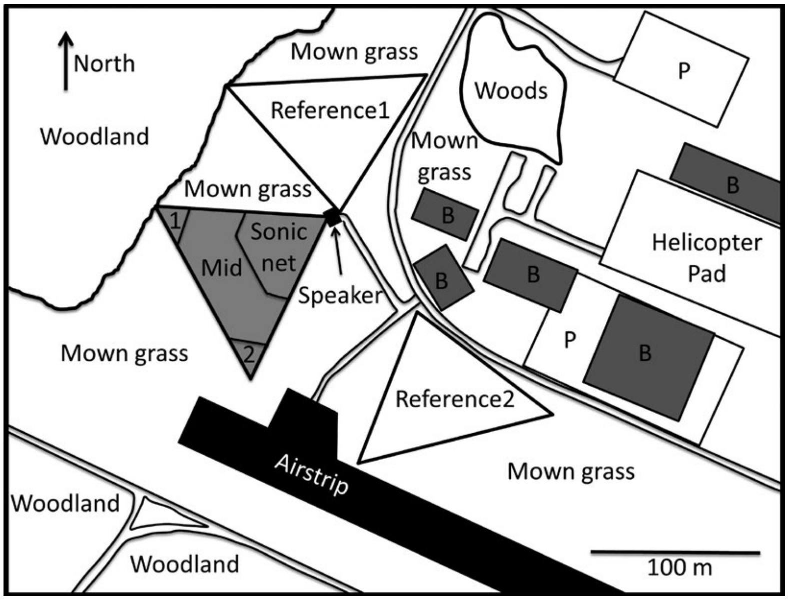

FIG. 1. Schematic of study sites. The Reference 1 and Reference 2 areas did not experience additional noise. The sonic net area experienced a loud 2–10 kHz sound broadcast through a speaker. The mid area experienced lower amplitude of the same sound (Methods). Areas 1 and 2 were counted as extensions of the relevant reference areas, as the amplitude of the experimental sound was quiet in these areas. B represents buildings, and P represents parking lots.

and species richness, for each site on each day of observation.

Sonic net treatment

Before we conducted any of the point counts we installed a large outdoor speaker and amplifier (Technomad Berlin loudspeaker with Chiton amplifier; Technomad, South Deerfield, Massachusetts, USA) adjacent to our central (of three) sites. The speaker was mounted on a tripod and surrounded with sound reflecting walls on three sides so that it broadcast a noise mostly in one cardinal direction, directly on to the intended site and not the other two (Fig. 1). After the end of week 4 we turned the speaker on, so that it broadcast 2–10 kHz pink noise that was amplified to maintain a reasonably high-amplitude sound across most of the target site (Fig. 1). This sonic net was maintained uninterrupted 24 h a day from the end of week 4 to the end of week 8.

At the end of week 8, after all point counts were completed but before the speaker was turned off, we recorded ambient sound pressure levels (Extech 407730 digital sound meter, using A weighting; Extech, Waltham, Massachusetts) every 10 m through all three study sites to confirm how the sonic net spread through the habitat. We found that our target site was affected by the sonic net but the sound pressure levels decreased more rapidly than expected with distance from the speaker, such that the entire site did not experience the full sonic net. We defined the sonic net area by a sound pressure level greater than 80 dB SPL (decibel of sound pressure level), a "mid-noise" area by a sound pressure level between 65 and 80 dB SPL, and two small "non-affected" areas by a sound pressure level below 65 dB SPL (Fig. 1). Each of the non-affected areas was treated as an extension of the adjacent reference sites in analyses, as these areas did not experience the intended sound manipulation even though they were within the central target site.

Estimation of costs to aviation

As we sought to apply our findings to the aviation industry, we generated a metric of the risk and cost of potential bird strike. The Federal Aviation Administration, US Department of Transportation, and US Department of Agriculture Animal and Plant Health Inspection Service, Wildlife Services produced a 24-year-long (1990–2013) database of wildlife strikes to aircraft. This database includes the species that strike aircraft, the likelihood of a strike causing damage, and the cost of that damage in terms of repairs and time down from flight. For each species we observed in our sites we gathered the data reported for the taxonomic family (or order when information was not specific to family) and calculated the reported cost divided by number of strikes, and then multiplied this value by the percent of strikes that caused damage. For example, in 24 years of entries in the database European Starlings accounted for 3348 strikes on aircraft, 116 of which caused damage (3.5%), but these 116 strikes caused \$6865043 of costs to the airline. Considering the percentage of strikes that cause damage, we calculated the potential cost of a starling bird strike to be $2050 on average. We performed similar calculations for all species observed during our study. We then multiplied the potential cost per bird family by the number of birds observed on each site before and during the noise treatment and measured the effect size of cost reduction in the noise sites as compared to the reference sites per observation.

Statistical analyses

Weeks 1–4 were considered before treatment, while weeks 5–8 were considered during the sound treatment. To test if bird abundance, species richness, and the potential cost of bird strikes were reduced by our noise treatments, we ran a difference-in-difference Poisson regression model which measures the effect size of the treatment by comparing the before to during treatment time periods and comparing the size of this change to the changes in reference sites and generating a resultant net effect size (Rosenbaum 2010). Poisson distributions are appropriate for count data and data sets that include multiple zeros or are right-skewed. To determine if the effect was persistent over the four weeks of treatment, we performed t tests comparing abundance in week 5 to weeks 6–8. Statistical analyses were performed using R (R Development Core Team) and t tests were performed in SAS 9.4 (SAS Institute Incorporated 2013). All tests were interpreted using two-tailed tests of probability.

Results

Bird abundance

Our model showed a large decrease in mean bird abundance in both the sonic net and mid-noise sites during the sound treatment as compared to before, and in comparison to the two reference areas (Fig. 2, Poisson regression sonic net log-coefficient = −1.79, standard error [SE] = 0.11, $Z = -15.9$, $P < 0.001$; mid-noise log-coefficient = −0.491, SE = 0.11, $Z = -4.36$, $P < 0.001$). For the two reference sites, there were no notable differences between the two time periods (before and during sound playback): the mean abundance in reference site 1 showed a slight increase from the first four weeks to the second four weeks, while the mean abundance in reference site 2 stayed roughly the same throughout the eight weeks. Overall, the effect sizes associated with the sound deployment indicated that there was an 82.3% reduction in bird abundance in the sonic net area and a 65% reduction in the mid-noise area. Additionally, this effect persisted from the beginning of the deployment of the sonic net throughout the four weeks of

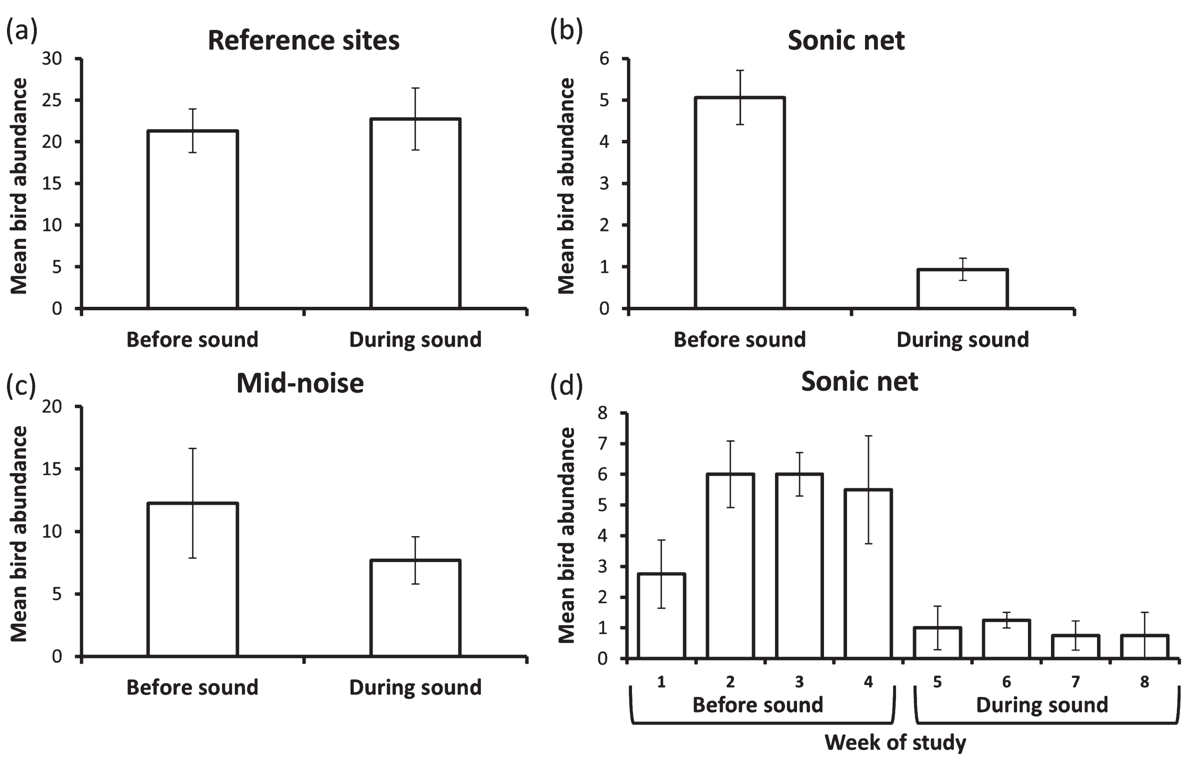

Fig. 2. Mean (± standard error [SE]) bird abundance per 30 min point count, before and during sound treatment. (a) The two reference sites showed no change in bird abundance from before to during the sound treatment. However, both the (b) sonic net and (c) mid-noise treatment sites showed reductions in bird abundance when the sound treatment was broadcast over the sites. (d) The reduction in bird abundance at the sonic net site remained consistent during the four weeks of sound treatment.

sound treatment; observations in the first week of sound treatment did not differ from subsequent weeks (Fig. 2d; t tests, $P > 0.75$, in all cases).

Focusing in on the bird families and species observed across the study sites, we observed that the sonic net was particularly effective at deterring a number of problem species associated with high risk and costs of bird strike. A few problem species were uncommonly observed in our study site. Only 22 individual gulls and terns were observed at our study site, and the vast majority of these were observed in the reference sites, except for five recorded in the mid-noise site, only two during the noise treatment, while none were observed in the sonic net site. Common species within the study site included members of the Hirundinidae, Icteridae, and Sturnidae families. In the sonic net area, the Barn Swallow *Hirundo rustica* showed a net reduction effect of 44.0%, measured as the difference between the change in abundance from before to during noise exposure in the sonic net site compared with the same change in the reference sites. The various icterid species (Eastern Meadowlark *Sturnella magna*, Common Grackle *Quiscalus quiscula*, Red-winged Blackbird *Agelaius phoeniceus*, Orchard Oriole *Icterus spurius*, and Brown-headed Cowbird *Molothrus ater*) were completely excluded from the sonic net site, but a concurrent drop in abundance was also observed in the reference sites resulting in a net effect of 46.2% reduction of icterids. Most notable, during the four weeks of noise exposure, a large flock of European Starlings (a high-risk bird strike species) came in to the study area. While abundance in reference sites increased from 249 to 372 individuals, a nearly 50% increase, both the mid-noise and sonic net sites showed a decrease in starlings of 34.7% and 91%, respectively.

Species richness

Deployment of the sound treatment reduced species richness in the sonic net area compared with the two reference sites (Poisson regression sonic net log-coefficient = −1.00, SE = 0.158, $Z = -6.36$, $P < 0.001$). Overall, there was a 75% reduction in the number of unique species observed in the sonic net area. This finding, however, is greatly tied to the decrease in abundance seen in the sonic net treatment site. The average species richness in the mid-noise site was lower during the noise treatment as compared to before, but this difference was not close to statistical significance (i.e., $P > 0.05$) ($Z = 0.57$, $P = 0.568$).

Potential cost of bird strike

Both the sonic net and mid-noise treatments reduced estimated costs due to bird strike risk, at least according to the way we estimated the costs of bird strike (sonic set, Poisson coefficient = −3.24, SE = 0.03, $Z = -96.3$, $P < 0.001$; mid-noise: Poisson coefficient = −0.398, SE = 0.03, $Z = -11.8$, $P < 0.001$). In terms of US dollar calculations, we found a reduction from a potential cost of $4526 per half hour to only $162 with the use of the sonic net. In other words, use of the sonic net showed the potential to reduce cost by 96.4%, and for the mid-noise treatment we calculated a cost reduction of 39.0%.

Discussion

Our results show that deliberately introduced noise led to clear reductions in the abundance of birds and a concomitant decrease in the potential costs associated with bird strike. A large proportion of the birds in both the sonic net and mid-noise treatment sites, relative to the two reference sites, were displaced after the speaker was turned on. The effect sizes indicated an 82% reduction in bird abundance in the sonic net area, and a 65% reduction in the mid-noise area.

Should the detection of birds near the airfield lead to bird strike on aircraft, we estimated the cost associated with bird strike based on the numbers and species of birds observed in each site. Our estimates follow from reports of costs associated with strikes over the last 24 years (Dolbeer et al. 2014), and probability that a strike would lead to damage. Other studies have similarly estimated the cost of bird strike and of bird strike prevention techniques (Allan 2000) and the cost of assessing risk of individual species to aviation (Dolbeer et al. 2000). The effect sizes generated by our analyses suggest a reduction in the costs of bird strike to potentially exceed 95% in the sonic net area, and to reach almost 40% in the mid-noise area.

Notably, the observed reductions in bird abundance persisted throughout the four weeks of sound deployment. The observation that birds did not habituate or acclimate to our sound treatment stands in contrast to results from other auditory techniques such as "startle" devices or biosonic playback of predatory, alarm, or distress calls. We reason that birds are unable to acclimate to the sonic net stimulus because of the almost complete communication-masking effect of the noise (cf. Mahjoub et al. 2015). There may be little birds can do to adjust their hearing to accommodate for the background noise that we played in our study. Additionally, the (fitness) costs to the birds of disrupted communication may be much larger than the cost of a short-term response to a startle stimulus. Hence, we believe that our method of disrupting communication is more effective, in the longer term, at consistently displacing birds than direct startle stimuli.

There is growing evidence that broad-spectrum noise masks communication for birds. Our lab group has previously reported that a 2–10 kHz noise causes acoustic masking for European Starlings, who subsequently increase their vigilance behaviors (Mahjoub et al. 2015). Similarly, Chaffinches (*Fringilla coelebs*) exposed to a broad spectrum white noise increased aspects of vigilance while foraging in captivity, and did not habituate to this noise over several trials (Quinn et al. 2006). Taken together, these studies suggest at least one mechanism that may cause the displacement of birds under the sonic net; we propose that the sonic net treatment increases birds' perceived predation risk. In an open field setting, such as the airfield habitat in this study, birds may assess the habitat covered by the sonic net as too risky to inhabit because of their compromised abilities to detect alarm calls or predator noises. If birds persist in an area with increased predation risk, theory predicts that foraging efficiency will decline as there is often a trade-off between the quality of vigilance and foraging activities in many birds (Lima and Bednekoff 1999). Hence, we expect our sonic net treatment to reduce pre- and post-harvest crop losses in agriculture beyond any direct displacement of birds from agricultural sites.

General communication masking may also contribute to the strong displacement effects we report here. In addition to warning individuals of potential predators, birds' vocalizations serve a number of other fitness-related functions, including mate choice, territory defense, social coordination, and group foraging (Marler and Slabbekoorn 2004). As a consequence, bird species that rely on acoustic signals likely choose to occupy habitats that minimize acoustic masking, as masking will degrade the efficacy of vocal signals (Wiley and Richards 1982). For example, in an experiment conducted at sites near noisy natural gas-extraction infrastructure, species such as Mourning Doves (*Zenaida macroura*) and Black-headed Grosbeaks (*Pheucticus melanocephalus*), which vocalize at low frequencies, were more likely to avoid noisy sites with low-frequency noise (Francis et al. 2009, 2011). Additionally, in a study of parks south of Washington, District of Columbia, USA, Goodwin and Shriver (2011) found that two birds species with vocalizations in the frequencies overlapped by traffic noise were 10 times less likely to occupy areas affected by traffic noise. When noise is experimentally altered in the environment, we see the same effects; birds that rely on vocal communication will often leave the noisiest areas (McClure et al. 2013, McLaughlin and Kunc 2013). Thus, we propose that we observed a large decrease in abundance of birds in the experimentally noise-affected areas, in part, because of acoustic masking generated by the 2–10 kHz sound broadcast in to these areas. This bandwidth is so broad in comparison with bird song that it is highly unlikely that most bird species could move their communication channels out of this range, hence reducing the likelihood of acoustic accommodation to the sonic net.

In conclusion, we have demonstrated that a broadband noise treatment, that is designed to mask avian acoustic communication, can exclude birds from an airfield site for at least four continuous weeks, albeit at a limited spatial scale. The effectiveness of our sonic net technology may also vary among sites and avian communities, hence it will be important to expand this initial study to multiple locations and note the effects on a more expansive range of avian fauna, including geese and gulls that were largely absent from the airfield we studied. Future studies will aim to deploy an array of speakers to explore whether the effects reported here can scale to a whole airport and decrease the incidence of bird strike. It is important to note that the amplitude of sound must be maintained in excess of 65 dB SPL (somewhat equivalent to the noise of a conversation in a busy restaurant), but preferably greater than 80 dB SPL (somewhat equivalent to the noise generated by a domestic dishwasher), to observe the effects we report here. These factors should determine how many and what types of speakers must be deployed over an area to reduce bird abundance. In a previous study (Mahjoub et al. 2015), we used a very directional speaker that can target sounds at a specific locality. By blending highly directional with somewhat omnidirectional speakers it is possible to cover large areas of target habitat without introducing extraneous noise pollution outside of intended areas. Given the magnitude of our results, and the parallels with captive testing (Mahjoub et al. 2015), we feel this technology has great potential to reduce problems of bird strike and crop-reductions associated with pest birds.

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