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A Sonic Net reduces damage to sunflower by blackbirds (Icteridae): Implications for broad-scale agriculture and crop establishment

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ABSTRACT

Blackbirds, such as red-winged blackbirds (*Agelaius phoeniceus*), are notorious agricultural pests and damage crops at multiple stages of growth. Our aim was to test a novel deterrent, the use of sound designed to mask communication among birds (termed a “Sonic Net”), to deter blackbirds (Icteridae) from target areas of maturing sunflower crops. The Sonic Net masks communication of a target species by delivering “pink noise” that overlaps with the frequencies that the species uses for acoustic communication. If birds cannot hear predators or conspecific warning calls their perceived predation risk increases, and they relocate to an area with lower predation risk. Working with local sunflower producers in North Dakota, USA we set up experimental sites in three sunflower fields that were actively used by mixed-species blackbird flocks. In each field, we established two 0.2 ha plots and measured the initial area of damage for 63 individually-marked sunflowers. We applied the Sonic Net treatment to one of the paired plots in each field. At the end of the 20-day treatment period, we measured the total area damaged on the individually-marked sunflowers from each plot to calculate the change in damage for each sunflower. In all three fields, Sonic Net treatments substantially reduced percent damage to sunflowers, by 28.6% (95% CI: 12.5–41.7%), 63.6% (57.2–69.0%) and 22.6% (16.6–28.1%) for fields in Burleigh, McIntosh, and Emmons, respectively. In addition, sunflowers with a higher initial area of available seed experienced higher damage. We predict that the effect of the Sonic Net treatment may be greater in other crop phases and types, such as in the establishment phase or ground cover crops. During crop establishment there is a relative lack of tall, three-dimensional vegetational structure, which would allow for more effective spread of the Sonic Net sound and offer fewer physical refugia for birds to lower their perceived predation risk. We suggest both larger scale agricultural tests of the Sonic Net and efficacy tests for protecting crops at early growth stages to further explore the usefulness of this technology for crop protection.

1. Introduction

Avian pests cause direct damage to many crops at multiple vulnerable stages of growth, from establishment through crop maturation (Holler et al., 1982; Durrant et al., 1988; Linz et al., 2011; Anderson et al., 2013). In the United States, native blackbirds (Icteridae) and invasive European starlings (*Sturnus vulgaris*) are some of the most notorious avian agricultural pests (Linz et al., 2017). Large, mixed-species flocks form in the non-breeding season, and are comprised primarily of red-winged blackbirds (*Agelaius phoeniceus*) but may also include yellow-headed blackbirds (*Xanthocephalus xanthocephalus*), common grackles (*Quiscalus quiscula*), and European starlings.

These large flocks cause significant damage to a variety of crops in different stages. For example, blackbirds depredate seeds at planting and newly emerging sprout stages in crops such as rice (*Oryza sativa*), corn (*Zea mays*), wheat (*Triticum* spp.), soybeans (*Glycine max*), lettuce (*Lactuca sativa*), and sugar beets (*Beta vulgaris*) (Ingram et al., 1973; Crase and DeHaven, 1976; Dolbeer et al., 1979; Holler et al., 1982; Daneke and Decker 1988; Wilson et al., 1989). Blackbirds and starlings are also notorious for depredating ripening and maturing fruits or seeds in crops as diverse as sunflower (*Helianthus annuus*), corn, wheat, millet (*Pennisetum glaucum*), cherries (*Prunus* spp.), grapes (*Vitis* spp.), and other varieties of stone fruit and grains (Mott et al., 1972; Peer et al., 2003; Anderson et al., 2013). Of all these problems, one of the most

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well-studied is the damage blackbirds cause to mature sunflower (Linz et al., 2017). This conflict is particularly pronounced in North Dakota, where sunflower production has declined in excess of 75% since the 1980s, in part due to blackbirds (Klosterman et al., 2013).

Blackbirds cause millions of dollars of damage to North Dakota sunflower crops each year (Ernst et al., 2019) and are estimated to damage 2% of the crop annually (Kleingartner, 2003). While the overall loss may seem low, this loss is not distributed evenly across sunflower producers (Dolbeer, 1981). Patterns of damage are highly skewed, leading to disproportionate damage and severe economic impact for some producers but not others (Klosterman et al., 2013). Accordingly, approximately 10% of sunflower producers cite blackbird damage as the most limiting factor on sunflower yield (Kandel, 2013).

Despite decades of research on blackbird deterrence this conflict is still ongoing as many control methods are either cost-prohibitive or inconsistent in performance (Kleingartner, 2003; Linz et al., 2011). Deterrence tools are categorized as physical, chemical, acoustic, visual, or some combination of these. Physical deterrents consist of a physical barrier to prevent a bird from being able to damage crops. The most common example is bird netting, which is commonly used in fruit production, and generally only economical in high value crops (Tillman et al., 2000; Taber 2002). Chemical deterrents generally rely on birds ingesting treated seeds (Werner and Avery 2017). However, in sunflower, disk flowers and seed husks cover the edible seed, which prevents direct application to the edible portion of the plant (Kaiser et al., 2020). In addition, as sunflower heads mature the face droops towards the ground making the preferred aerial application of chemicals ineffective (Klug 2017). Both acoustic and visual deterrents largely rely on scaring or startling birds (Avery and Werner 2017). Current acoustic deterrents include broadcasting bird alarm or distress calls, broadcasting predator vocalizations, or deploying propane cannons and “bird bangers” or “screamers” (i.e., pyrotechnics that produce loud startling sounds). Visual deterrents include balloons, kites (sometimes in the shape of a predator), reflective metallic tape, or effigies of avian predators or conspecifics of the avian pests (Avery and Werner 2017). Hazing tactics with aircraft or drones can also fall into this category, combining both visual and acoustic cues (Wandrie et al., 2019; Egan et al., 2020). However, among visual and acoustic deterrents, habituation limits their effectiveness as birds quickly learn that these scare tactics do not pose actual risk and can be ignored (Rivadeneira et al., 2018).

In this study, we tested the effectiveness of an emerging acoustic deterrent technology, the Sonic Net, in reducing blackbird damage to sunflower crops. The Sonic Net uses directional speakers to produce a wide range of sound frequencies, which can be adjusted to overlap the range of frequencies used in vocal communication by a target species (Mahjoub et al., 2015; Swaddle et al., 2016). Acoustic disruption, such as that caused by a Sonic Net, reduces the ability of birds to gather acoustic information from their environment, such as conspecific alarm calls or other auditory cues (Mahjoub et al., 2015). Such acoustic degradation of habitat reduced European starling foraging behavior by 46% in an aviary (Mahjoub et al., 2015) and abundance of free-ranging birds by 82% at an airfield by creating a high-risk environment in which birds could not effectively communicate (Swaddle et al., 2016). Sonic Net technology is distinguishable from other control methods because birds will not easily habituate to the treatment as long as natural predator risks are present in the landscape and birds have alternative food resources (Swaddle et al., 2016). It is theorized that birds’ repeated exposure to the sound of Sonic Net will help them to associate the sound with real predation risk, which will prevent habituation and maintain the deterrence effects of the Sonic Net over time (Swaddle et al., 2016). We surmised that the acoustic environment produced by a Sonic Net would disrupt foraging activity of blackbirds, which in turn would reduce crop damage. In this study we conducted a manipulative field experiment to assess the efficacy of Sonic Net technology to mitigate crop damage by blackbirds in sunflower fields. Specifically, we analyzed damage to mature sunflower crops with and without a Sonic Net.

2. Methods

2.1. Field sites and experimental design

We identified three sunflower fields with active blackbird flocks in Burleigh County, McIntosh County, and Emmons County, North Dakota, USA (46.834872°N, 100.337794°W, confectionary; 46.570976°N, 100.058311°W, oilseed; 46.126252°N, 99.553080°W, oilseed) to install the Sonic Net deterrent. In each field, we established two 0.2 ha plots (45 × 45 m) that were approximately 300–600 m apart (Fig. 1). We established this distance based on the attenuation of sound from the Sonic Net device so that the control plot was not directly affected by the sound on the treatment plot. The Sonic Net sound was barely audible in any of the control plots and unable to disrupt vocal communication among birds in those plots. Each pair of plots was established to be equidistant from the field edges (range among sites = 5–60 m) and cattail-dominated wetlands (i.e., potential roosts). One plot was randomly selected as a treatment while the other was assigned as a control. In treatment plots, a Sonic Net device (a speaker mounted on a 2.5 m pole) was deployed at the center of the plot. The Sonic Net speaker was powered by a marine grade battery, power inverter, and solar panel that were a minimum of 31 m away from the speaker. In control plots a decoy speaker that closely resembled the appearance of the Sonic Net was erected in the center of the plot to control for visual effects of the equipment. All equipment was obtained from Midstream Technology Inc., Williamsburg, Virginia USA.

In treatment plots we applied the Sonic Net sound treatment (1–8 kHz at 80 dBA SPL 10 m from the speaker) from 30 min prior to sunrise to 30 min after sunset, every day during a 20-d period. This is a loud sound that covers the frequency (pitch) range over which blackbirds hear calls and songs of conspecifics, extending to a radius of approximately 30 m from the Sonic Net device. Experiments took place between 25 August and 13 October 2019 (Burleigh = 30 August to 21 September; McIntosh = 23 September to 13 October; Emmons = 25 August to 14 September). In control plots, the decoy Sonic Net was present for the same 20-d period. At the end of the 20-d treatment window, we measured the total area damaged on the same 63 individually-marked sunflowers from each plot to calculate the change in damage for each sunflower.

2.2. Sunflower damage estimates

Within each of the plots (treatment and control), we established three north-south transects (45 m), one that bisected the center of the plot and two parallel transects halfway (11 m) between the center transect and plot edge (Fig. 1). We identified and individually marked 21 sunflower plants equally spaced 2.5 m apart along each transect for a total of 63 sunflowers per plot. We measured each sunflower with a tape measure across the center of the head to estimate head diameter to the nearest 0.5 cm. We conducted baseline damage estimates for each sunflower using a semicircular plastic template divided into 5-cm² segments organized in concentric tiers (Dolbeer, 1975). The damage template was held against the sunflower head and the number of 5-cm² sections overlaying damaged seed area were counted to the nearest half-section; the template was then rotated until the entire sunflower head had been assessed. To improve consistency and accuracy of damage estimates, a single observer (AKW) conducted the damage estimates for all three fields in both the baseline and post-treatment estimates.

We repeated measurements on 21 sunflowers to assess precision of damage estimates by calculating the standard deviation (SD) of the three repeated damage estimates for each sunflower and the SD of damage estimates among these 21 sunflowers. The mean SD of damage estimates among the 21 sunflowers (i.e., among-sunflower variation) was 27.75 cm² compared with a mean SD within sunflowers (i.e., variation due to repeat measurements of the same sunflower) of 1.81 cm². As the variation among sunflowers was approximately 15-fold larger than the

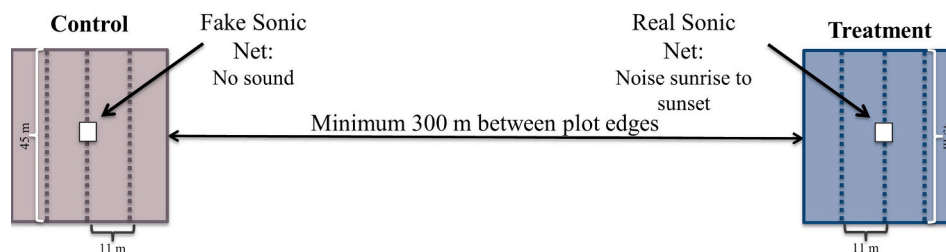


Fig. 1. Example experimental set up within one sunflower field in North Dakota, USA. Shaded squares represent the control or treatment plots (0.2 ha); dotted lines represent the three sampling transects within the plots, with each dot representing an individually marked sunflower. White squares represent the placement of the Sonic Net device or decoy box positioned at the center of each plot.

variation we observed due to repeat measurements of the same sunflower, we concluded that our method for estimating damage was sufficiently precise and we did not require replicates of all damage estimates. Although sunflower head size varied (range, 78–962 cm²) among fields and among plants within fields, we measured the within-plant extent of damage, such that sunflower head size was accounted for in our metric of change due to damage.

Our evaluation of percent area damaged was based on the difference between seed area at the start of the experiment and that at the experiment’s end. This comparison was based on the assumption that seed area doesn’t change over time in the absence of consumers. But an increase of apparent seed area over time can occur in sunflowers due to growth compensation (i.e., after damage, remaining seeds grow more) and shrinkage (i.e., areas of damage shrink faster during drying period) (Sedgwick et al., 1986). Thus, based on Sedgwick et al. (1986), we conservatively adjusted our measured response for a 15% increase in seed area due to growth compensation and damaged area shrinkage for all sunflowers in control and treatment fields. For this adjustment we calculated 15% of the total sunflower area for each sunflower and added this area to the baseline undamaged seed area (used as a covariate in our analysis) and to the seed area after 20 d. With this adjustment, negative estimates of damage to sunflowers were precluded.

2.3. Statistical analyses

We specified one dependent variable, *damaged area post-treatment*, and one covariate, *initial undamaged seed area*, for each individual sunflower to account for the effect of available seed area (before the experiment started) on subsequent damage by blackbirds (i.e., during the experimental period). The experimental design also included two fixed factors, *field* to account for differences in damage due to environmental variables associated with each field, and *treatment* to determine the effects of the Sonic Net treatment.

In our initial analysis, we determined whether there was a significant interaction between the fixed factor, *field*, and the covariate, *initial undamaged seed area*. Under a significant interaction the slopes of the relationship between the dependent variable and the covariate would differ between fields, which required separate analyses for each field. To do so, we analyzed raw and log₁₀-transformed dependent variables as a function of the covariate and the interaction between the two fixed factors and the covariate using the “glm” procedure in R. For both cases, the interaction effect was statistically significant, so we analyzed the effects of the covariate and Sonic Net treatment separately for each field.

In the analysis of each field, we evaluated statistical assumptions of normality visually and of homogeneity of variance using Levene’s test and the GLM procedure in R (R core team 2016). Using raw data, variances were not homogeneous for two of the three fields. Consequently, we used log₁₀-transformed data for all three fields to be consistent. In all three cases, log₁₀-transformed data were approximately normally distributed with homogeneous variances (Levene’s test, *p* = 0.26, 0.43 and 0.80 for fields in Burleigh, McIntosh, and Emmons, respectively).

For the final analysis of each field, we formed statistical models (*g_i*) based on multiple alternative hypotheses plus the null and global models (Table 1), following an information theoretic approach (Anderson 2008). The five alternative models included only the covariate influencing damage (*g₁*), only the Sonic Net treatment (*g₂*), both the covariate and Sonic Net treatment in an additive model (*g₃*), the global model with an interaction between the covariate and Sonic Net treatment (*g₄*), and the null model (*g₅*).

Each model was run as a general linear model in R using the “glm” procedure (“stats” package version 3.6). The resulting Akaike Information Criterion (AIC) values from each model were used to calculate AIC_c, a second-order bias correction estimator (Anderson 2008). Model probabilities (*w_i*), based on Δ_i values, were used to rank the different models (*g_i*) against the model with the lowest AIC_c and estimate the probability that a particular model *g_i* was the best model. Any model with *w_i* less than 0.10 was eliminated (Anderson 2008). Likelihood ratio X² tests were used to test alternate models. Parameter estimates of the best-fitting model were used to calculate the percent damage reduction under the Sonic Net treatment as:

$$(1 - 10^{\beta_2}) \times 100\%$$

where β₂ = parameter estimate for the Sonic Net effect (Table 1). This equation was used to back-transform the effect size from the log₁₀ base.

3. Results

In the three separate field-by-field analyses, sunflower damage was best explained by the additive effects of the Sonic Net *treatment* and *initial undamaged seed area* (*g₃*), with Akaike weights of 0.71, 0.72, and 0.70 for fields in Burleigh, McIntosh, and Emmons counties, respectively (Table 2). For all fields, sunflower damage was a positive nonlinear function of initial undamaged seed area (Fig. 2, Table 3), such that the additional damage increased with the initial seed area available for consumption. Importantly, the Sonic Net treatment substantially and significantly reduced percent damage to sunflowers in all fields, by 28.6% (95% CI: 12.5–41.7%), 63.6% (57.2–69.0%) and 22.6% (16.6–28.1%) for fields in Burleigh, McIntosh, and Emmons,

Table 1

General linear models (*g_i*) and parameters (*β_i*) corresponding to hypotheses about blackbird damage to sunflowers. Model *g₄* is the global model and *g₅* is the null model. The Xs indicate the presence of those variables in the model.

Model	Variables (parameters)			
	Intercept (<i>β₀</i>)	Covariate (<i>β₁</i>)	Sonic Net (<i>β₂</i>)	Covariate x Sonic Net (<i>β₃</i>)
<i>g₁</i>	X	X		
<i>g₂</i>	X		X	
<i>g₃</i>	X	X	X	
<i>g₄</i>	X	X	X	X
<i>g₅</i>	X			

Table 2

AIC_C calculations from general linear models (g_i) corresponding to hypotheses about blackbird damage to sunflowers (*damaged area post-treatment*). UnSA = covariate, *initial undamaged seed area*; SN = Sonic Net treatment. Interaction effects are indicated within parentheses. For all three fields, model g_3 was statistically significantly better than the null and global models (Likelihood ratio X^2 test, $\alpha = 0.05$).

Model	Variables	k	AICc	Δ_i	w_i
<i>Burleigh</i>					
g_3	UnSA + SN	4	-4.41	0	0.71
g_4	(UnSA x SN)	5	-2.49	1.92	0.27
g_2	SN	3	3.84	8.25	<0.01
g_1	UnSA	3	4.21	8.62	<0.01
g_5	null	2	19.87	24.27	<0.01
<i>McIntosh</i>					
g_3	UnSA + SN	4	-46.15	0	0.72
g_4	(UnSA x SN)	5	-44.3	1.85	0.28
g_2	SN	3	23.03	69.18	<0.01
g_1	UnSA	3	53.78	99.93	<0.01
g_5	null	2	19.87	24.27	<0.01
<i>Emmons</i>					
g_3	UnSA + SN	4	-244.76	0	0.70
g_4	(UnSA x SN)	5	-243.07	1.68	0.30
g_1	UnSA	3	-206.05	38.71	<0.01
g_2	SN	3	-70.89	174.06	<0.01
g_5	null	2	-69.38	175.47	<0.01

Table 3

Estimate, standard error (SE), and 95% confidence interval (CI) of the parameters from the best-fitting general linear model (g_3). Percent damage reduction was 28.6% (95% CI: 12.5–41.7%), 63.6% (57.2–69.0%) and 22.6% (16.6–28.1%) for fields in Burleigh, McIntosh, and Emmons, respectively. For all three fields, parameters β_1 and β_2 differed significantly from 0, as 95% CIs did not overlap with zero. UnSA = *initial undamaged seed area*; SN = Sonic Net treatment.

Parameter	Variable	Estimate	SE	95% CI
<i>Burleigh</i>				
α	Intercept	1.271	0.356	(0.559, 1.983)
β_1	UnSA	0.416	0.128	(0.160, 0.672)
β_2	SN	-0.146	0.044	(-0.234, -0.058)
<i>McIntosh</i>				
α	Intercept	0.278	0.192	(-0.106, 0.662)
β_1	UnSA	0.741	0.076	(0.589, 0.893)
β_2	SN	-0.439	0.035	(-0.509, -0.369)
<i>Emmons</i>				
α	Intercept	-0.882	0.132	(-1.146, -0.618)
β_1	UnSA	1.044	0.054	(0.936, 1.152)
β_2	SN	-0.111	0.016	(-0.143, -0.079)

respectively (Fig. 2, Table 3). The total area of bird damage per plant ranged from 15 to 759 cm² (mean \pm SEM, 167 \pm 10 cm²) in control plots and 12–572 cm² (103 \pm 7 cm²) in treatment plots. Between the three fields the damage prevented by the Sonic Net ranged from 12 to 92 cm² seed area per sunflower head.

4. Discussion

In each of our three field sites, both the presence of a Sonic Net and the amount of sunflower seed initially available to birds (i.e., initial undamaged seed area) best explained the observed damage to sunflower heads. In all cases, the Sonic Net treatment reduced the amount of additional damage accrued by sunflowers over 20 days. The amount of damage caused by the birds was positively related to the initial area of undamaged seed, which indicates that blackbirds are more likely to feed from sunflower heads that contain more food. In sweet corn, blackbirds have fidelity to feeding sites and do not forage randomly within fields (Dyer 1967). All of our plots (control and treatment) in all fields had previous damage before the onset of the experiment, indicating birds were using these locations for foraging. Thus, the Sonic Net was effective in disrupting foraging at an established feeding area, leading to reduction in damage as compared to the control plots.

While a protective effect of the Sonic Net treatment occurred in all three fields, the magnitude of this effect was not consistent among fields. The average amount of additional damage to a sunflower head in a control plot was 167 cm² while flower heads in the treatment plots experienced on average only 103 cm² of additional damage. Between the three fields the percent damage prevented by the Sonic Net ranged from 22.6% to 63.6% and between 12 and 92 cm² seed area protected per sunflower. Some of the variation between fields was likely due to site-specific differences that we were unable to capture in our experiments (e.g., surrounding landscape [wetlands or woodlots], sunflower densities, insect abundance, weed prevalence, time of season, and size of flocks) but which could be considered in future studies with an increased sample size of field sites. In addition, our 15% adjustment of damage to account for sunflower compensation and shrinkage was likely an underestimate of the relative protection offered by the Sonic Net. Improved methods for estimating damage would be valuable in improving accuracy in estimates of effect size. In addition, this experiment only represents damage prevented over a 20-d period. Additional damage protection may be achieved if applied for the entire duration of sunflower maturation, or if applied prior to the establishment of foraging grounds by flocks within a field.

Generalization of our results may be limited due to the small number of fields in our experiment and to the relatively small area sampled in

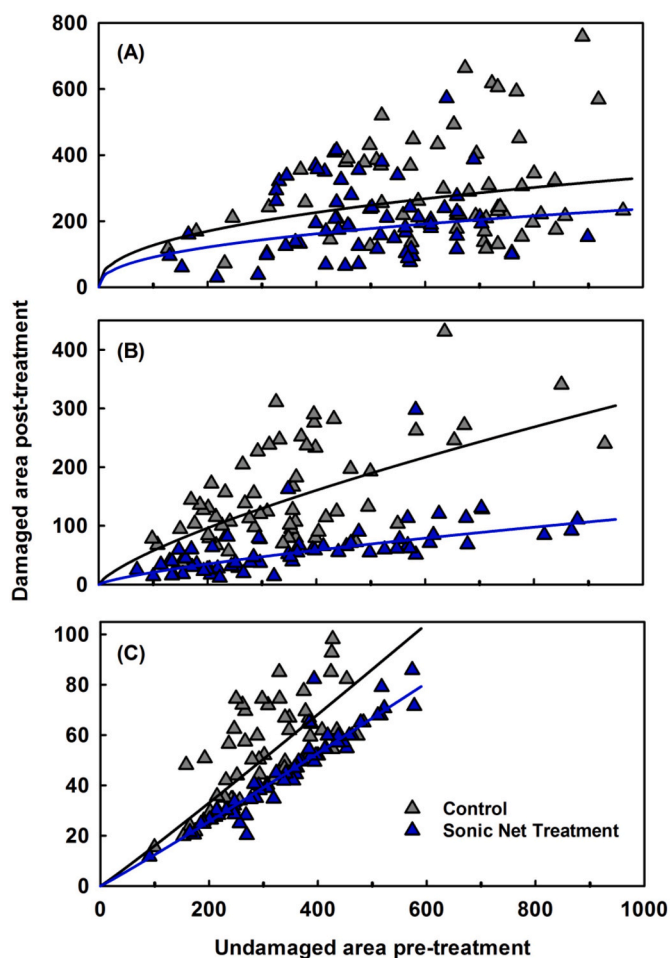


Fig. 2. Amount of additional blackbird damage (cm²) to sunflower heads during the 20-d test period as a function of initial undamaged seed area (cm²) by treatment for (A) Burleigh, (B) McIntosh, and (C) Emmons counties in North Dakota, USA. The curves were drawn using equations calculated from the back-transformed values of model g_3 (Table 3).

each field (0.2 ha within 150–780 ha fields). Nevertheless, the findings are promising in that a positive effect of the Sonic Net occurred in all three fields. But the positive effect may change if larger areas or entire fields are treated rather than the relatively small patches we treated here. For blackbirds, the cost of relocating away from an acoustically deteriorated patch was low, as other foraging locations were abundant and close. By moving as little as 300 m the birds could recover acoustic information that was degraded by the Sonic Net. Larger scale applications are thus required to determine if this technology will be effective at the field scale of sunflower production. In addition, the Sonic Net may be more effective when used in conjunction with alternative forage sites or “decoy plots” (Hagy et al., 2008), where flocks perceive lower predation risk. Sonic Net devices could also be deployed in combination with other deterrent methods (e.g., frightening devices) as part of an integrated management strategy to increase perceptions of predation risk in areas with a Sonic Net.

The current study has implications for reducing avian damage at crop establishment. The Sonic Net appears to work by altering perceived predation risk of birds by degrading acoustic information (Mahjoub et al., 2015). The current study occurred in a highly three-dimensional space where blackbirds could likely find structural pockets within the mature sunflower field that shielded or muffled the Sonic Net sound and provided protective cover from predators. During crop establishment, there is very little three-dimensional vegetative structure, which allows the Sonic Net sound to travel farther and offers less protective cover to foraging birds. Hence, we expect the Sonic Net to be more effective in displacing birds in situations of crop establishment, as birds will be more susceptible to an increase in perceived predation risk. Notably, installation of the Sonic Net in mown grass associated with an airfield resulted in more than 80% displacement of numerous bird species (Swaddle et al., 2016). Furthermore, given that the sound of the Sonic Net may travel farther in the sparsely vegetated landscape during crop establishment, it might take fewer devices that are perhaps powered to lower levels (amps) to effectively fill the area with the appropriate sound intensity. This would lower the costs associated with protecting an establishing crop compared with our study of mature sunflower, as fewer speaker devices would be required to cover the same area.

In conclusion, a Sonic Net was effective in reducing damage to mature sunflower crops caused by foraging blackbirds, and the reduction could be substantial (e.g., up to 57–69% in one of the fields). We predict that we have underestimated the protective value of the Sonic Net if it were to be deployed at a larger scale. Without a broader-scale application, we cannot fully assess the value of the Sonic Net as part of a practical management strategy; hence we consider our results promising but not necessarily generalizable. Further, we predict that the Sonic Net will be useful in reducing damage by foraging birds during stages of crop establishment as the acoustic degradation caused by this technology increases perceived predation risk when fields have limited three-dimensional structure (i.e., little above ground vegetative growth). We suggest that both broader-scale agricultural tests of the Sonic Net and tests of the technology during early growth stages should be implemented and cost-effectiveness assessed.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

John 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.

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