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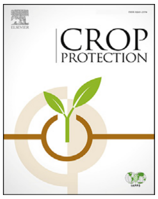

Proportions of bird damage in tree fruits are higher in low-fruit-abundance contexts

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ABSTRACT

Frugivorous birds impose significant costs on tree fruit growers through direct consumption of fruit and grower efforts to manage birds. We documented factors that influenced tree fruit bird damage from 2012 through 2014 with a coordinated field study in Michigan, New York, and Washington. For sweet cherries, percent bird damage was higher in 2012 compared to 2013 and 2014, in Michigan and New York compared to Washington, and in blocks with more edges adjacent to non-sweet cherry land-cover types. These patterns appeared to be associated with fruit abundance patterns; 2012 was a particularly low-yield year for tree fruits in Michigan and New York and percent bird damage was high. In addition, percent bird damage to sweet and tart cherries in Michigan was higher in landscapes with low to moderate forest cover compared to higher forest cover landscapes. 'Honeycrisp' apple blocks under utility wires were marginally more likely to have greater bird damage compared to blocks without wires. We recommend growers prepare bird management plans that consider the spatial distribution of fruit and non-fruit areas of the farm. Growers should generally expect to invest more in bird management in low-yield years, in blocks isolated from other blocks of the same crop, and in blocks where trees can provide entry to the crop for frugivorous birds.

1. Introduction

Increasing fruit and vegetable consumption is a goal of the World Health Organization (2010) because of the strong positive effects of fruits and vegetables on human health (Lock et al., 2005). U.S. per capita consumption of non-citrus fruits increased approximately 35% from 1976 through 2012 (USDA ERS, 2013). Fruit production is also a critical component of the global economy; the top five cherry-growing nations produced a collective yield valued at more than one and a half billion dollars in 2011 (FAOSTAT, 2011).

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Thus, increasing fruit production has both social and economic benefits.

Birds damage and consume numerous cultivated fruits (Tobin et al., 1991; Avery et al., 1992; Curtis et al., 1994; Tracey and Saunders, 2010; Lindell et al., 2012). Fruit growers from Michigan, New York, Oregon, California, and Washington estimated that bird damage to sweet cherries in 2011 was between 4.8 and 31.4%, to tart cherries between 3.0 and 26.7% and to 'Honeycrisp' apples between 0.4 and 7.4% (Anderson et al., 2013). Birds pose unique management challenges because of their high mobility (Bomford and O'Brien, 1990; Linz et al., 2011). This mobility means that spatial context is likely to influence levels of bird damage to fruit crops. Despite increasing awareness of the importance of spatial context to agricultural systems (Robertson et al., 2007), few studies have systematically investigated spatial effects on bird damage to fruit crops (Johnson et al., 1989).

Two spatial scales likely to be important are the farm scale, which we consider, roughly, as fractions of hectares, and the landscape scale, which we consider to be hectares. Different mechanisms may drive bird damage effects on these different scales. On the farm scale (Ries and Sisk, 2004), fruit blocks and adjacent areas that are not fruit may provide complementary resources, for example, food in one and nest sites in the other. Fruit blocks may be particularly susceptible to damage if they are adjacent to woody vegetation, which may provide cover from predators, and nesting and/or roosting sites. Johnson et al. (1989) suggested that higher bird damage in grapefruit groves close to sugarcane fields was a result of the sugarcane providing roost sites for great-tailed grackles (*Quiscalus mexicanus*), the species causing the majority of grapefruit damage. Similarly, sunflower fields near cattail marshes that provided roosting habitat for blackbirds suffered higher bird damage than those fields not adjacent to marshes (Otis and Kilburn, 1988). We refer to these farm-scale spatial effects as edge effects hereafter.

On the landscape scale, percent bird damage to fruit may be greater in areas with overall low fruit abundance. For example, grapefruit groves farther from other groves had higher bird damage than those close to other groves (Johnson et al., 1989). Additionally, fruit blocks in landscapes with alternative and supplemental food for frugivorous birds may be at higher risk for bird damage. For example, farms with grain or corn silage may provide food for species like European starlings (*Sturnus vulgaris*), which also eat fruit, thus contributing to higher starling population sizes and more fruit damage.

Apart from spatial context, areas that have resources important to birds may be at higher risk for bird damage. For example, fields with overhead utility wires that provide perches may experience greater damage than adjacent blocks without wires.

Our specific objective was to quantify the influence of environmental characteristics on bird damage in several tree fruit crops in three important fruit-growing states of the U.S. Identifying factors at the farm and landscape scales that influence levels of bird damage can provide a basis for making recommendations to fruit growers about the vulnerability to bird damage of areas with particular features. This information can aid in orchard site selection, farmland use, and selection of bird management strategies. Extension personnel and regional planning agencies also can use the information as a basis for land-use recommendations at a larger spatial scale than individual farms.

2. Methods

2.1. Study regions

The study was conducted from 2012 through 2014 in important production regions for sweet cherries (*Prunus avium*), tart cherries (*Prunus cerasus*), and 'Honeycrisp' apples (*Malus x domestica*). Sweet cherries were sampled in the northwestern Michigan counties of Leelanau, Antrim, and Grand Traverse, the New York counties of Niagara, Orleans, Monroe, Wayne, Oswego, and Tompkins, and the Washington counties of Franklin, Walla Walla, Yakima, Chelan, and Douglas. Tart cherry sampling took place only in Leelanau County in northwestern Michigan. 'Honeycrisp' sampling took place in the northwestern Michigan counties of Leelanau, Antrim, Grand Traverse, and Benzie, the New York counties of Niagara, Orleans, Wayne, Oswego, Tioga, and Tompkins, and the Washington counties of Whatcom, Skagit, Franklin, Walla Walla, Yakima, Okanogan and Douglas.

2.2. Block selection

We defined a block as a contiguous area of one crop, with boundaries delimited by other land-cover types at least 5 m wide. For example, orchard roads at least 5 m wide often comprised block boundaries. We approached fruit growers in each state to gain access to commercial orchards to conduct sampling of bird damage. We used one apple block at a university horticultural research station.

2.3. Sampling bird damage within blocks

To measure bird damage within blocks, and to quantify potential differences in damage between edges and interiors of blocks, we followed the method of Tracey and Saunders (2010) where blocks were divided into four edge strata and one interior stratum. Within a block, edge strata were two rows wide with the interior stratum comprising all other rows.

2.4. Plant selection

We sampled up to 12 plants per stratum. Within each stratum, we randomly selected a starting plant and then systematically chose 11 more plants to provide approximately even coverage of the stratum. For example, if we randomly selected the 4th plant from the southeast corner as the starting plant for a stratum and the stratum contained 103 plants in total, we sampled every 9th plant so that the 11 remaining sample trees were from all areas of the stratum.

2.5. Branch selection

For each plant, we randomly selected a branch by choosing random numbers to delineate the horizontal and vertical components of the branch location. For the horizontal component we randomly selected one of the eight half-winds of the compass rose (NNE, ENE, ESE, SSE, SSW, WSW, WNW, NNW). For the vertical component, we measured the height of the tree and randomly selected a number, based on the number of 0.5-m intervals between the base of the plant's foliage and the height of the tree. We sampled the branch closest to the randomly selected half-wind and height.

2.6. Sweet and tart cherry sampling

On the selected branch, we located the terminal tip of woody growth and followed the branch 1 m back toward the trunk. We counted all intact cherries, missing cherries, and damaged cherries on the 1-m-section of the branch. We identified missing cherries by fresh pedicels, grown in the year of sampling, without fruit. We disregarded desiccated pedicels from previous years. For selected branches that were less than 1 m in length, we used the branch length to standardize cherries per meter across samples.

2.7. Apple sampling

On the selected branch, we located the terminal tip of woody growth and followed the branch back to the trunk. We counted all intact apples and bird-damaged apples on this branch and on all side shoots and spurs. If there were fewer than 50 apples on the chosen branch we went clockwise around the tree to the next half-wind, found another branch at the same randomly selected height, and repeated the process of counting the intact and damaged apples on the selected branch. If there was no branch at the correct height in a given sector, we went to the next sector. We repeated this process until we had counted at least 50 apples for a tree, although we did not sample more than four branches per tree, even if we had not yet reached 50 apples. We measured the length of the selected branch and determined the abundance of apples per unit length of branch.

Before official sampling began, field workers practiced counting damaged and intact fruits, and identifying evidence of bird damage. For example, cylindrical holes in apples were considered evidence of bird damage. When there was evidence of mammal damage near or in a sampled tree (e.g., scat on the ground, substantial damage to leaves as well as fruit), these plants were removed from data analyses.

2.8. Bird observations at edges of sweet cherry blocks

We suspected that wooded areas might provide resources like cover from predators and serve as “staging grounds” for birds to enter fruit bocks, making blocks next to wooded areas particularly susceptible to bird damage (Johnson et al., 1989; Tracey and Saunders, 2010). Therefore, we conducted 22 30-min observations at 11 sweet cherry blocks (2 observations at each block) in Leelanau and Benzie Counties, Michigan, in July 2014, as close as possible before harvest. There was no active bird management in eight of the blocks, a methyl anthranilate bird repellent spray and scare devices were used at two blocks and one block had an occupied American kestrel, *Falco sparverius*, nest box (kestrels sometimes consume fruit-eating birds, Shave and Lindell, unpubl. data). Blocks were between 0.4 and 9.3 ha. Observers conducted observations from block corners at block edges that were adjacent to deciduous and/or coniferous forest that was greater than 5 m tall (forest edges) or at edges that did not meet this criterion (non-forest edges, generally sweet or tart cherries or herbaceous cover). For each observation period, the observer used binoculars to count and identify birds that traversed the edge in either direction, i.e., from the block to forest/non-forest or from forest/non-forest to the block. Edges observed were approximately 100 m long although in two cases they were less than 100 m. Observations took place between 8:30 and 17:00 when diurnal birds were active and in coordination with other project activities.

These observations, as well as other work in sweet cherries in Michigan in 2013 and 2014 provided a list of bird species we observed actually eating cherries and which we thus classified as frugivorous species. We classified other bird species that we did not actually observe eating cherries as frugivorous if their diet regularly includes fruit in summer, as described by Rodewald (2015).

2.9. Landscape analyses

Initially we planned to use the Cropland Data Layer (CDL, Johnson and Mueller, 2010) to provide land cover data for landscape analyses. However, the CDL land cover/use (LCLU) classifications for the specialty crops that were the focus of our study proved to be too inaccurate (Lusch, 2015) based on comparisons with LCLU visually interpreted from National Agriculture Imagery Program (NAIP, 2013) true-color imagery (Table 1). Therefore, we used the LCLU that was visually interpreted from the NAIP 1-m orthoimagery for all land cover analyses.

We classified NAIP imagery within roughly 500-m buffers around each study block into the following categories: urban/built, bush fruit (e.g., blueberries), tree fruit (e.g., cherries and apples), vine fruit (e.g., grapes), other agriculture, grassland, shrub land, forest, wetland, water, and barren. These LCLU classes were visually interpreted from the NAIP imagery in a GIS environment and subsequently verified/corrected based on ground-truth observations by field workers. The area of each LCLU type in each buffer was calculated in the GIS, as was the perimeter length of each study block that was adjacent to particular LCLU types. Areas and lengths are in meters squared and meters, respectively.

One limitation of the NAIP imagery classification was that different types of tree fruits, for example cherries vs. apples, could not be distinguished from each other. Therefore, we also used ground-truth data to create another variable, the number of block edges of the same fruit type. While block boundaries were delimited by adjacency to land-cover types different from the fruit crop (often mown roads), we also recorded the land-cover type that made up the majority of the area within 25 m of each block boundary and these were often of the same fruit crop. For example, a sweet cherry block separated from other sweet cherry blocks by orchard roads at least 5 m wide but in the center of a group of blocks could have a maximum score of 4 for the number of block edges of the same fruit type. This variable represented the degree to which a block was surrounded by alternative food sources for birds. For tart cherries, we included the number of edges with either sweet or tart cherries. Sweet cherries ripen earlier than tart cherries; thus there are residual sweet cherries available when tart cherries are ripening because harvest does not remove all sweet cherries.

Fruit growers we worked with, particularly in the Pacific Northwest, have concerns about the potential positive effect of grain sources on the distribution of European starlings (*Sturnus vulgaris*) a species that eats both grain and fruit, can occur in large numbers, and travels widely. Other frugivorous bird species vary in their use of grain and so proximity of grain sources and fruit crops may or may not influence their use of the fruit crops. Therefore, we determined the number of farmsteads with potential grain food sources around each block by visually identifying and digitizing the boundaries of farmsteads within a 10-km buffer. The 10-km buffer was based on the flight distance starlings travel in an agricultural landscape (Homan et al., 2013) and the fact that identifying grain sources from imagery within larger buffers would have been prohibitively time-intensive. We included farms that showed evidence of sources of potential grain for birds such as bunkers, uncovered hay, open grain bins, or livestock yards, all easy targets for identification from most NAIP imagery. Completely enclosed operations, such as poultry farms or enclosed grain elevators, were not included unless the property also included open food sources.

2.10. Statistical analyses

We calculated weighted bird damage estimates for each block by first determining the mean damage per stratum from the 12 trees sampled in each of the five strata per block. We then multiplied the mean for each stratum by the proportion of the plants in that stratum given the number of plants in the whole block (Tracey and Saunders, 2010). We calculated standard errors of the weighted damage estimate for each block following Tracey and Saunders

(2010). Percent fruit loss to birds at edges and interiors of blocks was calculated only for blocks for which we had data for both edges and interiors, i.e. some blocks were too small to have interior strata.

To obtain normally distributed response variables we used a log transformation for sweet cherries and an arcsine transformation for tart cherries for the weighted damage estimates for each block. The 'Honeycrisp' data could not be successfully transformed so we used another approach for these data, detailed below. For the transformed sweet and tart cherry data, we examined potential explanatory variables of bird damage (Table 2) for significant correlations ($P < 0.05$) and avoided using correlated variables within one model.

To develop sets of candidate models to explain damage for sweet and tart cherries, we generated generalized linear models using PROC MIXED (SAS 9.4, 2013). PROC MIXED allows mixed models with fixed and random factors. Year and block were considered random factors in analyses and the other factors were considered fixed (Table 2). We first examined AIC (Akaike's Information Criterion) values for sweet cherry single-variable models, and AICc values for tart cherry single-variable models. (The smaller sample size for tart cherries necessitated using AICc values Burnham and Anderson (2002). The variables from single-variable models with the lowest AIC or AICc values were then used in combination with other potential explanatory variables and interaction terms to generate sets of models for comparison. The model with the lowest AIC or AICc value, that was at least 2 units lower than the AIC or AICc value of the next best model, was considered the best model (Burnham and Anderson, 2002). We checked if model fit was adequate by examining residual plots and values of fit statistics generated by SAS 9.4 (2013). We tested for significant differences between classes within variables (e.g. between individual years) using contrast statements (SAS/STAT(R) 13.2 User's Guide).

We found that state (Michigan, New York, or Washington) was a significant factor influencing bird damage to sweet cherries (see Results). Thus we did additional analyses separately for each state following the steps in the previous paragraph, using AICc values to determine best models. Because of smaller sample sizes in these state models we changed the variable "Proportion forest in 500-m buffer" into a categorical variable, landscape forest cover, with low to moderate landscape forest cover (<50%) or high landscape forest cover (>50%).

We tried other modeling procedures for the 'Honeycrisp' data, using distributions besides the normal distribution. However, resulting models had poor fit. Therefore, we used a simpler approach, comparing values of potential explanatory variables for blocks with less than 2% bird damage to blocks with greater than 2% bird damage. (Two percent was the average estimate of bird damage over all blocks, years, and state). We used contingency table analyses to examine associations between the two levels of bird damage and the discrete variables year, state, presence of wires overhead, and number of block edges of the same crop. We used a *t*-test to compare effects of the continuous variable block size on the two levels of bird damage.

To determine whether edge strata more commonly showed higher damage than interior strata of blocks, we calculated the number of edges for each block that showed higher damage than the interior of that block. For example, a block could have a maximum of four edge strata with higher damage than the interior. We then compared the number of edge strata with higher damage for all blocks within a state, year, and crop to the number of edge strata with less or equal damage to the interiors of the blocks with chi-square goodness of fit tests. We generated expected frequencies for the tests using the assumption that edge strata should be equally likely to show higher or lower damage than interiors.

To determine whether the numbers of frugivorous birds traversing forest-sweet cherry edges vs. non-forest-sweet cherry edges differed, we lumped data from the eleven blocks where we made observations, given no apparent difference in the number of birds detected from blocks with bird management ($n = 3$) versus blocks without bird management ($n = 8$, $t = 1.09$, $P = 0.30$). We determined the expected frequencies of frugivorous bird crossings at the two edge types based on the number of minutes we observed each type ($n = 270$ min for forest/sweet cherry edges and 390 min for non-forest/sweet cherry edges). Birds that could not be identified to species were excluded from analyses (roughly 18% of total detections and similar numbers from non-forest and forest edges). We used *G*-tests for goodness-of-fit with Williams's correction (Sokal and Rohlf, 1995).

3. Results

Percent bird damage in sweet cherries was best explained by a model containing the variables year, state, edge effects, and the three-way interaction of year, state, and edge effects (the number of block edges adjacent to sweet cherries, Table 3). There were lower percentages of bird damage in 2013 and 2014 compared to 2012, in Washington compared to Michigan and New York, and in blocks with more edges adjacent to sweet cherries, although these patterns varied by year and state (Fig. 1). Counterintuitively, bird damage in Michigan tart cherries was lower in landscapes with higher proportions of forest cover (Table 3). For the sweet cherry model, the random block effect explained a significant amount of the variation in bird damage (Wald Z-test, $P = 0.008$), while for tart cherries block was not a factor.

When we repeated the model building procedures for sweet cherries for each state separately we found that the best model to describe Michigan sweet cherry bird damage included the variables year, landscape forest cover, and the interaction of these two variables (Table 4). Although this best model contains two variables that don't reach the p-value of 0.05, it had an AICc value six units lower than any other model, indicating strong support for this model (Burnham and Anderson, 2002). We did not find any models for New York or Washington that included any variables with

Table 1
Land cover/use accuracies of the 2011 CDL data.

Land cover/use	Michigan		New York		Washington	
	Conditional kappa[a]	Average polygon size (ha)	Conditional kappa	Average polygon size (ha)	Conditional kappa	Average polygon size (ha)
Tree fruit	0.218	5.6	0.683	4.4	0.698	5.1
Bush fruit	0.371	5.6	−0.004	0.5	0.674	6.5
Vine fruit	0.172	2.2	0.709	2.6	0.589	4.2

[a] The conditional kappa coefficient is a measure of per-category classification accuracy based on a difference measurement between the observed agreement of the classified image vs. ground truth and the agreement contributed by chance. The conditional kappa coefficient ranges from −1 to +1. A conditional kappa coefficient of 0.65 means that the category classification is 65% better than that expected by random pixel assignments to this class. A negative conditional kappa coefficient means that the class accuracy is worse than random pixel assignments to this class.

Table 2
Potential explanatory variables tested for their influence on bird damage to sweet cherries in Michigan and New York (2012–2014) and Washington (2012 and 2013) and to tart cherries in Michigan (2012–2014).

Type of variable	Potential explanatory variables
Local resources for birds	Block size, Number of fruits inspected[a], Overhead wires[b]
Edge effects	Number of block edges of the same crop adjacent to focal crop[c], Proportion of total block edge adjacent to tree fruit, Proportion of total block edge adjacent to forest
Landscape effects	Proportion forest in 500-m buffer, Proportion tree fruit in 500-m buffer, Proportion urban/built in 500-m buffer, Number of farms within 10 km
State effects	State[d]
Year	Year

[a] Given our sampling procedure, with a fixed number of trees sampled per block, and a standardized length of branch per tree, the total number of fruits inspected provides an index of local fruit abundance.
[b] Over or within 25 m of a block.
[c] For example, a sweet cherry block adjacent to sweet cherries on two sides would receive a score of 2.
[d] Michigan, New York, or Washington.

significant p-values.

'Honeycrisp' apple blocks with wires overhead were marginally more likely to have greater than 2% bird damage compared to blocks without wires, which generally had less than 2% bird damage ($X^2 = 3.33$, df = 1, p = 0.07). Other potential explanatory variables were not different between the two levels of bird damage.

Sweet cherries in Michigan and New York, and tart cherries (only sampled in Michigan) had very low yields in 2012 compared to 2013 and 2014 as reflected in the number of fruits inspected (Table 5). Because we sampled approximately 60 branches per orchard in each block, the number of fruits inspected provides an index of the fruit yield. In a check of this assumption, we compared the mean number of fruits inspected per block in each state each year with the sweet cherry production in tons for each state (NASS, 2016). Our per-block numbers of fruits inspected corresponded well with state fruit production within a state for the years sampled. These data are available from the first author. This comparison was not valid across states because of the different numbers of farms producing sweet cherries in each state.

When we examined raw numbers of fruit lost to birds rather than percentages lost for six Michigan sweet cherry blocks sampled over three years, the numbers were remarkably consistent for each block, despite large variation in the number of fruits inspected (Table 6).

Proportions of bird damage at block edges and interiors did not show consistent patterns (Table 7). In Washington sweet cherries in 2012, significantly more edges had higher damage than interiors of blocks (*chi-square* = 23.7; $P < 0.001$). However, tart cherries in Michigan in 2012 and 2013 showed the opposite pattern with greater numbers of edges showing lower damage than interiors (*chi-square* = 7.32; $P < 0.01$ and *chi-square* = 4.06; $P < 0.05$, respectively).

During 6.5 h of observations at non-forest/sweet cherry edges, we observed 46 identifiable frugivorous birds traverse the edges that definitively started their flight in the non-forest and landed in the sweet cherries or started their flight in the sweet cherries and landed in the non-forest (i.e., birds that flew over the non-forest and landed in the cherries were not included in this total). During 4.5 h of observations at forest/sweet cherry edges we observed 60 identifiable frugivorous birds traversing the edges with definitive takeoffs from the forest or sweet cherries and landings in the sweet cherries or forest, respectively (Table 8). Frugivorous birds were significantly more likely to be observed traversing forest/sweet cherry edges than non-forest/sweet cherry edges ($G = 10.99$, $n = 106$, df = 1, $P < 0.001$). This pattern was largely driven by American robins which were significantly more likely to be observed traversing forest/sweet cherry edges than non-forest edges ($G = 10.76$, $n = 63$, df = 1, $P < 0.001$). When robins were removed from the analysis, the difference in likelihood of crossing was no longer significant ($G = 0.84$, $n = 43$. df = 1, $P < 0.1$).

4. Discussion

The study produced the following key findings: 1) percent bird damage to tree fruit can vary greatly from year to year and state to state, likely linked to fruit abundance and 2) forest cover at the farm and landscape scales may influence bird damage to fruit in different ways. Based on these findings, a key message to fruit growers is that contexts where fruit abundance is low, for example low-yield years and areas with little fruit, will produce higher percent bird damage in the fruit that is available. Also, determining the risk posed by forest cover at the farm and landscape scales will help growers plan their bird management strategies.

Percent bird damage showed high variation among years and states. We believe these effects are best explained through differences among years and states in fruit abundance, linked to weather, along with consistent levels of fruit consumption by birds from year to year. There was unusually warm weather during the spring of 2012 in Michigan and New York. Growing degree days (GDD) is a measure that combines the number of degrees above which various types of biological development occur with the number of days such a threshold temperature is reached. For example, in Leelanau County Michigan, by April 11, 2012, GDD50 was 169.4, whereas it was only 0.3 by April 11, 2013 and 7.0 by April 11, 2014 (Michigan State University AgBioResearch, 2016). The early warm weather in Michigan and New York in 2012 led to early bud development for tree fruits and then widespread bud destruction and fruit loss with later freezes (Milkovitch, 2012; NASS, 2014; NASS, July 2015). The low fruit yield in Michigan and New York in 2012 compared to 2013 and 2014 is evident from our data on the number of fruits inspected (Table 5).

In addition, we found that birds damaged a consistent amount of fruit over the years of the study (Table 6). There is likely a ceiling on the amount of fruit that can be used by the birds inhabiting a particular area in any given year. When fruit yields are high because of weather (and wild fruit will also likely be abundant in such years), the proportion of fruit lost to birds will be lower because there is far more fruit than birds can eat. Percent fruit loss to birds was much higher in 2012 in Michigan and New York sweet cherries than in the higher-yield years of 2013 and 2014 (Table 5). The same pattern of higher percent bird damage in the low-yield year of 2012 in Michigan and New York, compared to 2013 and 2014, was evident for 'Honeycrisp' apples, and for tart cherries in Michigan (Table 4). Similar results were obtained in a study of cervid damage to sunflowers (Johnson et al., 2014); in a year with high levels of crop and natural food resources, percent damage to sunflowers was

Table 3
Best models to explain bird damage to sweet and tart cherries.

Crop	Explanatory variables in best model	Numerator *df*	Denominator *df*	*F*	*P*
Sweet cherries	Year	2	13	16.13	<0.001
	State	2	13	10.79	0.002
	Edge Effects	4	13	0.66	0.633
	Year*State*Edge Effects	14	13	3.80	0.011
Tart cherries	Proportion forest	1	12	7.52	0.018

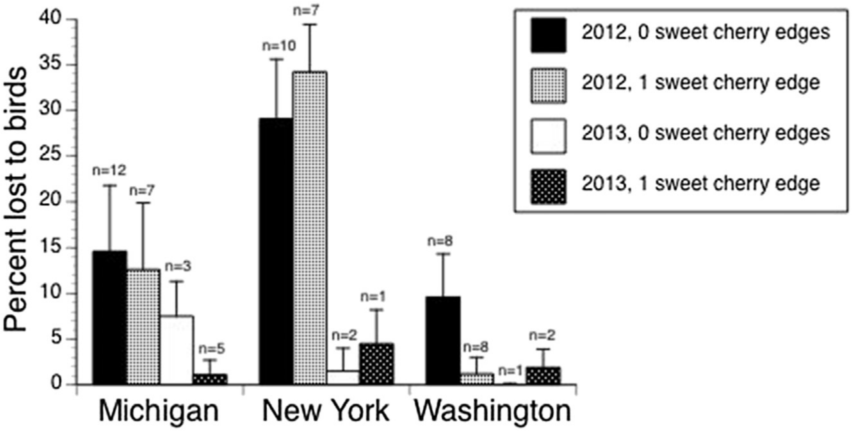

Fig. 1. State, year, and number of block edges adjacent to sweet cherries interacted to influence percent sweet cherries lost to birds.

Table 4
Best model to explain bird damage to sweet cherries in Michigan.

Explanatory variables in best model	Numerator *df*	Denominator *df*	*F*	*P*
Year	2	17	8.03	0.004
Landscape forest cover	1	17	1.77	0.201
Year*Landscape forest cover	2	17	1.69	0.214

Table 5
Average percent fruit loss to birds and mean number of fruits inspected per block ±S.D. Low yields in 2012 in Michigan and New York are reflected in the numbers of fruits inspected.

	Sweet cherries			'Honeycrisp' apples			Tart cherries
	MI	*NY*	*WA*	*MI*	*NY*	*WA*	*MI*
2012							
% loss	13.3 ± 12.0 (23)[a]	31.2 ± 30.4 (17)	4.7 ± 9.3 (20)	3.4 ± 7.5 (18)	2.2 ± 5.8 (24)	2.1 ± 2.6 (16)	4.2 ± 4.9 (10)
Mean S.E.[b]	7.4%	6.0%	3.0%	2.7%	1.8%	2.4%	3.9%
Fruits inspected	401 ± 332	233 ± 313	3082 ± 1769	762 ± 801	486 ± 474	1317 ± 653	58 ± 32
2013							
% loss	3.1 ± 4.3 (10)	2.5 ± 1.9 (3)	2.8 ± 3.3 (5)	0.7 ± 1.2 (7)	0.8 ± 1.5 (7)	1.5 ± 1.5 (10)	2.1 ± 1.1 (5)
Mean S.E.	3.7%	2.9%	2.7%	0.8%	0.9%	2.5%	2.9%
Fruits inspected	3071 ± 1524	1270 ± 594	1053 ± 739	1951 ± 653	941 ± 632	1162 ± 644	2601 ± 747
2014							
% loss	1.5 ± 1.3 (16)	2.7 (1)	–	0.6 ± 0.1 (4)	0.0 ± 0.0 (3)	–	1.5 ± 1.2 (8)
Mean S.E.	2.0%	2.4%	–	1.2%	0%		1.8%
Fruits inspected	4696 ± 2584	1383	–	2277 ± 959	650 ± 368	–	3259 ± 1044

[a] Number of blocks sampled in parentheses; applies to both % loss to birds and mean fruits inspected.
[b] Mean S.E. of block estimates.

low while the next year, with lower levels of food resources, percent crop damage was higher. These results correspond to the general principle that absolute damage in a region is likely to be similar from year to year while local damage is strongly influenced by the area of crop planted and available to pest species (Leitch et al., 1997). For example, corn and sunflower crops in regions of North Dakota with the greatest coverage of these crops had the lowest levels of bird damage (Klosterman et al., 2013).

We note that our index of local fruit abundance, “number of fruits inspected”, was significantly associated with the variable “year” for sweet cherries (Pearson correlation coefficient = 0.52, $P < 0.0001$). We used both “year” and “number of fruits inspected” in our model building; year was consistently part of the stronger models, as indicated by AIC values. We think this may be because the “number of fruits inspected” varied a good deal, both among orchards and states because of weather but probably also for other

Table 6
For six Michigan sweet cherry blocks sampled in 2012–2014, the number of fruits lost to birds was similar among years for each block, although number of fruits inspected, i.e. local fruit abundance, varied greatly.

Block	No. fruits lost to birds (No. fruits inspected)		
	2012	2013	2014
1	33 (184)	51 (2703)	34 (4521)
2	45 (1031)	100 (3218)	89 (8220)
3	18 (44)	43 (517)	29 (3292)
4	0 (5)	3 (308)	6 (1979)
5	52 (559)	39 (3572)	46 (11416)
6	6 (462)	25 (3495)	13 (6211)

Table 7
Average percent fruit loss to birds ± S.D. at edges and interiors of blocks[a]. Underlined type shows one case (sweet cherries in WA in 2012) where more edges than interiors of blocks had significantly higher damage and italicized type shows two cases (tart cherries in MI in 2012 and 2013) where significantly more block interiors than edges had higher bird damage.

	Sweet cherries			‘Honeycrisp’ apples			Tart cherries
	MI	*NY*	*WA*	*MI*	*NY*	*WA*	*MI*
2012							
Edges	12.0 ± 11.5 (21)[a]	25.3 ± 28.9 (13)	6.6 ± 9.1 (20)	4.8 ± 10.0 (16)	0.8 ± 0.7 (8)	2.4 ± 2.1 (16)	*8.0 ± 9.4 (10)*[b]
Interiors	13.2 ± 15.5 (21)	32.9 ± 39.8 (13)	4.5 ± 9.9 (20)	2.4 ± 3.8 (16)	0.2 ± 0.3 (8)	2.0 ± 2.8 (16)	*5.7 ± 8.7 (10)*
2013							
Edges	4.5 ± 5.7 (9)	1.1 ± 1.2 (3)	3.6 ± 2.8 (5)	1.2 ± 1.3 (6)	1.0 ± 0.0 (2)	1.3 ± 1.1 (10)	*1.3 ± 0.6 (5)*
Interiors	1.8 ± 2.1 (9)	4.2 ± 3.0 (3)	2.7 ± 3.6 (5)	0.4 ± 0.9 (6)	0.2 ± 0.3 (2)	1.5 ± 1.8 (10)	*2.6 ± 1.5 (5)*
2014							
Edges	2.8 ± 3.7 (15)	3.5 (1)	–	1.1 ± 0.7 (4)	0.0 ± 0.0 (2)	–	2.5 ± 1.8 (8)
Interiors	1.1 ± 0.9 (15)	1.6 (1)	–	0.2 ± 0.1 (4)	0.0 ± 0.0 (2)	–	1.0 ± 1.1 (8)

[a] Number of blocks sometimes varies from Table 5 because we only calculated averages for blocks for Table 7 with both edge and interior strata. Also, these percent damage values are not weighted by areas of blocks covered by edges and interiors, as are the values in Table 5.

[b] For tart cherries in Michigan in 2012, there was a significantly higher number of block edges that had lower damage than block interiors despite the mean damage level for edges being higher than for interiors.

reasons, for example the varieties prevalent in different states. This might have made “number of fruits inspected” not as strong and consistent a predictor of differences in percent bird damage as year.

There were several spatial patterns of interest. First, we saw lower levels of block-level damage when sweet cherry blocks had more edges adjacent to other sweet cherry blocks (Fig. 1, Table 3) although this effect was not apparent for New York blocks. Second, in 2012, Washington sweet cherry block edge strata were significantly more likely to have higher damage levels than block interiors (Table 7). Third, significantly higher numbers of frugivorous bird crossings occurred at forest/sweet cherry edges compared to non-forest/sweet cherry edges in Michigan. These results indicate that sweet cherries are more likely to be protected from bird damage when they are adjacent to other sweet cherries and that they may be particularly at risk from forest edges which can serve as staging areas for frugivorous birds.

These patterns did not always hold. For example, several state/year combinations did not show consistently higher bird damage in sweet cherry block edge strata compared to interiors and New York, in particular, showed little evidence of edge/interior differences (Table 7), in contrast to previous work (e.g., Johnson et al., 1989; Somers and Morris, 2002; Tracey and Saunders, 2010). These unexpected results could stem from high variability in damage estimates in Michigan and New York sweet cherries in 2012. Damage tended to be low in 2013 and 2014 which may have made it difficult to detect differences between edge strata and interiors. New York sweet cherry blocks may be especially unlikely to show edge/interior bird damage differences because of the small size of the blocks; NY blocks used in analyses were 0.6 ± 0.6 ha while MI blocks were 3.1. ± 2.8 ha, and WA blocks were 4.9 ± 5.7 ha. Because even the interior of a small block is near edges, the benefit we assume accrues to block interiors because they are more distant from birds flying in from areas adjacent to blocks may not exist for small blocks (Wilcove et al., 1986). The small size of NY blocks may negate the protective effect of interior locations.

The spatial patterns described above were at the farm level. We also detected spatial patterns at the landscape level; both sweet and tart cherry blocks in Michigan showed higher bird damage when the 500-m buffer surrounding blocks had low to moderate forest cover (Tables 3 and 4 and Fig. 2). Given anecdotal accounts from growers of the high susceptibility of blocks with forest nearby, along with our result showing more frugivorous bird crossings at forest/sweet cherry edges, we initially found this result counterintuitive. However, two factors may increase the risk of bird damage to cherries in low-to-moderate forest cover landscapes. First, American robins and cedar waxwings, two of the most important cherry consumers in our Michigan study region (Lindell et al., 2012), have larger population sizes in, and/or prefer habitats associated with, agriculture and human development while also using forest edges (Tewksbury et al., 2002; Vora et al., 2003; Witmer et al., 2014). Thus we expect these species to be more abundant and/or active in low-to-moderate forest cover landscapes compared to high forest cover landscapes. Second, low-to-moderate forest cover landscapes likely provide more fine-grained mixing and adjacency of habitat types. The greater interspersion and adjacency of resources offered in a low-to-moderate forest cover landscape–cover from predators and insectivorous food in forest and fruit resources in cherry blocks–may lead to higher use of orchards within these landscapes (Ries and Sisk, 2004).

An additional conclusion from the study, of particular value to researchers studying bird damage to crops, is the importance of conducting studies over multiple years and maximizing sample sizes to the extent possible. Despite the large geographic scope of this study, the multiple years over which it was conducted, and the large sample sizes we garnered, particularly considering an entire block was only one data point, we were not always able to identify determinants of bird damage. For example, we were not able to develop a robust explanatory model for ‘Honeycrisp’ apple bird damage. ‘Honeycrisp’ apples showed lower losses from birds than sweet and tart cherries, with the exception of a few blocks, and the only factor associated with loss levels >2% was overhead utility wires. We can say that wires provide perches for birds and that

Table 8
Species identified traversing edges between non-forest and sweet cherries and forest and sweet cherries, Leelanau and Benzie Counties, Michigan, July 2014.

Species[a]	Number of crossings	
	Non-forest edge	Forest edge
American robin *Turdus migratorius*[b]	24	39
Baltimore oriole *Icterus galbula*	0	3
Black-capped chickadee *Poecile atricapillus*	6	1
Blue jay *Cyanocitta cristata*	1	5
Cedar waxwing *Bombycilla cedrorum*[b]	1	0
Chipping sparrow *Spizella passerine*	6	0
Downy woodpecker *Picoides pubescens*	1	0
Eastern bluebird *Sialia sialis*	5	0
Eastern kingbird *Tyrannus tyrannus*	1	0
European starling *Sturnus vulgaris*	1	0
Purple finch *Carpodacus purpureus*	0	2
Rose-breasted grosbeak *Pheucticus ludovicianus*	0	7
Red-bellied woodpecker *Melanerpes carolinus*	0	2
Scarlet tanager *Piranga olivacea*	0	1

[a] Species observed and excluded from analyses because they rarely eat fruit include American goldfinch (*Spinus tristis*), eastern phoebe (*Sayornis phoebe*), mourning dove (*Zenaida macroura*), northern flicker (*Colaptes auratus*) and song sparrow (*Melospiza melodia*, Rodewald, 2015).

[b] Major frugivorous species in Michigan sweet cherries, based on numbers and occurrence in orchards.

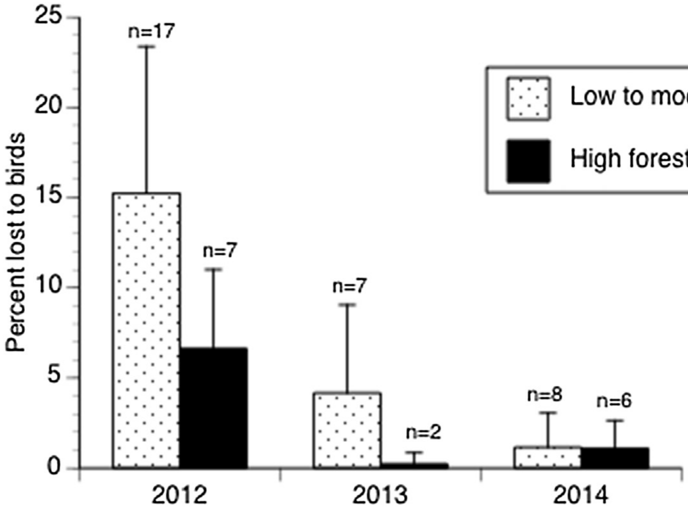

Fig. 2. Michigan sweet cherry bird damage was high in 2012. Also, orchards in landscapes with low to moderate forest cover (<50%) tended to have higher bird damage compared to those with greater than 50% forest, although this effect varied by year. Error bars are mean S.E. of block estimates.

likely increases the risk for bird damage but there are probably other factors we were not able to determine. Both the low mean levels of bird damage to 'Honeycrisp' in all regions and the somewhat smaller sample sizes for this fruit compared to what we garnered for sweet cherries, probably contributed to the limited findings. Similarly, we were not able to develop state-specific models of bird damage to sweet cherries for New York and Washington, although we were able to for Michigan. Despite strong efforts in all states, we sampled fewer sweet cherry blocks for baseline estimates in New York (13 in 2012, 3 in 2013, and 1 in 2014) and Washington (20 in 2012 and 5 in 2013) than in Michigan (21 in 2012, 9 in 2013, and 15 in 2014), which may account for some of the difference in successful model development. Additionally, Washington did not experience the great variation in weather conditions in 2012 and 2013 of Michigan and New York. We expect these challenges to be particularly important in studies of vertebrates where damage may be spatially spotty and vary greatly from year to year.

5. Conclusions and management implications

Lack of predictability has been a challenge in developing and deploying effective programs of bird-damage management. Our results indicate that, in low-yield years, a greater proportion of the crop will suffer bird damage. This information can help growers be prepared with bird management plans before the season begins in years when natural and cultivated fruit for birds is anticipated to be low in abundance, perhaps because of factors like late frost or drought. Also, it is likely bird management will not be as cost-effective or efficacious when yields are high, given that percent loss will generally be low even without management (e.g. Klosterman et al., 2013; Johnson et al., 2014).

Other risk factors related to forest cover at landscape and farm scales should be considered by fruit growers and may be amenable to grower or agency manipulation (e.g. Linz and Homan, 2011). Cherry orchards in landscapes with low-to-moderate forest cover may be particularly at risk from frugivorous species like American robins and cedar waxwings that are abundant in, and use, multiple habitat types. At a finer, farm scale, blocks adjacent to non-fruit land cover types, particularly forest, are generally at higher risk. Depending on their situations and resources, growers may: 1) focus management on edges, the source of many frugivorous birds, which should provide some protection if bird pressure is not very high and management is consistently implemented, 2) focus management throughout high-risk blocks, 3) consider the spatial layout of the farm to minimize edge areas by merging blocks so they are as large as possible or 4) accept higher damage levels in these contexts. We recommend farm-specific analysis of risk factors to in order to limit bird damage. Bird management planning is addressed in detail in Tracey et al. (2007, pages 211–218).

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