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A Sonic Net deters European starlings Sturnus vulgaris from maize silage stores

John P. Swaddle

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RESEARCH ARTICLE

A Sonic Net deters European starlings *Sturnus vulgaris* from maize silage stores

Richard D. Woods[1] | **John P. Swaddle**[2] | **Stuart Bearhop**[3] | **Kendrew Colhoun**[4] | **William H. Gaze**[5] | **Suzanne M. Kay**[1] | **Robbie A. McDonald**[1]

[1]Environment and Sustainability Institute, University of Exeter, Penryn, Cornwall, TR10 9FE, UK

[2]Institute for Integrative Conservation, William & Mary, Williamsburg, VA 23187, USA

[3]Centre for Ecology and Conservation, University of Exeter, Penryn, Cornwall, TR10 9FE, UK

[4]KRC Ecological Ltd., 33 Hilltown Road, Bryansford, Northern Ireland, BT33 0PZ, UK

[5]European Centre for Environment and Human Health, University of Exeter, Penryn, Cornwall, TR10 9FE, UK

Correspondence

Robbie A. McDonald, Environment and Sustainability Institute, University of Exeter, Penryn, Cornwall, TR10 9FE, UK.
Email: R.McDonald@exeter.ac.uk

John P. Swaddle, Institute for Integrative Conservation, William & Mary, Williamsburg, VA 23187, USA.
Email: jpswad@wm.edu

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Abstract

Deterrents against avian pest species might be more effective if they were based on some aspect of the target species' sensory salience. Sonic Nets broadcast a loud and spatially-focused pink noise that spans the frequency range of the target species' vocalizations, restricting interspecific communication so that it is costly for birds to remain in the treated area. In parts of their native and introduced ranges, European starlings (*Sturnus vulgaris*) impact livestock operations where they consume and contaminate animal feed, damage infrastructure, and may contribute to pathogen transmission. We evaluated Sonic Net technology to exclude starlings from outdoor maize silage stores on 10 dairy farms in Cornwall, U.K. in February–March and November–December 2019. We quantified frequency of starling presence and approximate flock size and combined these to estimate starling burden in starling-minutes before, during, and after Sonic Net treatment. During an initial proof-of-concept trial, each phase lasted 2 days, whilst in a second, longer experiment, treatment lasted 14 days. During Sonic Net treatment, frequency of starling presence was reduced, flock sizes were smaller, and starling-minutes were reduced by 94% and 89% in the 2-day and 14-day treatments, respectively. In the last 2 days of the 14-day treatment, starling-minutes remained 85% lower than before treatment, but 4 of 10 farms experienced some diminution of effects after 6 days. Sonic Nets had a significant and sustained effect, with potential for deterring avian pests from agricultural and other settings.

KEYWORDS

acoustic masking, agricultural damage, deterrent, disease transmission, pest, sensory ecology, starling, *Sturnus vulgaris*

Avian pests inflict extensive damage to primary industries and although individual producers might suffer a variety of direct losses, pest infestations can have global socioeconomic and human health consequences (Allan 2006, Triplett et al. 2012, Mukerji et al. 2019). In agriculture, damage to crops is widespread and impacts are often greater when yields are poor (Lindell et al. 2016). Challenges occur in meat and dairy operations, where wild birds consume food intended for livestock, damage farm infrastructure, and spread pathogens affecting both livestock and humans (Pimentel et al. 2000, Triplett et al. 2012).

The European starling (*Sturnus vulgaris*) has, in some contexts, become a pest species, both within its native range, and in regions where it is an invasive, nonnative species (Barras et al. 2003, Linz et al. 2007). During the breeding season, native starlings live in low densities across their European range, from the northern Mediterranean coast to Scandinavia and eastern Russia. Many starlings are migratory and overwinter in regions, including southwest Britain, where they concentrate in large numbers from mid-October as migrant flocks arrive and add to resident bird populations (Shipton et al. 2013). Peak numbers typically occur in December–January, but large flocks persist until March. By day, starlings leave roost sites in flocks that can exceed 50,000 individuals and travel up to 40 km to foraging sites (Peach and Fowler 1989). Once prospecting flocks discover a plentiful food source, they will return if food remains available.

Starlings are not a new problem for farmers (Glahn et al. 1982), but their use of livestock farms has risen over recent decades (Shipton et al. 2013). Increased use of high nutrient maize (*Zea mays*) silage in cattle feed attracts starlings to bulk stores of such feed, and to cattle housing (Depenbusch et al. 2011), depleting the nutritional and energetic value of feed (Shipton et al. 2013). Starling droppings, as well as material on their feet and bills, may increase transmission of pathogens (Carlson et al. 2011, Cernicchiaro et al. 2012). Nutrient-rich and corrosive droppings can also damage infrastructure (Linz et al. 2007). Thus, the combined effects of feed-loss, pathogen transmission, and infrastructure damage (Linz et al. 2007, Carlson et al. 2011, Depenbusch et al. 2011, Cernicchiaro et al. 2012, Shipton et al. 2013) mean that starling impacts can substantially increase costs to producers. On dairy farms in the United Kingdom, an average starling infestation was found to cost £1.06/head/day (Shipton et al. 2013). In the U.S., a comparable figure of US$0.92/head/day was estimated at beef finishing operations (Depenbusch et al. 2011). Based on these estimates of costs, over the course of winter, affected farms with 100–1000 cattle stand to lose £10–100,000 or $8–80,000. Combining crop and livestock losses, starlings are estimated to cause $800 million in damage each year in the U.S. (Pimentel et al. 2000).

Mitigating damage by starlings and other pest birds can involve physical exclusion, capture, and lethal control, but these approaches are often impractical (Reiter et al. 1999, Shipton et al. 2013, Atwell 2014). Although use of auditory and visual deterrents is widespread (Bomford and O'Brien 1990, Avery and Werner 2017), many are subject to habituation, whereby repeated exposure to the stimulus, in the absence of real costs, reduces responses (Berge et al. 2007, Atwell 2014, Blumstein 2016, Lindell et al. 2018). Sonic Net is an acoustic deterrent that aims to overcome problems of habituation by imposing a real cost on target species through disruption of their acoustic communication (Mahjoub et al. 2015). Instead of a stimulus that pest birds might associate with a particular threat, Sonic Nets involve broadcast of noise with a frequency range encompassing the vocal range of the target species, at a sound pressure level sufficiently loud to mask vocal communication between individuals of the target species. Starlings' hearing range extends from 0.7–8.7 kHz, with peak sensitivity around 2 kHz, typical of many birds (Dooling et al. 1986, Beason 2004). The frequency range of starling vocalizations is 0.25–12.0 kHz (Goller and Riede 2013), though most calls, including predator alarm calls, fall within the 3–9 kHz (Feare 1984). In aviary trials, treatment with a Sonic Net reduced starling presence by 46%, reduced foraging time by ~55%, and food consumption by 45%, compared to untreated controls (Mahjoub et al. 2015). Within the Sonic Net treatment area, starlings did not respond to conspecific alarm call playbacks, whereas they did show vigilance responses where the deterrent's frequency range did not match their vocalization frequencies (Mahjoub et al. 2015). In a larger, ~0.5 ha, airfield trial, Sonic Net treatment reduced wild starling abundance by 91% relative to nearby reference sites, with no habituation detected during the 4-week trial (Swaddle et al. 2016). Sonic Nets also reduced damage caused by blackbirds (*Agelaius phoeniceus*) to 3 sunflower plots of 0.2 ha by 38.3%, relative to control plots (Werrell et al. 2021).

Notwithstanding evidence of the Sonic Net's success thus far, in a farm setting food can be unusually abundant, and there could be a trade-off where birds may be more tolerant of the cost of staying within a Sonic Net in order to benefit from access to rich food resources. To explore whether a Sonic Net can displace starlings in such a challenging setting, we tested its effectiveness in deterring starlings from outdoor stores of maize silage on dairy farms in England where farmers reported major starling problems.

STUDY AREA

Our study took place at outdoor stores of maize silage, known as clamps (Figure 1), on 10 dairy farms in 2 areas of Cornwall, U.K (annual daily high temperature 13°C, average annual precipitation 742 mm). Five farms were in Penwith (50°06′46.8″N 5°37′22.8″W), and 5 were ~75 km away, near Bodmin Moor (50°31′27.2″N 4°46′27.6″W). Distances between each farm and its nearest participating neighbor ranged from 0.8km to 10.6 km ($\bar{x}$ = 4.1 km). There are high levels of site fidelity for starlings foraging on livestock feed stores, with individuals typically venturing ≤5 km from a preferred foraging site (Homan et al. 2010). Possible movement of birds between nearby farms (≤5 km) was addressed by simultaneous initiation of treatments. Due to logistical constraints, 2 farms in the proof-of-concept experiment were not used in the longer experiment but were replaced with similar farms in the same locality.

FIGURE 1 Starlings foraging on a maize silage clamp on a dairy farm in Cornwall, U.K., February 2019. Clamps typically have earth, concrete or timber walls on 3 sides. Silage is piled in the clamp, compressed, and protected under weighted covers. Covers are peeled back incrementally, enabling mechanical extraction of feed, but incidentally enabling access by starlings and other birds.

METHODS

We attempted to deter starlings from maize silage clamps where they had free access to the exposed face of the silage (Figure 1). We performed an initial proof-of-concept trial with 2 days of treatment in February–March 2019, and a longer trial of durability with 14 days of treatment the following winter in November–December 2019. Based on effects in the earlier aviary (46%) and airfield (91%) trials, we predicted that starling abundance on silage clamps would be reduced by ~80%, which accounts for the high value of silage clamps as food patches relative to the surrounding landscape, potentially leading wild starlings to accept more risk (Swaddle et al. 2016). In both experiments, all 10 trials were started within 4 consecutive days. We ensured minimal lag (<20 minutes) between start times for farms ≤5 km apart to reduce the likelihood that displaced starlings might fly to another participating farm where the Sonic Net had not yet been initiated. The starlings in the study were free-living and able to move in and out of study sites at any time.

Sonic Net setup

We created a Sonic Net using a custom-made loudspeaker to produce a targeted region of sound from 2–10 kHz that covered the exposed front face of each silage clamp with a sound pressure level (SPL) of at least 80 dBA (Dieckman et al. 2013, Mahjoub et al. 2015). Loudspeakers were made by combining a Faital Pro HF100 compression driver with a Faital Pro WG101 plane wave guide (Faital, Milan, Italy), mounted within a sealed plastic container. A Sandisk Clipsport MP3 player (Western Digital, San Jose, CA, USA) was linked to an SMSL SA-98E amplifier (Foshan ShuangMuSanLin Technology, Shenzen, China) connected via weatherproof cables to the loudspeaker. The weatherproof loudspeaker emitted sound at the frequency range and sound pressure level (SPL) required, focused in a vertically narrow (10°) and horizontally wide (140°) dispersion pattern. The planar dispersion pattern allowed sound to be focused on the wide and low (Figure 2) face of the silage clamp, whilst reducing noise spilling into surrounding areas. Escaping noise was further limited on 3 sides by the clamp's enclosed structure, and by the sound-absorbing properties of the silage itself. The loudspeaker was positioned on one of the sidewalls of the clamp at a distance from the exposed face of the silage that was adjusted (5 to 8 m) for each clamp, such that the minimum amplifier power was used that produced a minimum 80 dBA SPL at all points on the silage face. The SPL measurements were taken using an Extech Instruments 407730 Sound Level Meter (Extech, Nashua, NH, USA).

Image capture and quantification of starling activity

Observations of birds were made using Bushnell Natureview HD 12 MP trail cameras (Bushnell, Kansas City, KS, USA) set to take one image of the exposed silage face every 5 mins between 0700 and 1700 (approximate dawn and dusk), ensuring we obtained images when starlings were likely to be feeding. Ambient lighting varied due to time of day and weather conditions, which affected the visibility of starlings, potentially adversely affecting flock size estimation. In addition, changing weather conditions, as well as movements of objects (e.g., farm machinery, livestock) visible in the periphery of images, provided information about treatment phase, which could have biased the quantification process. To mitigate the potential effects of variation in conditions, images were cropped as much as possible, whilst preserving the exposed face of the silage, and their contrast and saturation were enhanced and equalized to improve identification of starlings and reduce association of lighting conditions with experimental phase.

From each image, we derived 3 measures of starling activity: frequency of starling presence, flock size category and overall starling-burden. Frequency of starling presence was a simple proportion of photographs in which starlings were present. For flock size, preliminary analyses indicated that identifying and counting individuals in dynamic flocks and low light conditions were not generally possible. Automated counts using image analysis software also proved unreliable due to variable light conditions and the frequent overlap of adjacent starlings. Thus, for images where starlings were present, we

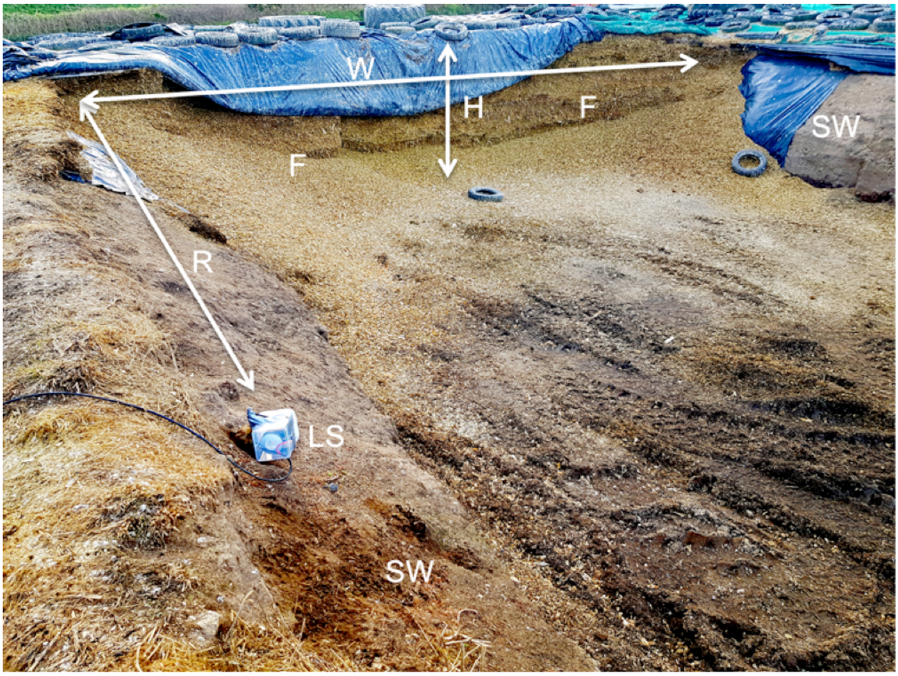

FIGURE 2 Example of Sonic Net loudspeaker setup in a silage clamp on a dairy farm in Cornwall, U.K., February 2019. The loudspeaker (LS) is positioned below the inside edge of the sidewall (SW) of the clamp at a range (R) from the exposed face (F) of maize silage. Height (H) and width (W) of the exposed face of silage varied between farms ($H = 3.75\text{ m} \pm 0.21\text{ m}$, $W = 11.58\text{ m} \pm 0.74\text{ m}$).

categorized each into 1 of 6 ranked flock size categories based on estimated number of starlings, on an approximately logarithmic scale (1–5, 6–30, 31–100, 101–200, 201–400, and 401–1000). Categories were based on maximizing the repeatability of categorization by a single observer (RDW). Overall starling burden was quantified by combining an estimate of the time starlings spent on the clamp, intervals between images, and flock size category. We multiplied the time between consecutive images by the mid-point of the flock size category for each image. For example, an image with flock size category of 31–100 starlings was converted to starling-minutes by multiplying the mid-point of that category (66 starlings) by the time between images (5 minutes), resulting in an estimate for that image of 330 starling-minutes. To ensure flock size categorization was blind with respect to farm and phase, image filenames were randomized and images presented for categorization in random order. Following categorization, images were unblinded and reassigned to farm and phase.

Proof-of-concept experiment

We used a reversal design where observations of starling activity on each clamp were recorded for 3 sequential 48-h phases: before (Sonic Net off), during (Sonic Net on) and after (Sonic Net off again) treatment. We first tested whether the Sonic Net affected frequency of starling presence by fitting a generalized linear mixed model (GLMM) with the daily proportion of images with starlings present as the response, weighted by the number of images taken, treatment phase as a fixed effect, farm as a random effect and a binomial error structure. Second, we tested whether the Sonic Net affected flock size, to assess the possibility that within the Sonic Net starlings formed larger flocks, potentially to mitigate predation risk. Using data for images where starlings were present, we used a GLMM with daily median flock size category at each farm as the response term, treatment phase as a fixed effect and farm as a random effect. Finally, we examined whether the Sonic Net had an overall effect by fitting total daily starling burden in starling-minutes, as the response term in a GLMM, with treatment phase as a fixed effect, farm as a random effect and, after initial checking of residuals, a negative binomial error structure.

Durability experiment

We followed a similar protocol as the proof-of-concept experiment, with the exception that the Sonic Net treatment phase (during) was extended to 14 days. Before and after phases remained at 2 days each. For the 14-day trial, we focused on starling burden and created 3 models to analyze variation in efficacy over the course of this longer trial. First, we calculated the mean daily starling burden for each phase at each farm and fitted this as the response term in a GLMM using a negative binomial error structure, with treatment phase as a fixed effect and farm as a random effect. Second, we tested whether the Sonic Net was still deterring starlings towards the end of treatment by using a subset of the data that included the whole of the before and after phases, but only the last 2 days during Sonic Net treatment. We fitted a GLMM as specified above. Third, we examined changes in starling burden over the 14 days of the treatment phase only. A subset was created containing only data collected during Sonic Net treatment and log-transformed daily starling burden for each farm was fitted as the response term in a GLMM, with day (1 to 14) fitted as a repeated factor, farm as a random effect, an autoregressive correlation structure (to account for temporal autocorrelation), and a Gaussian error structure.

Data were analysed using R (v. 4.1.2; R Core Team 2021). Models were created with package lme4 (v1.1-21; Bates et al. 2015) and package glmmTMB (v1.0.1; Magnusson et al. 2020). Full models were compared to null models using the Akaike information criterion (AIC). Significance of explanatory variables was calculated using function pamer.fnc in LMERConvenienceFunctions (v2.10; Tremblay and Ransijn 2015). Contrasts within GLMMs were estimated using package emmeans (v1.3.3; Lenth et al. 2019).

RESULTS

Proof-of-concept experiment

The Sonic Net significantly reduced the frequency of starling presence ($F_{2,47} = 111.2$, $P < 0.001$), reduced the sizes of starling flock size categories ($F_{2,32} = 3.945$, $P = 0.029$), and reduced total daily starling burden ($\chi^2_2 = 62.23$, $P < 0.001$) on maize silage clamps (Figure 3A–C). Mean frequencies of starling presence were reduced by an average of 88% during Sonic Net treatment, compared to both before ($Z = 14.69$, $P < 0.001$) and after ($Z = 14.23$, $P < 0.001$) treatment. After cessation of treatment, starling flocks returned to pre-treatment conditions and there was no difference in the frequency of starling presence before and after treatment ($Z = 0.869$, $P = 0.660$). Flock sizes were reduced, with a daily median flock size category of 6–30 starlings during treatment, compared to 31–100 starlings both before ($Z = 2.498$, $P = 0.033$) and after ($Z = 2.781$, $P = 0.015$) treatment. There was no difference in median flock size categories before and after treatment ($Z = 0.703$, $P = 0.762$). Sonic Net reduced starling burden, measured in starling-minutes, by an average of 94% during treatment, when compared to before ($t_{54} = 7.84$, $P < 0.001$) and after ($t_{54} = 7.62$, $P < 0.001$). There was no difference in starling burden between before and after phases ($t_{54} = 0.54$, $P = 0.852$).

Durability experiment

Sonic Nets significantly reduced daily starling burden ($\chi^2_2 = 339.1$, $P < 0.001$; Figure 4A) over the 14-day treatment. Mean daily starling burdens during treatment were 89% lower than before ($t_{24} = 18.40$, $P < 0.001$) and 80% lower

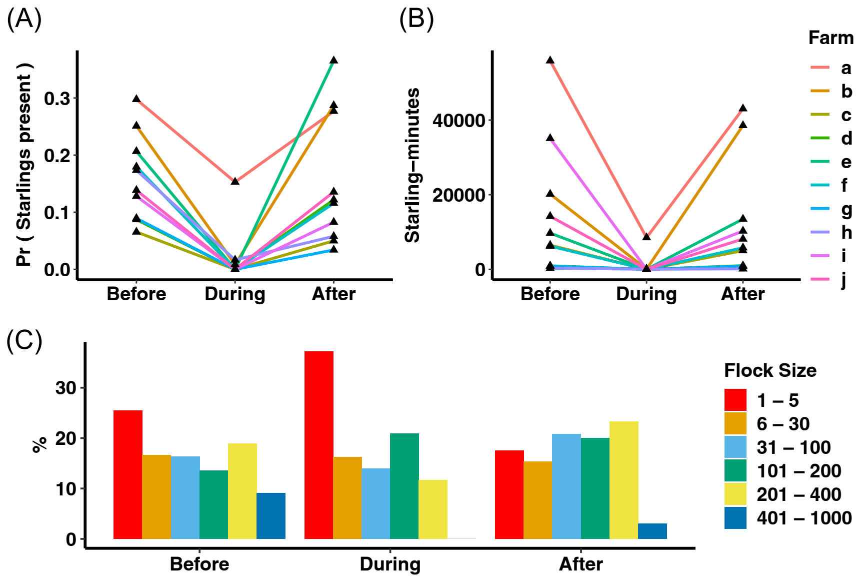

FIGURE 3 Effects of Sonic Net treatment on 3 measures of starling activity on maize silage clamps over 3 phases before, during, and after treatment with Sonic Net for 48 hours, on 10 dairy farms in Cornwall, U.K., February–March 2019. A) Frequency of starling presence. Triangles show proportion of images where starlings were present. B) Starling burden, measured as starling-minutes. Triangles show mean daily total for each phase. For both panels A and B, colored lines link data for each farm. Farm a was an outlier where, due to a technical fault, the sound pressure level of the Sonic Net was low for part of the time during treatment. C) Frequency distributions of starling flock size categories. Columns show the percentage of flocks of different size categories in each phase.

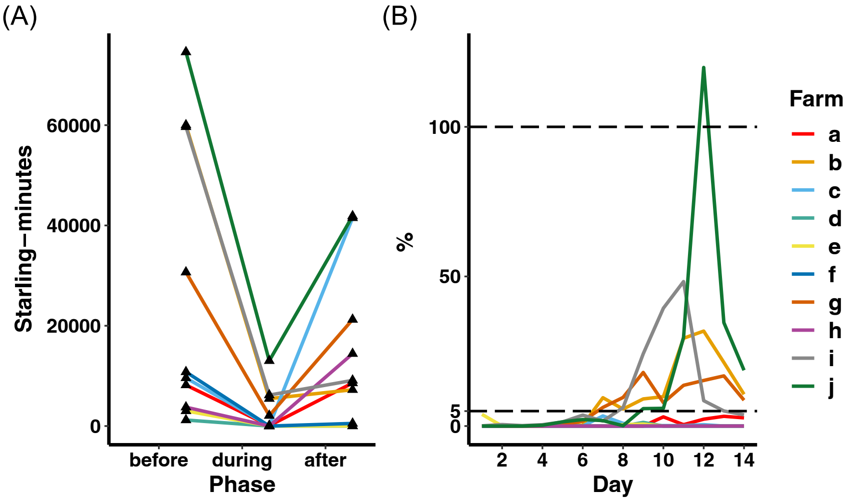

FIGURE 4 Effects of 14 days continuous treatment with a Sonic Net on starling burden at maize silage clamps on 10 dairy farms in Cornwall, U.K., November–December 2019. A) Starling burden, measured in starling-minutes. Triangles show mean daily total for each phase. B) Starling burden for each day during Sonic Net treatment, measured as starling-minutes and expressed as a percentage of mean daily starling-minutes before treatment. For both plots, colored lines show data for individual farms.

than after ($t_{24} = 7.317$, $P < 0.001$) treatment. Following cessation of Sonic Net treatment, the effect of treatment on starling burden continued, but was diminished, and daily starling-minutes were 54% lower in the 2 days after treatment than before ($t_{24} = 6.243$, $P < 0.001$). Post hoc comparison showed that farms with higher starling burdens before treatment were associated with lower percentage decreases in starling burden during Sonic Net treatment (Kendall's tau test, $r_\tau = 0.63$, $P = 0.011$). Flock size category was significantly reduced ($F_{2,14} = 9.514$, $P = 0.003$), to a median flock size category of 6–30 starlings during 14 days of Sonic Net treatment, compared to 101–200 starlings both before ($Z = 4.063$, $P < 0.001$) and after ($Z = 3.488$, $P = 0.001$) treatment. There was no difference in median flock sizes before and after treatment ($Z = 0.459$, $P = 0.890$). When the analysis was limited to the last 2 days during treatment, the significant reduction in daily starling burden remained ($\chi^2_2 = 39.87$, $P < 0.001$) and mean daily starling burden for the last 2 days of treatment were 85% lower than before ($t_{52} = 6.042$, $P < 0.001$) and 72% lower than after ($t_{52} = 3.076$, $P < 0.001$) treatment. During Sonic Net treatment only, there was no significant variation among days in starling burden ($\chi^2_{13} = 17.34$, $P = 0.184$). However, starling burden across the treatment period appeared to vary among farms (Figure 4B). For the first 6 days during Sonic Net treatment, daily starling burden was <5% of the daily average before treatment on all farms. Starling burden at 4 farms subsequently exceeded 5% of the daily average before treatment. On one farm starling burden surpassed the daily average before treatment on day 12 during treatment.

DISCUSSION

Our results show the Sonic Net to be highly effective in deterring European starlings from outdoor maize silage clamps, and that the deterrent effect is largely sustained over 14 days of continuous use. Starling burden, measured in our study as starling-minutes, is perhaps the most useful metric for farmers, as the amount of feed lost, or contaminated, is likely a function of the number of starlings present and the time they spend on the feed stores. The Sonic Net reduced starling burden in the treated area in both trials. The deterrent effect exceeded our predictions, and the 82% reduction observed in the earlier airfield trial (Swaddle et al. 2016). There was a notable outlier during treatment at one farm in the shorter trial, associated with a technical fault that reduced MP3-player output by ~50% mid-way through the trial. Because of the technical fault, the Sonic Net was only at full power for half of the treatment phase but there was still a reduction of about half (47%) in starling presence. Such a partial reduction is in line with Swaddle et al. (2016), where the mid-noise area, in which the Sonic Net was present but at a lower SPL of 65–80 dBA, showed 65% reduction in bird abundance, compared to 82% reduction in the full Sonic Net area.

Under Sonic Net treatment conditions, starlings were not only present less frequently, but when they were present, flocks tended to be smaller, dispelling the possibility that Sonic Net simply caused starlings to form larger groups. If the Sonic Net functions, as expected, by disrupting vocal communication within groups, and there is a plausible increase in acoustic information use with increasing group size (Freeberg et al. 2012), this could explain the smaller flocks observed during Sonic Net treatment. Highly social bird species have been shown to attend to various details of recruitment calls (McDonald 2012, Woods et al. 2018) that may be partly or totally masked by the Sonic Net, thereby reducing recruitment to flocks and overall flock size.

Overall, the results of the 14-day trial were in line with the 2-day trial. There was some evidence of a carry-over effect in the longer trial, where starling burdens were much lower after treatment than before. A carry-over effect implies that starlings deterred by the Sonic Net over an extended period did not return immediately once the Sonic Net was turned off. Analyzing starling burden in the last 2 days during treatment and comparing to phases before and after enabled us to test the durability of the deterrent effect. Mean daily starling burden for the late stage of treatment was still much lower than before and after treatment. The indication of a sustained deterrent effect is further supported by our analysis of daily starling burdens at each farm across the 14 days during Sonic Net treatment, where we found no significant variation associated with day of treatment.

Farm-level observations of individual farmers, however, suggest that treatment efficacy varied among farms; most remained far below pretreatment levels, but a minority showed increasing starling burdens as treatment progressed. Our post hoc testing showed that farms with higher starling burdens before treatment experienced smaller decreases in mean daily starling burden during treatment. Although reasons for between-farm differences in pretreatment starling burden are not the focus of this study, several factors may explain how higher initial burdens of starlings might reduce the durability of the Sonic Net. First, starlings were present on each farm before the trial, but starling groups that had been regularly visiting a farm for longer would have had more time to attract arriving migrants and become more habituated to local conditions, relative to starlings that began visiting a farm more recently. Second, each farm in the study had multiple resources frequented by starling flocks, often adjacent to the trial silage clamp. Resources consisted of trees or buildings for perching, sheltering, or roosting, but also included alternative food sources such as other feed clamps, livestock feeding areas, or undigested feed in slurry. Starlings utilizing these resources during Sonic Net treatment could have been subjected to low-intensity sound. Behavioral accommodation, whereby subjects adjust their behavioral routines in response to threats (Watson et al. 2018), may have allowed starlings experiencing a Sonic Net of reduced intensity to become progressively tolerant of its presence through reliance on mitigation behaviors, such as heightened vigilance (Mahjoub et al. 2015). Mitigation behaviors could have reduced their perceived predation risk when entering a full Sonic Net, enabling them to do so more readily than starlings with less experience of Sonic Net conditions. These potential temporal and spatial factors are difficult to quantify and discern. Consequently, further work is needed to understand whether a diminution in Sonic Net's effect might eventually happen at all farms, or whether Sonic Nets can be tailored around farm characteristics, to offer a lasting deterrent.

Cost-benefit assessments for Sonic Nets would require additional research beyond the scope of this study. The energetic or nutritional changes to maize silage due to starling damage have rarely been calculated (Shipton et al. 2013) or accurately linked to metrics of starling burden. Moreover, any downstream effects of Sonic Net treatment on milk yield or transmission of pathogens among livestock are not quantifiable from our data. However, the large reduction in starling burden during Sonic Net treatment is close to the maximum possible benefit from this technology, since prospecting flocks must land in the treatment area to experience the deterrent. Quantifying economic benefits from Sonic Nets to dairy farms would require extended whole-farm trials, comparing farm inputs and productivity to previous years and to similar, untreated farms.

Our study highlights the practical benefits of the Sonic Net approach. In no case did farm workers report any hindrance to working conditions. Sonic Net's efficacy meant that manual uncovering and covering of the silage face was often deemed unnecessary, saving labor. Clamp structure and our directional loudspeaker restricted encroachment of noise into areas where it might have been a nuisance to people or livestock. Since silage is typically collected using loading machines with a cab, Sonic Nets are unlikely to impact even the people working directly within them. Thus, our study suggests that carefully implemented Sonic Nets are unlikely to hinder daily routines on farms and may reduce the need for some manual tasks, improving worker safety and efficiency.

Although habituation to previous sonic deterrents has happened within a few days or even hours (Bomford and O'Brien 1990), none has occurred in previous Sonic Net studies (Mahjoub et al. 2015, Swaddle et al. 2016). Since the acoustic masking and resulting increased predation risk (Mahjoub et al. 2015) caused by Sonic Nets present a real cost to birds, we were surprised that, at some farms, efficacy declined after 6 days. The observed decline in efficacy requires further work to accurately diagnose and, if confirmed as an important issue, modifications to the Sonic Net could be tested. An intermittent, rather than continuous, Sonic Net could reduce potential for accommodation. The Sonic Net might best be triggered only when target species are present. Triggering would require a control module and sensors with acceptable specificity. If future iterations of Sonic Net treatments resulted in lasting displacement of starling flocks, strategies to reduce farm impacts may then be required that balance wider conservation concerns for the species (Robinson et al. 2006).

MANAGEMENT IMPLICATIONS

Sonic Nets were effective in reducing starling burdens on outdoor maize silage stores at dairy farms in Cornwall, England, by 94% and 89%, across 2-day and 14-day treatments, respectively. Sonic Nets could offer value as a deterrent on farms where stores of feed are vulnerable to damage from pest birds. Further trials should aim to explore and mitigate any declines in efficacy over time.

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CONFLICTS OF INTEREST

The authors declare the following financial interest, which may be considered as a potential competing interest: John P. Swaddle is a co-inventor of the Sonic Net and is named on the issued US patent (9,693,548 B2) that can be licensed for commercial opportunities related to this technology.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Zenodo data repository at https://doi.org/10.5281/zenodo.6948971.

ETHICS STATEMENT

Our study protocol was approved by the University of Exeter College of Life and Environmental Sciences Penryn Campus Ethics Committee (Application reference eCORN000089 v3.1).

ORCID

Robbie A. McDonald http://orcid.org/0000-0002-6922-3195

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