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When a pest is not a pest: Birds indirectly increase defoliation but have no effect on yield of soybean crops

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Abstract

Natural habitats near agricultural systems can be sources of both ecosystem services and disservices on farms. Ecosystem disservices, those aspects of an ecosystem that have negative impacts on humans, may disproportionately affect conservation decisions made by farmers. Birds, in particular, can have complex effects on crops, ranging from positive to neutral to negative. Therefore, it is important to quantify them in a meaningful way. Birds may be more abundant on farms near natural areas and may provide ecosystem services by consuming insect pests. However, when birds consume beneficial predatory arthropods rather than pest species (intraguild predation), they can provide a disservice to the farmer if the intraguild predation decreases crop yield. We studied bird intraguild predation in Illinois (USA) at six soybean fields adjacent to grasslands that provided source habitat for bird populations. We placed cages over soybean crops, which excluded birds but allowed access to arthropods, and measured differences in leaf damage and crop yield of plants in control and exclosure plots. We also conducted point counts at each site to quantify the bird communities. We found that plants within the bird exclosures had lower levels of leaf damage by pests than those in control plots, but there was no resulting effect on crop yield. We also found that sites with higher bird abundance had higher levels of leaf damage by pests, but bird species richness was not a significant predictor of leaf damage. These results suggest that although birds may have released pests through intraguild predation, there was no net disservice when considering crop yield, the variable most important to stakeholders.

KEYWORDS
birds, crop yield, ecosystem disservice, soybeans, trophic cascade

INTRODUCTION

Within an agricultural landscape, uncultivated "natural" habitat patches can provide numerous ecosystem services to neighboring farmland (Zhang et al., 2007). The valuation of ecosystem services has been an important approach to incentivizing conservation of those natural areas and their wildlife, and particularly of birds and their habitats (Şekercioğlu et al., 2016; Wilsey et al., 2016). The valuation of the negative impacts of nature on humans (ecosystem disservices), however, may be equally if not more important to conservation, because many stakeholders make their decisions based on losses rather than gains (Blanco et al., 2019; Kross et al., 2018). This is especially significant in cases where a perceived pest may not actually have a measurable economic impact. For instance, Borkhataria et al. (2012) found that although blackbirds directly damaged rice crops, this did not reduce the average crop yield. In fact, most agricultural crop plants can withstand pest damage with no effect on crop yield until they reach an economic injury threshold level, after which point crop yield declines (Pedigo et al., 1986).

Birds are highly mobile, and many species make use of agricultural habitats, especially when natural areas occur nearby to provide additional nesting and foraging opportunities. While birds on farms often provide important pest control services (Whelan, Şekercioğlu, et al., 2016; Whelan, Tomback, et al., 2016), they can also provide disservices in a variety of ways. Most research on agricultural ecosystem disservices by birds examines direct effects such as crop consumption or damage, or decreased food safety due to pathogens spread by birds (Pejchar et al., 2018). Indirect disservices caused by birds are harder to measure than direct ones, but still have the potential to cause measurable and important effects on agroecosystems. Birds can provide an indirect disservice when they consume beneficial arthropods such as pollinators (Knight et al., 2006) or predatory arthropods that would otherwise consume pest species (i.e., intraguild predation; Garfinkel et al., 2020). However, just as low levels of herbivory may not affect crop yield, low levels of intraguild predation might also not negatively impact yield. Whether intraguild predation by birds is a real disservice, and not just a perceived one (e.g., Basili & Temple, 1999), depends on its ultimate effect on crop loss or damage.

Integrated pest management (IPM) is an approach to agricultural pest control that greatly increases farmland resiliency while providing biological conservation benefits (Barzman et al., 2015). Under an IPM approach, farmers may use a combination of chemical, cultural, mechanical, and biological control techniques to keep pest damage below an economic injury threshold level (Stenberg, 2017). Low pest densities that cause damage but have non-significant effects on crop yield are tolerated under this approach. Similarly, birds that consume predatory arthropods below a level that affects crop yield would also be tolerated. Because birds also have the potential to simultaneously provide services by consuming pest insects, they can be valuable for farmers using IPM (Garfinkel et al., 2020). Disentangling the causes of net positive or negative bird effects within agricultural systems may therefore be an important way to incentivize conservation of birds and their nearby habitats within the agricultural matrix.

Many studies of bird trophic effects in agriculture take place in orchards, vineyards, or agroforestry systems (Crisol-Martínez et al., 2016; Johnson et al., 2010; Koh, 2008; Mangan et al., 2017), perhaps because the complex vegetative structure provided by trees and shrubs provides good habitat for birds (Erdelen, 1984; Rodenhouse & Best, 1983; Wilson et al., 2017). Studies that examine bird trophic effects in row crop agriculture often take place in small scale, organic, or otherwise "wildlife friendly" agroecosystems where bird populations may be larger (Garfinkel & Johnson, 2015, Jones & Sieving, 2006, but see Garfinkel et al., 2020, Kross et al., 2016, Olimpi et al., 2020). Although row crop agriculture is grown extensively worldwide, few studies have examined bird trophic effects in these systems (Borkhataria et al., 2012; Tremblay et al., 2001).

Soybean crops are an ideal system in which to study bird trophic interactions in large-scale conventional row-crop agriculture for several reasons. First, soybeans are consistently one of the top commodities in the United States, with over 3.7 million hectares of land planted in 2017 (National Agricultural Statistics Service, 2017). Second, soybeans are vulnerable to a variety of arthropod crop pests of varying sizes and taxonomic orders (Bissonnette, 2008). Finally, although soybeans are generally grown in large monocrop fields, differing habitat surrounding the fields may allow us to compare trophic effects in landscapes with increased bird diversity. For instance, in the Midwest of the United States where the majority of U.S. soybeans are grown (National Agricultural Statistics Service, 2017), remnant and restored prairies and grasslands are among the dominant "natural" habitat types, and often may be found near cultivated land. We might expect to find more intraguild predation by birds in fields close to natural habitats, because these areas may show both increased bird foraging activity (Puckett et al., 2009; Rodenhouse & Best, 1994) and increased density of predatory arthropods (Macfadyen & Muller, 2013), although they may harbor higher pest densities as well (Nguyen & Nansen, 2018).

In a previous study of agricultural fields next to grassland habitat (Garfinkel et al., 2020), we found that birds provided indirect services in a corn field but disservices in a soybean field. Here, we describe a follow-up study that was designed with the goal of determining whether birds consistently provide disservices in soybean fields adjacent to grasslands. We used bird exclosures over soybean crops to measure the indirect effect of birds on soybean leaf damage and total crop yield. We hypothesized that there would be a more pronounced bird effect in sites with higher bird biodiversity or abundance, and along the edges of the field closer to grassland habitat. This study will clarify the variables that affect the net ecosystem services provided by birds in soybeans and therefore help farmers make educated decisions that maximize crop yield without negatively affecting nearby bird habitats.

METHODS

Study sites and experimental design

We conducted our study at six sites in Kane, DeKalb, and Ogle counties in northern Illinois, USA. We selected sites that had a soybean field that shared at least one field edge with a grassland or prairie, and where we were able to obtain permission from all involved landowners to conduct our research. Each site was separated from others by at least 1 km. The average size of the soybean fields was 23 ha (range = 4–42 ha).

At each of the six sites, we placed four bird exclosures over soybean crops in mid-June in 2017. Each exclosure was paired with a marked control plot 2 m away. The exclosure array was centered along the crop field edge that shared a border with the prairie or grassland. Two exclosure–control pairs were placed 5 m into the crop field from the field edge and 50 m from each other, and the other two were 55 m into the field interior from the field edge and 50 m from each other (Figure 1).

We constructed the exclosures from PVC pipe frames covered with 2.5 cm^2 (5 cm stretch) monofilament netting (Memphis Net and Twine Company, Memphis Tennessee, USA). We chose this netting size to be small enough to exclude all birds, but large enough to allow access by most arthropods. Previous studies have used even finer mesh over soybeans and found no direct effect of the exclosure itself on plant growth (see Costamagna et al., 2007), suggesting that any differences in crop yield between control and exclosure plots should only be due to bird exclusion. Each exclosure was 0.6 m wide (which fit over one or two rows of plants depending on row spacing), 1.5 m long, and 1.5 m tall. Although each exclosure covered differing numbers of soybean plants, we marked the central five plants in the exclosure with small plastic plant tags for future measurements.

We placed the exclosures over crops once they were established in the field, but before they started flowering. Once deployed, we left the exclosures in place for the rest of the growing season and removed them once the crops were dry and ready for harvest.

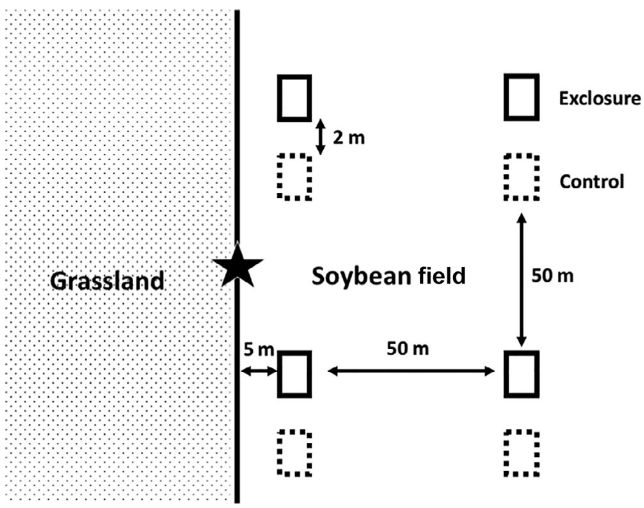

FIGURE 1 Experimental configuration at each of six study sites. Exclosure plots are represented by rectangles surrounded by solid black lines and control plots are represented by rectangles surrounded by dotted black lines. The star represents the approximate location where observers stood for point counts. Arrows highlight the distances between plots. Distances and exclosure and control plots are not drawn to scale

Leaf damage and crop yield

We scored insect damage to soybean leaves three times throughout the growing season: (1) immediately before the exclosures were placed, (2) when the crops were just beginning to bloom (also known as growth stage R1; Licht, 2014), and (3) when the crops were beginning to develop seed pods (growth stage R5). We selected these two stages because soybeans, like many other crops, may be more sensitive to damage at different growth stages (Stacke et al., 2018). Ten haphazardly selected leaf triads were chosen from among the plants in each exclosure and control plot, and we scored insect defoliation of each triad as 0%, 5%, 15%, 25%, 35%, etc. based on a visual guide developed by University of Minnesota Extension (Koch, 2016). At each visit, we newly selected the leaf triads to be scored, therefore likely scoring different leaves at each time point. Upon removing the exclosures at the end of the growing season, we hand-harvested soybean seed pods from the five marked plants in each exclosure and control plot, oven dried the soybeans after removing them from the pods, and recorded the dry mass and count of soybeans from each focal plant.

Point counts

Two experienced observers conducted bird point counts together two times at each site, once in June and once in July 2017. Owing to logistical constraints, we conducted the first point count at one site on May 21 instead of in early June. The point counts were conducted between sunrise and 9:00 AM in appropriate weather conditions (i.e., no rain or strong wind). The observers were positioned on the border between grassland and cropland at each site, equidistant from the two nearest exclosures (see Figure 1). Each point count lasted 10 minutes, during which time the observers recorded all birds seen or heard within a 50 m radius of the point count location. The 50-m fixed radius point count both aligned with our experimental design for exclosure placement, and also allowed us to assume consistent bird detectability among sites by expecting that all birds within 50 m were detectable (Ralph et al., 1995). Birds that flew over the site without landing were excluded from analyses, except for aerial insectivorous species such as swallows and swifts that may have been hunting without landing. We calculated two summary metrics for the bird communities at each site from point count data: (1) the abundance of all individuals of all bird species at the site averaged between both point count visits and (2) the cumulative species richness of birds at the site from both point count visits.

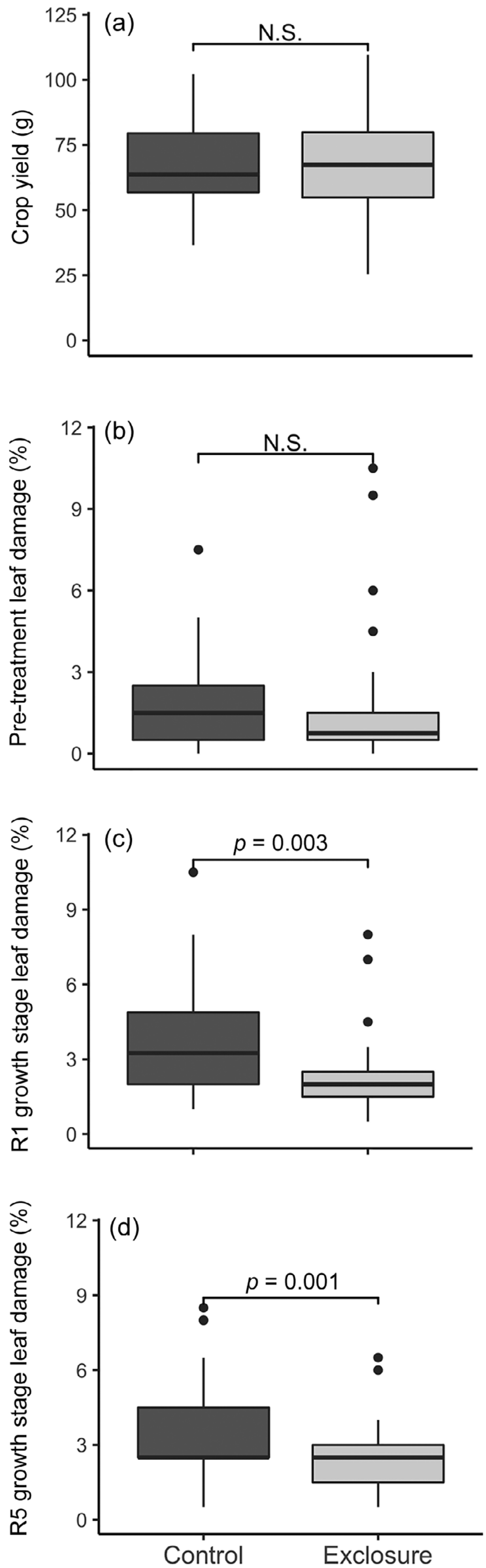

FIGURE 2 Boxplots showing the differences in (a) crop yield and (b–d) leaf defoliation between control and exclosure plots. Leaf damage is an index based on the mean percent defoliation score (binned as 0%, 5%, 15%, 25% defoliation, etc.) of 10 leaf triads per plot. Leaf damage was measured pre-exclosure (b), and post-exclosure at growth stages R1 (c) and R5 (d). The p values listed in panels C and D are extracted from the most parsimonious mixed-effects model describing each of the four response variables. N.S. is not significant at $\alpha = 0.05$. The boxplots depict the median, first and third quartiles, range, and outliers within each data set

Analysis

We modeled the effects of exclosure treatment and nearby bird populations on leaf damage and crop yield. Leaf damage was analyzed at three different time periods, as described above: before exclosure placement, post-exclosure placement at growth stage R1 (flower growth), and post-exclosure placement at growth stage R5 (seed pod growth). We conducted separate analyses for leaf damage instead of a single repeated measures analysis because we did not follow the growth of individual leaves throughout the growing season. Therefore, leaf damage measurements taken at different times were not directly comparable. The leaf damage response variables were calculated from the percent damage scores averaged per plot; crop yield was calculated as the total grams of dried soybeans produced per plot.

We conducted similar analyses on each of our four response variables (leaf damage pre-exclosure, leaf damage post-exclosure at R1, leaf damage post-exclosure at R5, and crop yield). First, we ensured that all four response variables were either normally distributed, or

TABLE 1 Results of top model for each of four response variable analyses

Response variable/Predictor variable	β	e^{β}	SE	df[a]	p	95% CI
log(defoliation) pre-exclosure						
Intercept	−0.62	0.54	0.6	22	0.312	(−1.85, 0.61)
Bird abundance[b]	0.072	1.07	0.03	22	0.025	(0.01, 0.13)
log(defoliation) post-exclosure R1						
Intercept	1.66	5.26	0.12	22	<0.001	(1.44, 1.89)
Treatment (exclosure)[c]	−0.34	0.71	0.1	22	0.003	(−0.54, −0.14)
Distance (interior)[d]	−0.38	0.68	0.14	16	0.014	(−0.64, −0.11)
log(defoliation) post-exclosure R5						
Intercept	−0.14	0.87	0.34	5	0.695	(−0.99, 0.64)
Treatment (exclosure)	−0.37	0.69	0.08	2	<0.001	(−0.53, −0.22)
Distance (interior)	−0.4	0.67	0.09	28	<0.001	(−0.59, −0.21)
Bird abundance	0.09	1.09	0.02	5	0.004	(0.05, 0.13)
Treatment × Distance	0.26	1.30	0.11	22	0.025	(0.04, 0.48)
Crop Yield						
Intercept	67.21	NA	3.56	22	<0.001	(60.24, 74.18)

Note: Defoliation pre-exclosure measurements are the average leaf damage score per plot before exclosures were placed. Defoliation post-exclosure measurements are the average leaf damage score per plot measured at two time periods (R1 and R5) after exclosures were placed. Crop yield is the total dry mass of grain yield per plot (g). All defoliation models were fit with a log-normal distribution; crop yield was normally distributed.

[a]Denominator degrees of freedom.

[b]Abundance of birds averaged over two point counts for each site.

[c]Treatment is exclosure vs. control plot.

[d]Plot distance is either field edge (5 m from field edge) or field interior (55 m from field edge).

log-transformed them to normal as confirmed with Shapiro–Wilk tests (Shapiro & Wilk, 1965). We created linear mixed effects models with the normal or lognormal data and compared the models using Akaike's Information Criterion corrected for small sample sizes (AIC_c; Anderson, 2008). To decrease the overall number of models run per response variable, we used a step-down approach: first we compared an a priori set of two models per response variable, where each model included one of the two summary bird metrics (richness or abundance) as the lone fixed effect predictor variable. Next, we chose the summary bird metric that best fit the data according to AIC_c model selection and included that variable alone and in combination with other variables in a final set of 10 models per response variable.

All four AIC_c final model sets (one for each response variable) included models with treatment (exclosure or control), plot location (field edge or interior), and bird population variables as fixed effects, and site and treatment replicate as nested random effects. We also created models with interactions between treatment and plot location to test whether distance from field edge affected the strength of the treatment effect, and interactions between treatment and bird population variables to test whether the bird populations affected the strength of the treatment effect.

RESULTS

Point counts

We detected a total of 37 bird species across both point counts at all sites (mean = 9.58 species, SD = 1.93, per site visit). The cumulative species richness per site ranged from 11 to 16, and the average abundance of birds per site ranged from 14.5 to 24. Bird abundance was not driven by the presence of large single-species flocks: the maximum number of individuals of a single species at a site was nine, with a mean of two individuals detected per species per site.

Effects on soybean leaf damage

All leaf damage that we recorded appeared in patterns typically caused by arthropod herbivores, as illustrated in the visual guide to soybean defoliation (Koch, 2016). At growth stage R1, ~8% of all leaf triads had a defoliation score ≥15%; at R5, ~5.5% of the measured triads showed 15% defoliation or greater. Leaf damage data from each of the three collection dates best fit a lognormal distribution, while the crop yield data were normally distributed.

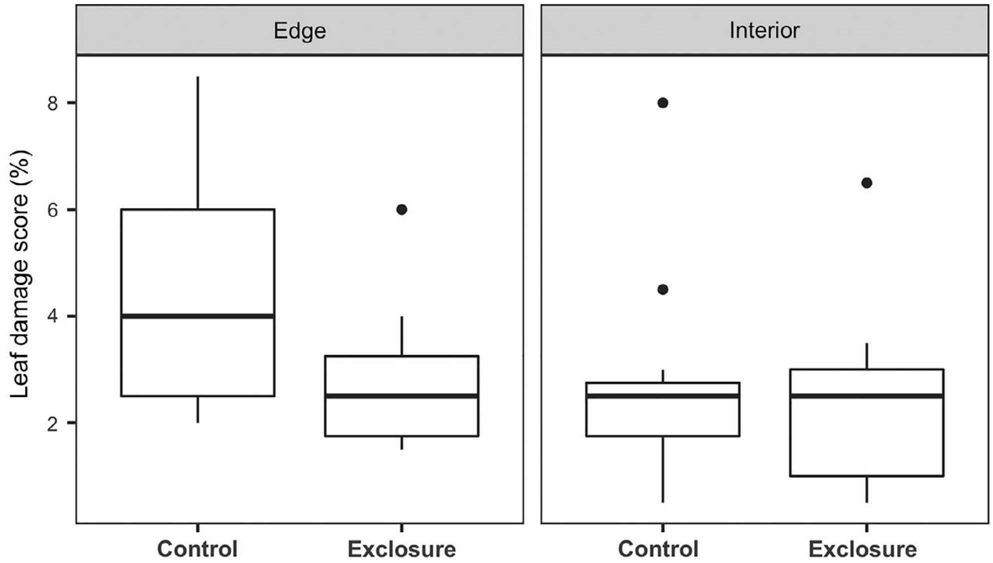

FIGURE 3 Boxplots of average leaf damage at growth stage R5 (post exclosure) for control and exclosure plots at two distances from the field edge. Leaf damage is an index based on the mean percent defoliation score (binned as 0%, 5%, 15%, 25% defoliation, etc.) of 10 leaf triads per plot. The most parsimonious model for this growth stage included a significant interaction between exclosure treatment and plot location ($p = 0.025$). Edge plots were located 5 m from the field edge, interior plots were located 55 m from the field edge

Of the two summary bird metrics, bird abundance was the best predictor of leaf damage pre-exclosure and at R5, but species richness was a better predictor of leaf damage at R1 and of crop yield (Appendix S1: Table S1); we used the appropriate summary bird metric in each of our subsequent model sets. We present here the results of only the top model for each response variable because in each case the second-best performing model added only statistically insignificant covariates (i.e., covariates with $p > 0.05$ and confidence intervals that overlap 0) and/or were >2 ΔAIC from the top model. Our full AIC_c tables for each analysis are in Appendix S1: Table S2.

Exclosure treatment was a significant predictor of leaf damage in both post-exclosure (R1 and R5) but not the pre-exclosure analysis (Figure 2 and Table 1). In both post-exclosure analyses, plants in exclosure plots showed significantly lower damage scores than those in control plots ($p < 0.01$, Figure 2c,d). The top model of leaf defoliation in both post-exclosure analyses also included distance from field edge as a significant predictor variable (Table 1). Field interior plots in both analyses showed lower levels of leaf damage than field edge plots. In the R5, but not the R1 analysis, we found a significant positive interaction between exclosure treatment and distance from field edge (Table 1 and Figure 3). Leaf damage increased significantly with increasing bird abundance in the pre-exclosure analysis and the R5 analysis (Figure 4), but not the R1 analysis (Table 1).

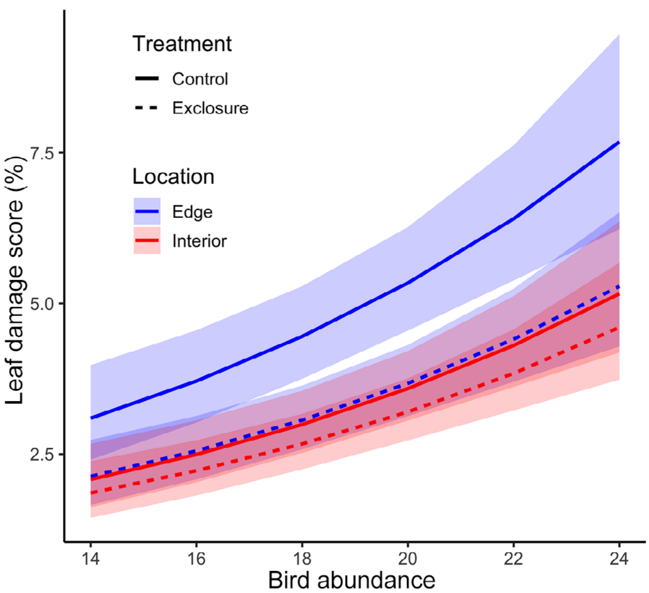

FIGURE 4 Predicted average leaf damage scores measured at growth stage R5 by bird abundance. Lines and 95% confidence intervals (shaded areas around the lines) were predicted based on the top model of leaf damage at stage R5

Effects on soybean crop yield

The best model of crop yield was a null model (Table 1 and Figure 2a). The null model was 0.84 ΔAIC_c from the next best model, which included bird species richness as the only predictor (Appendix S1: Table S2). However, both the p value ($p > 0.05$) and confidence intervals of the second-best model indicated that bird species richness was not actually a significant predictor of crop yield.

DISCUSSION

Our findings emphasize the importance of measuring crop yield rather than simply plant damage when assessing trophic cascades in agricultural systems, as the two are not always equivalent. We found that excluding birds from plants resulted in lower arthropod pest damage to leaves but did not affect grain yield (Figure 2). This leaf damage is likely due to intraguild predation of birds on predatory arthropods (Garfinkel et al., 2020); birds consuming predatory arthropods such as spiders and carnivorous beetles indirectly release arthropod pests, which then cause damage to the crop in a typical four-level trophic cascade (Grass et al., 2017; Martin et al., 2013). However, this increased damage did not affect crop yield and therefore did not reach the economic injury level.

When plants experience damage below the economic injury level, they can compensate and show no overall reduction in reproductive output (i.e., grain yield; Pedigo et al., 1986). Soybeans, in particular, can withstand large amounts of leaf defoliation without yield loss because they exhibit delayed leaf senescence following injury. The delayed leaf senescence allows them to compensate for earlier lost leaf area (Abu-Shakra et al., 1978). Therefore, although birds in our system may have indirectly promoted leaf damage through their intraguild predation of arthropod predators, they exerted neutral net effects on crop yield.

We did not directly measure the quantity of arthropods birds consumed in this study, but we did examine the species identity of bird prey items in a complementary study conducted at the same sites (Garfinkel et al., 2021b). In that previous study, we used fecal metabarcoding to determine that birds consumed both known soybean pests as well as arthropod natural enemies. While these birds consumed a significantly higher proportion of herbivorous prey species than natural enemy species, we were unable to determine the comparative biomass of herbivores vs. natural enemies that were consumed. Therefore, it is possible that birds consumed more species of herbivores, but more natural enemy biomass, which could explain our finding that bird exclosures had higher levels of leaf damage. One other study that directly measured consumption of natural enemies by birds in agriculture found that bird exclusion resulted in a 4% increase in predatory hoverfly larvae density in wheat but a 45% hoverfly increase in oat crops (Grass et al., 2017). This is further evidence that birds can reduce arthropod natural enemy density, but the magnitude of that reduction may be dependent on local conditions including crop type.

Although some studies have found that bats can provide similar or complementary pest control services to those provided by birds (Maas et al., 2016), we believe that the exclosure effects in this experiment were primarily due to bird and not bat exclusion. Studies that examine bat exclusion effects often use large, tall exclosures to keep bats from the air space above crops (Maine & Boyles, 2015). Because our exclosures were shorter (1.5 m tall), they would not have prevented bats from foraging above the crops. Furthermore, no bat species in our study system forage by gleaning insects from leaves. Therefore, we believe that our exclosure results are due only to birds that glean arthropods directly off of the crop leaves rather than bats that forage in the air space above the crops.

In a previous study in a similar agroecosystem (Garfinkel et al., 2020), we found that birds indirectly negatively affected crop yield in soybeans grown adjacent to a prairie patch. The contrasting findings in these two studies likely result from several factors. First, pest densities can vary widely between years (Rhainds et al., 2010). If pests were at an overall lower density during the current study than the previous, then we would expect to see a smaller effect of birds on crop yield. Because we did not measure leaf damage in the previous study, we cannot compare that parameter between studies. Additionally, pest identity varies between years, with the most economically important pest species varying over both time and space (Bueno et al., 2013). It is possible that the pests during the previous study were less palatable to birds, causing them to consume more predatory arthropods than herbivorous ones. Finally, soybean crops need adequate growing conditions such as ample water to compensate for damage with delayed leaf senescence and compensatory regrowth (Haile et al., 1998). In northeast Illinois, the summer of the current study was slightly wetter than that of the previous study (28.9 cm of precipitation in June and July combined in 2017 vs. 25.2 cm in 2016 during the previous study; NOAA National Centers for Environmental information, 2020). It is therefore possible that rainfall was sufficient to allow for compensatory regrowth in 2017 but not during the earlier study in 2016. Regardless, our findings emphasize the need for longer-term research on services and disservices within this study system. Future studies should determine how often yearly net bird effects are positive, negative, or neutral, so we can determine how these trophic interactions affect long-term gains or losses and farmland resiliency (Admiraal et al., 2013).

We found that bird abundance was a significant positive predictor of average leaf damage at two time points: pre-exclosure, and post-exclosure at growth stage R5 (Figure 4). We found no evidence that bird abundance was correlated with the strength of the treatment effect (i.e., treatment × bird abundance interaction was not a significant predictor). Furthermore, bird species richness was not a significant predictor of leaf damage or crop yield at any time point. The fact that bird abundance was positively correlated with overall levels of leaf damage supports our interpretation that birds indirectly affected crops through intraguild predation. However, further study at sites with a wider range of bird biodiversity would be needed to confirm the relationship between bird populations and leaf damage. In fact, systems with high bird species richness may see net positive effects on crops if species-rich communities are more likely to include birds that consume more pests than predatory arthropods. Moreover, some studies have shown that species-rich natural enemy assemblages may complement each other, thus strengthening top-down control (Letourneau et al., 2009; Mooney et al., 2010; Philpott et al., 2009).

We found lower overall leaf damage in field interior than in edge plots in both post-exclosure analyses, and a significant interaction between treatment and plot distance from edge in the R5 analysis (Table 1 and Figure 3). This significant interaction suggests that bird trophic effects were stronger at the field edge than in the field interior. This is likely due to the fact that many pests are found in higher densities near field edges (Nguyen & Nansen, 2018). The trophic interactions that occur at field edges are often more complex than those in field interiors, because, in addition to increased pest densities and bird activity (Puckett et al., 2009; Rodenhouse & Best, 1994), field edges may exhibit spillover of predatory arthropods from natural habitat into crop, and vice versa (Macfadyen & Muller, 2013; Rand et al., 2006). Future studies should specifically examine movement patterns of species from all trophic levels, from pests to birds, along field edges within a mixed soybean/grassland system. This information may help to optimize the incorporation of grassland patches into agricultural matrices to maximize vertebrate and invertebrate natural enemy activity within cropland while maintaining high crop yields.

The data presented here describe only a small portion of the chain of interactions that occur in an agricultural trophic cascade. To make specific management recommendations for this system, we would need to also have information about pest and arthropod natural enemy density, arthropod biomass consumed by birds (see Garfinkel et al. [2021b] for more detailed information on bird prey in this system), and measurements under multiple field conditions describing the relationship between pest damage to soybeans and effects on crop yield. For instance, research suggests that during the blooming and pod-forming growth stages (when we measured defoliation), soybeans can withstand up to approximately 20% foliage loss before yield is decreased (Mississippi State University Extension, 2021). However, this can vary with cultivar, pest type, and farm geographic location (Bueno et al., 2013). Few of our leaves showed >20% defoliation, suggesting that during our study season overall pest pressure may not have been strong enough to substantially affect grain yield. This is an important limitation of our study, and we recommend that future studies take place across a range of pest densities and include plots that exclude both birds and arthropods to examine and control for differences in overall pest pressure. Nevertheless, our study still demonstrates that a perceived "pest" (i.e., birds) may not always cause economic damage.

Our study raises the question: When is a pest a pest? If we define a pest "as any organism that decreases fitness, population size, growth rate, or economic value of any resource important to humans" (Whelan, Şekercioğlu, et al., 2016; Whelan, Tomback, et al., 2016), then we suggest that, in agricultural systems, bird arthropod predators are pests only when their consumption of beneficial arthropod predators causes an increase in arthropod herbivores and leads to crop losses or increased crop damage. Similarly, herbivorous arthropods are themselves pests only when their herbivory reduces crop yield. In the present study, although bird predation of arthropod predators appeared to release crop pests, this predatory activity of birds did not cause a reduction in crop yield, a variable of paramount importance from the perspective of the farmer. Our study thus illustrates the critical importance of quantifying net effects in agricultural systems when assessing the roles of birds and other natural predators in these systems.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data (Garfinkel, Minor, Whelan, & Fuka, 2021a) are available from Figshare: 10.6084/m9.figshare.14109833.v3.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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