

BIRDS AND BERRIES: THE COSTS AND BENEFITS OF BIRDS IN AGRICULTURAL
ECOSYSTEMS

By

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ABSTRACT

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There is a long history of studying bird interactions with agriculture. The field of economic ornithology, which looked at the positive and negative aspects of birds in agricultural, was popular at the end of the 19th century. However, the field quickly fell into disrepair. Today, we once again recognize that birds can provide both services and disservices to agriculture. The balance of services and disservices that birds can provide depends on many factors, such as the species found in the crop, the crop in question, and other factors such as surrounding landcover. Many of these factors are currently being disentangled in this rapidly evolving area of research.

To understand how birds interact with crops, we first need to know more about the species that use different crops. In Chapter 1 I characterized the different species that use sweet cherry orchards, blueberry fields, ‘Honeycrisp’ apple orchards, and vineyards in three major fruit growing regions during the early 2010s. I also determined the abundance of fruit-consuming birds found in each crop and investigated which fruit-eating species could be considered important fruit consumers based on their frequency of detection and fruit consuming habits. I also examined if the heterogeneity of the surrounding landcover influenced the abundance of birds found in the various fruit fields/orchards. I found that the abundance of fruit-eating birds varied by both region and crop, as did which species were designated as important fruit consumers. However, abundance was not influenced by the heterogeneity of the surrounding landcover, counter to our predictions.

Certain species of birds are known to be beneficial in agricultural areas. Birds of prey are of particular interest, as they can deter vertebrate pests. In Chapter 2, I investigated the effectiveness of installing nest boxes in attracting American Kestrels to blueberry growing operations in Western Michigan. I then compared the results with a similar study where nest boxes were used to attract kestrels to sweet cherry orchards in Northern Michigan. By installing nest boxes and performing survey transects, I found that boxes did increase the overall presence of kestrel in blueberry fields, although the effect was much weaker than in the sweet cherry study. Nest box occupancy was much lower in the blueberry system when compared to the sweet cherry study region, but reproductive success measures, such as mean clutch size, were similar.

While birds of prey have been documented consuming and deterring fruit-eating birds, they may consumer/deter other species of birds as well. In Chapter 3 I investigated the effect of American kestrel presence on bird abundances in blueberry fields in Western Michigan. I found that active American kestrel boxes did not deter fruit-eating birds from blueberry fields. However, active boxes did deter non-fruit-eating birds, although this trend only held when the box was active. This finding introduces the possibility that kestrels might deter beneficial insectivorous birds, which could be detrimental to the blueberry fields.

Through my work, I have found that the effect that birds will have on a particular agricultural system will be highly context dependent. The mixture of bird species present, the crop type, region, and many other factors will influence how birds fit into an agroecosystem. Introducing predators to control for pests could induce a trophic cascade with positive or negative outcomes. Predicting the nature of the outcome will require intensive studies of the crop in question, with knowledge of the bird and arthropod community in the region.

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PREFACE

There has been an increased interest in the last couple decades in integrating natural systems into agricultural systems. These natural systems have the potential to lend services such as pollination or pest control to agriculture, deemed “ecosystem services”. There are a variety of reasons for the increased interest in ecosystem services: cost savings provided by enhancing ecosystem services, interest in saving natural systems, and the fact that integrating natural systems polls well with consumers represent a few of these reasons.

Pest control is a big driver for trying to integrate natural systems into agriculture. Pests are numerous and onerous in agricultural systems, and expensive to control. Often methods of control are toxic and/or lethal to the organisms in question, and studies have shown that consumers prefer natural methods of pest control when possible.

Fruit-eating birds have been shown to cause lots of damage. Control of fruit-eating birds is expensive, and lethal control is often seen in a poor light by consumers. Any natural control of fruit eating birds will likely be highly sought after. Previous work has shown that predatory birds can be effective at controlling fruit-eating birds found in agricultural areas. Species such as barn owls (*Tyto alba*), New Zealand falcons (*Falco novaeseelandiae*), and American kestrels (*Falco sparverius*) have been shown to decrease fruit-eating birds in a variety of crops.

However, integrating a predatory bird to provide pest control is not always simple. Introducing a predatory bird in one agricultural system may not have the same effect that it does in another system. For example, while one particular crop may experience pest control benefits, a different crop, or crop in a different region, might find no benefit. The process of introducing a predatory bird may also have unintended consequences. For one, methods to attract such birds, like nest boxes, may attract undesirable species as well. Additionally, the predatory bird may

consumer/deter beneficial species, such as insectivorous birds that consume crop-damaging insects. The total effect that birds can have in an agricultural ecosystem is termed ‘net effects’ and is a field that is just now gaining prominence.

My work aims to contribute to the growing field of the net effects of birds in an agricultural ecosystem. To determine the effects of birds in agricultural systems, it will first be important to document which species are present. This is the focus of the first chapter of my thesis, which demonstrates that the species found in an agricultural system will vary by region and crop. The effectiveness of methods to attract beneficial species to an agricultural system will also be important. This is the focus of the second chapter of my thesis, which shows that the effectiveness of nest boxes varies when compared to other nest box systems in different regions and crops. Calculating the total net effect of introducing a predator to an agricultural system will also be important; my third chapter focuses on the kestrel effect on fruit-eating versus non-fruit-eating birds.

In summary, my work demonstrates that bird interaction with agricultural systems has the potential to vary greatly by locality and crop type. Projects to incorporate predator driven ecosystem services will need local, information-rich studies to determine their potential effectiveness.

TABLE OF CONTENTS

LIST OF TABLES	x
LIST OF FIGURES	xi
CHAPTER 1: BIRD SPECIES AND ABUNDANCES IN FRUIT CROPS AND IMPLICATIONS FOR BIRD MANAGEMENT	1
ABSTRACT	2
INTRODUCTION	2
METHODS	5
Study sites	5
Point counts	6
Bird observation data	7
Classification of fruit-eating birds	8
Land-cover data	8
Data analysis and modeling	9
RESULTS	11
Point count results	11
Model results	15
Abundance estimates	15
DISCUSSION AND CONCLUSION	17
ACKNOWLEDGEMENTS	21
LITERATURE CITED	22
CHAPTER 2: NEST BOXES INCREASED PRESENCE OF AMERICAN KESTRELS IN A BLUEBERRY PRODUCTION REGION DESPITE LOW BOX OCCUPANCY	27
ABSTRACT	28
INTRODUCTION	28
METHODS	30
Study area and nest box installation	30
Kestrel surveys and site occupancy	32
Model for site occupancy	33
Box occupancy and reproductive success	35
Model for box occupancy	35
RESULTS	36
Kestrel site occupancy	36
Box occupancy and reproductive success	39
DISCUSSION AND CONCLUSION	40
Site occupancy	40
Box occupancy and nest success	42
Geographic variability in site and box occupancy	43
Implications for using nest boxes to attract natural predators to agricultural regions	45
ACKNOWLEDGEMENTS	46

LITERATURE CITED	47
CHAPTER 3: EFFECT OF AMERICAN KESTRELS ON FRUIT-EATING AND NON- FRUIT-EATING BIRDS IN BLUEBERRY FIELDS IN MICHIGAN.....	52
INTRODUCTION	53
METHODS	55
Kestrel nest boxes and study area	55
Bird surveys	56
Landcover analysis.....	57
Modeling	58
RESULTS	59
Kestrel boxes.....	59
Bird observations	61
Model results: fruit-eating birds.....	63
Model results: non-fruit-eating birds	66
DISCUSSION AND CONCLUSION	69
ACKNOWLEDGEMENTS.....	72
LITERATURE CITED	74

LIST OF TABLES

Table 1.1 Number of study blocks in each crop and region in 2012 and 2013	6
Table 1.2 List of all fruit-eating species observed during point counts.....	12
Table 1.3 The most frequently sighted fruit-eating bird species in each region for 2012 and 2013	14
Table 2.1 The number of sites with at least one kestrel detection for each year 2015-2018	36
Table 2.2. Parameter values from site occupancy model.....	38
Table 2.3. Parameter results from box occupancy model.....	39
Table 2.4. Box occupancy and mean clutch size	40
Table 3.1. Species detected in observations blocks from 2017-2018, and if the species consumes fruit.....	61
Table 3.2. Parameter values for fruit-eating bird model.....	65
Table 3.3. Parameter values for non-fruit-eating bird model.....	68

LIST OF FIGURES

Figure 1.1. Abundance estimates from the fruit-eating bird models, shown as mean number of birds per point count area, comparing within crops among regions in Michigan (MI), New York (NY), and the Pacific Northwest (PNW) during 2012 and 2013	17
Figure 2.1. Map of the Michigan blueberry study area.....	31
Figure 2.2. American Kestrel site occupancy estimates from model for 2015 to 2018.....	37
Figure 3.1. Location of observation blocks, and whether the blocks were associated with an active kestrel nest box, for 2017-2018.....	60
Figure 3.2. Model estimates of fruit-eating bird abundance for the survey season per orchard in 2017 and 2018.....	64
Figure 3.3. Model estimates of non-fruit-eating bird abundance for the survey season per orchard in 2017 and 2018.....	67

CHAPTER 1:

BIRD SPECIES AND ABUNDANCES IN FRUIT CROPS AND IMPLICATIONS FOR BIRD MANAGEMENT

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ABSTRACT

Fruit consumption by birds is a costly problem in North America, yet basic information about the species and abundance of fruit-eating birds in fruit crops, and factors that influence abundance, are lacking. We conducted a study of fruit-eating birds in 'Honeycrisp' apples, blueberries, grapes, and sweet cherries in Michigan, New York, and the Pacific Northwest in 2012 and 2013. We documented the most frequently observed fruit-eating birds in each crop across our study regions, and used fruit-consumption data to identify bird species for each crop and region that have a great impact via fruit consumption. We found that American Robins (*Turdus migratorius*; hereafter, 'robins') and Cedar Waxwings (*Bombycilla cedrorum*; hereafter 'waxwings') are important fruit consumers across regions and crops, while House Finches (*Haemorrhous mexicanus*), additionally, are important in the Pacific Northwest. We modelled and compared the abundance of fruit-eating birds in all four crops, and found that while abundance varied by region and crop, it was unaffected by heterogeneity in the surrounding land cover. Fruit growers can use information from this study to tailor bird management plans to specific crops and regions, depending on the species of concern.

INTRODUCTION

Birds are capable of causing extensive damage in a variety of crops, from fruit to grains (Johnson et al., 1989; Dolbeer et al., 1995; Linz et al., 2000; Lindell et al., 2016). Because they provide a concentrated and energy-rich food source, fruit crops are particularly vulnerable to consumption by birds. Losses caused by birds can have major economic impacts in North America; 'Honeycrisp' apple, blueberry, wine grape and sweet cherry growers in five major growing regions were estimated to suffer losses in the tens of millions of USD annually (Anderson et al., 2013).

Knowledge about the abundances and species of birds in particular regions and crops is necessary when mitigating bird damage (Luck et al., 2015). This type of information is still limited in North America (e.g., Eaton, 2016). Birds with diets that range from fully frugivorous to omnivorous consume fruit crops, including some species that are primarily insectivorous or granivorous (Boudreau, 1972). Species' fruit consumption can vary in magnitude; while robins and waxwings are both frequent visitors to fruit crops, waxwings consume fruit at a higher rate (Lindell et al., 2012a). Region- and crop-specific information can help to identify which species cause damage and indicate which bird management measures may be most effective, as species may exhibit different responses to management techniques. For example, scaring techniques such as air cannons or shooting may be less effective with sedentary territorial birds including many sparrow species, compared to highly mobile birds such as waxwings (Tracey et al., 2007; Rodewald, 2015). Recent advances in unmanned aircraft systems (known as drones) show promise as a bird management tool, but have been shown to be most effective against bird species with large body size, flocks, and birds outside of the breeding season (Mulero-Pázmány et al., 2017).

Fruit-eating bird abundance may vary regionally. Many crops are grown across distinct regions of North America; major grape producing operations exist in 13 different U.S. states from the East to West coasts (United States Department of Agriculture, National Agricultural Statistical Services, 2016). Bird assemblages and abundances in fruit crops will vary by the growing region, just as bird species vary in presence and numbers throughout North America. For example, waxwings are voracious fruit consumers, but are far more common in the eastern U.S. than the west (Sauer et al., 2017); thus, their abundance in fruit crops may vary regionally.

Different crops vary in the type of food resource they provide to birds, and in the season and time frame that the resource is available. Fruit types of differing size and sugar content will attract different species. Small, sugar rich fruits such as blueberries and sweet cherries are attractive to species like waxwings, while larger, thicker-skinned fruits such as apples are attractive to large-billed birds such as American crows (*Corvus brachyrhynchos*, Tobin et al., 1989; Witmer and Soest, 1998).

Bird abundance may be influenced by the surrounding land-cover. While crops can provide food resources, agricultural fields often lack the structural complexity needed for nesting, perching and predator evasion that could be provided in adjacent, non-crop land-cover types (Guerrero et al., 2012). High levels of land-cover heterogeneity could provide a fine scale mixture of resources that would allow for higher numbers fruit-eating birds. Fruit-eating birds cross edges between forest and sweet cherry orchards more often than edges between non-forest and sweet cherry orchards, possibly because sweet cherries and forest provide complementary resources (Lindell et al., 2016).

Our study had multiple objectives. First, we documented the species and estimated the abundance of fruit-eating birds observed in 'Honeycrisp' apples (hereafter 'apples'), blueberries, grapes, and sweet cherries in our study regions in Michigan, New York, and the Pacific Northwest. Second, we combined data on species detections with observations of fruit-consumption behavior to determine which species are likely *important fruit consumers* in each crop and study region. Third, we examined factors that may influence the abundance of fruit-eating birds in our study crops: crop type, region and habitat heterogeneity. We expected that small, high-sugar fruits (e.g., sweet cherries, blueberries and grapes) would have both higher bird abundances and numbers of fruit-consuming species than apples, given that many different sizes

of birds can access smaller fruits. We predicted that abundance estimates would vary by region, as our three different regions have different communities of birds. We predicted that higher habitat heterogeneity surrounding an orchard would lead to higher fruit-eating bird abundances, due to the existence of complementary resources in proximity.

METHODS

Study sites

We conducted this study in 2012 and 2013 in multiple counties in Michigan, New York, Washington, and Oregon. In Michigan, sampling took place in Antrim, Allegan, Berrien, Benzie, Grand Traverse, Lake, Leelanau, and Van Buren counties. In New York, sampling took place in Cayuga, Cortland, Monroe, Niagara, Orleans, Oswego, Onondaga, Schulyer, Seneca, Tioga, Tompkins, Wayne, and Yates counties. In the Pacific Northwest, we worked in Chelan, Douglas, Franklin, Okanogan, Skagit, Walla Walla, Whatcom, and Yakima counties in Washington and Umatilla county in Oregon. Study blocks were defined as contiguous areas of a single cultivar of a crop, delineated by different adjacent land-cover types that were at least 5 meters wide. The number of blocks sampled in each region and crop, are listed in Table 1.1. In Michigan apples, blueberries, grapes, and sweet cherries, study blocks had an average area of 1.2, 1.5, 0.9, and 2.8 hectares, respectively. New York apples, blueberries, grapes and sweet cherries had average areas of 0.4, 0.1, 0.4, and 0.5 hectares, while the Pacific Northwest had average areas of 3.1, 3.8, 1.2, and 5.1 hectares, respectively. Some blocks had bird management measures in place. These included audio broadcast of predator and distress calls, hawk-shaped kites, inflatable tubemen, sucrose spray and/or netting, and nest boxes for American Kestrels (*Falco sparverius*) – a species that can deter fruit-eating birds (Shave et al., 2018). For a given crop, the percentage of blocks with bird management varied greatly each year. For example, 0% of sweet cherry blocks

in the Pacific Northwest had bird management in place, while bird management was present in 93% of grape blocks in Michigan in 2012.

Table 1.1. Number of study blocks in each crop and region in 2012 and 2013.

	Michigan		New York		Pacific Northwest	
	‘12	‘13	‘12	‘13	‘12	‘13
Apples	17	11	15	8	22	7
Blueberries	16	12	10	8	25	5
Grapes	14	7	17	11	25	8
Cherries	22	20	15	8	27	6

Point counts

We performed point counts from June to October in 2012 and 2013, prior to the harvest of each block, as close to harvest as possible. Point counts are a common and well-accepted way to estimate bird abundance (Ralph et al., 1995; Royle and Nichols, 2003). In most cases two observers conducted independent point counts at the same location, with no communication between them during or after the count (Nichols et al., 2000). Both observers recorded all birds visually detected within a 25-meter radius for 15 minutes. Only birds that were in the point count area where recorded; those flying over head were not used in the analysis. Each observer’s point count was considered a separate temporal replicate. In most cases point counts for a site were performed before noon. Point counts were not conducted in rain or high winds. Point count locations were randomly chosen in each block surveyed, with both edge and interior points for blocks where interior points could be located at least 50 meters from any edge. Edge point locations were determined by first randomly choosing a direction (N, S, E, or W), representing which edge of the block to sample. A distance was randomly chosen along that edge to serve as

the center of the point count. For interior points, we randomly chose a column and row from all interior rows of the block. Interior and edge points were considered temporal replicates. Previous work has suggested that bird damage in crops may be higher in agricultural field edges versus the interior in certain landscape contexts; this suggests that bird abundance may be higher on edges (Lindell et al., 2016). Our study design took this possibility into account by including edge and interior points in our study block. If results from edge and interior points were significantly different, we would not be able to use them as replicates within a block. To determine if this was the case, we included a covariate in our fruit-eating bird models signifying whether the point count was conducted in the edge or interior of a study block. In all crop models, the 95 % confidence interval for this covariate included zero, indicating that edge vs. interior location was not significant in the models.

Bird observation data

Foraging observations can be used to document consumption behaviour (e.g. Morrison et al., 2009). To document which bird species consumed fruit, foraging observations were conducted in Michigan, New York, and the Pacific Northwest in 2013 and 2014, at the same study blocks as the point counts. Foraging observations were not conducted on the same day as point counts, so as not to disturb the area before point counts were conducted. Foraging observations were conducted as close to harvest as possible, prior to the harvest. Most observations were made before noon. Using binoculars, the observer moved slowly through a one-acre area in the block, covering the entire acre within 30 minutes. When a bird was observed, the observer kept it in sight as long as possible to record how many fruits were consumed and where the fruit was taken (either the ground or the crop). For our analyses, we disregarded fruit taken from the ground, as well as observations under 20 seconds in durations.

Fruit consumption behavior was only used for species observed 2 or more times in a given crop/region combination. We considered a bird species to be a high consumer of fruit if an individual of that species was observed eating fruit during our observations, with regional data pooled to allow for species-level information.

Classification of fruit-eating birds

Bird species detected from the point counts were classified as 'fruit-eating' if the species met one of two criteria: if the species was seen eating fruit on at least two separate instances during our bird observations, or if the Birds of North America entry for the species described any fruit consumption in the diet section of the account (Rodewald, 2015).

By combining point count and observation data, we identified species in each crop and region as *important fruit consumers*. These species are likely to visit the crop frequently, and to have high fruit consumption rates. For each crop and region, if a species was among the top five most frequently observed species, and had a high fruit-consumption rate for that crop, it was designated as an *important fruit consumer*.

Land-cover data

Surrounding land-cover types for each study block were visually interpreted using the National Agriculture Imagery Program (NAIP) land-cover layer (NAIP, 2013). Interpretations were verified by ground truthing (Lindell et al., 2016). Land-cover types were categorized for a 500-meter radius buffer around each study block, projecting from the centroid of the study block. A 500-meter radius was selected because it covers the breeding season territory sizes of many of the passerine birds we detected, and has been used to quantify the effect of landscape level features on bird abundance (Young, 1956; Mörtberg, 2001; Rodewald, 2015).

We categorized land-cover types as: developed land, bush fruit, tree fruit, vine fruit, other agricultural land, grassland, shrubland, forest, wetland, water, or barren. Land-cover heterogeneity was measured by edge density; calculating the amount of total 'edge' in the 500-m radius around the block (Fletcher et al., 2002; Saïd and Servanty, 2005). An edge was defined as any border between two different land-cover types. Landscapes with more edge will show more fine-grain mixing of different habitat types, and therefore increased heterogeneity.

Data analysis and modeling

Binomial mixture models can be used to estimate abundance when both site and temporal replicates are available; these models are hierarchical, and account for both abundance and observation processes (Royle, 2004; Kéry and Schaub, 2012). We constructed binomial mixture models for fruit-eating bird abundance for sweet cherries, blueberries, grapes and apples. There were multiple spatial replicates for each region, defined as the different study blocks. There were also, in most cases, temporal replicates for each study block. In cases where two observers were conducting independent point counts, the results were used as two temporal replicates. For some blocks, separate point counts were conducted in an edge vs interior area of the study block (as described above), in most cases on the same day or just a few days apart. These were also considered temporal replicates. Therefore, in cases where both edge and interior point counts were taken by two observers, there would be a total of four temporal replicates for a study block. These models were analysed in a Bayesian framework using the R2jags package (Su and Yajima, 2012).

The abundance model is as follows:

$$N_{i,k} \sim \text{Poisson}(\lambda_{i,k})$$

$$\log(\lambda_{i,k}) = \alpha_k + \beta_1 * (\text{Region}_i) + \beta_2 * (\text{Heterogeneity}_i) + e_i, \text{ where } e_i \sim \text{Normal}(0, \sigma^2_\lambda)$$

The observation model is as follows: $y_{i,j,k} | N_{i,k} \sim \text{Binomial}(N_{i,k}, p_{i,j,k})$

$\text{logit}(p_{i,j,k}) = \beta_k + \delta_{i,j,k}$, where $\delta \sim \text{Normal}(0, \sigma^2_p)$

Here, k represents the number of years in the study (2), j represents the number of temporal replicates (4 maximum), and i represents the number of blocks. Count data are often overdispersed due to a high number of 'zero' counts. Overdispersion was accounted for in the abundance models by including a random variable for block (e_i), and in the observation model through a random variable for each temporal replicate ($\delta_{i,j,k}$). Covariates included in the models were region and edge density (our measure of land-cover heterogeneity). The two years when we collected point count data (2012 and 2013) were modelled with different intercepts (α_1 and α_2). We used uninformative priors for each model. Three Markov chains were run for 350,000 iterations, with the first 50,000 iterations being thrown out as 'burn in'. Model convergence was checked visually by looking at the mixing of the three Markov chains, and by ensuring that Rhat values for all models were within 0.1 of 1, a range widely considered to be an acceptable range for convergence (Kéry, 2010). We assessed proper model fit using the ratio between simulated and actual data. A model can be considered a good 'fit' if this ratio is around one (Kéry and Schaub, 2012). Only models with a score of 1.00 +/- 0.02 were included in the results. All models also had a Bayesian p value within .02 of 0.5; values around 0.5 are considered ideal (Kéry and Schaub, 2012). A covariate effect was considered statistically significant if the 95% credible interval (CRI) for the posterior mean of the parameter for the covariate did not include zero (Kéry and Schaub, 2012). Four similar models were constructed to test the effectiveness of bird control, pooling all regions together. In these models, the only covariate was the presence of bird control.

RESULTS

Point count results

A total of 255.5 hours of point counts were conducted, 92.75 hours in 2012 and 162.75 hours in 2013. In Michigan apples, blueberries, grapes, and sweet cherries, 16, 14.25, 11.5, and 30.75 hours of point counts were conducted, respectively. In New York we conducted 18, 12, 22, and 19 hours of point counts in apples, blueberries, grapes and sweet cherries. Similarly, 22.5, 28.25, 19.5, and 31.5 hours were conducted in the Pacific Northwest. Eighty-one bird species were observed during the point counts. Of these, 57 (70.4%) were classified as fruit-eating species (Table 1.2).

The most frequently sighted species varied by growing region and crop (Table 3). Robins were the first or second most detected species in many of the crops across all regions. House finches were in the top five most frequently detected species in all Pacific Northwest crops. For apples, species that had a high consumption rate were house finches. For blueberries, Baltimore orioles (*Icterus galbula*), European starlings (*Sturnus vulgaris*; hereafter, ‘starlings’), robins, house finches, waxwings, black-capped chickadees (*Poecile atricapillus*), American goldfinches (*Spinus tristis*) and white-crowned sparrows (*Zonotrichia leucophrys*) had high fruit consumption. For grapes, only robins and dark-eyed juncos (*Junco hyemalis*) were recorded consuming fruit. For sweet cherries, waxwings, Northern cardinals (*Cardinalis cardinalis*), house finches and robins had high fruit consumption rates.

Important fruit consumers (Table 1.3) often varied by region and crop. We did not capture important fruit consumers in apples in New York and Michigan, as apple consumption behavior was not observed during observations. Robins were an important fruit consumer in blueberries and sweet cherries in all three regions. Grapes only had one important fruit

consumer, and only in the Pacific Northwest: robins. House finches were important fruit consumers in every crop in the Pacific Northwest except grapes.

Table 1.2. List of all fruit-eating species observed during point counts.

Common Name	Scientific Name	Common Name	Scientific Name
American Crow	<i>Corvus brachyrhynchos</i>	Gray Catbird	<i>Dumetella carolinensis</i>
American Goldfinch	<i>Spinus tristis</i>	Hairy Woodpecker	<i>Picoides villosus</i>
American Robin	<i>Turdus migratorius</i>	House Finch	<i>Haemorhous mexicanus</i>
Baltimore Oriole	<i>Icterus galbula</i>	House Sparrow	<i>Passer domesticus</i>
Black-billed Magpie	<i>Pica hudsonia</i>	Indigo Bunting	<i>Passerina cyanea</i>
Black-capped Chickadee	<i>Poecile atricapillus</i>	Lazuli Bunting	<i>Passerina amoena</i>
Black-headed Grosbeak	<i>Pheucticus melanocephalus</i>	Northern Cardinal	<i>Cardinalis cardinalis</i>
Blue Jay	<i>Cyanocitta cristata</i>	Northern Flicker	<i>Colaptes auratus</i>
Brewer's Blackbird	<i>Euphagus cyanocephalus</i>	Northern Mockingbird	<i>Mimus polyglottos</i>
Brown Thrasher	<i>Toxostoma rufum</i>	Orchard Oriole	<i>Icterus spurius</i>
Bullock's Oriole	<i>Icterus bullockii</i>	Palm Warbler	<i>Setophaga palmarum</i>
Cassin's Finch	<i>Haemorhous cassinii</i>	Pileated Woodpecker	<i>Dryocopus pileatus</i>
Canada Goose	<i>Branta canadensis</i>	Rose-breasted Grosbeak	<i>Pheucticus ludovicianus</i>
California Quail	<i>Callipepla californica</i>	Red-bellied Woodpecker	<i>Melanerpes carolinus</i>
Chestnut-backed Chickadee	<i>Poecile rufescens</i>	Red-headed Woodpecker	<i>Melanerpes erythrocephalus</i>

Table 1.2 (cont'd)

Cedar Waxwing	<i>Bombycilla cedrorum</i>	Savannah Sparrow	<i>Passerculus sandwichensis</i>
Chipping Sparrow	<i>Spizella passerina</i>	Scarlet Tanager	<i>Piranga olivacea</i>
Common Grackle	<i>Quiscalus quiscula</i>	Song Sparrow	<i>Melospiza melodia</i>
Common Raven	<i>Corvus corax</i>	Spotted Towhee	<i>Pipilo maculatus</i>
Dark-eyed Junco	<i>Junco hyemalis</i>	Summer Tanager	<i>Piranga rubra</i>
Downy Woodpecker	<i>Picoides pubescens</i>	Tufted Titmouse	<i>Baeolophus bicolor</i>
Eastern Bluebird	<i>Sialia sialis</i>	Vesper Sparrow	<i>Pooecetes gramineus</i>
Eastern Kingbird	<i>Tyrannus tyrannus</i>	White-crowned Sparrow	<i>Zonotrichia leucophrys</i>
Eastern Phoebe	<i>Sayornis phoebe</i>	Western Kingbird	<i>Tyrannus verticalis</i>
Eastern Towhee	<i>Pipilo erythrophthalmus</i>	Western Tanager	<i>Piranga ludoviciana</i>
European Starling	<i>Sturnus vulgaris</i>	Wild Turkey	<i>Meleagris gallopavo</i>
Great Crested Flycatcher	<i>Myiarchus crinitus</i>	Yellow-breasted Sapsucker	<i>Sphyrapicus varius</i>
Golden-crowned Kinglet	<i>Regulus satrapa</i>	Yellow Warbler	<i>Setophaga petechia</i>
Yellow-rumped Warbler	<i>Setophaga coronata</i>		

Table 1.3. **The most frequently sighted fruit-eating bird species in each region for 2012 and 2013.** ‘Frequent species’ are ranked by the number of birds detected per point count hour (denoted by ‘Freq.’). Region denoted by ‘Reg’.

Reg. ^a	Apple	Freq.	Blueberry	Freq.	Grape	Freq.	Sweet Cherry	Freq.
MI	American Goldfinch	0.25	American Robin^b	4.00	American Crow	0.17	American Robin	2.24
	Blue Jay	0.13	Cedar Waxwing	0.77	Vesper Sparrow	0.17	European Starling	1.30
	Eastern Bluebird	0.06	Chipping Sparrow	0.77	House Finch	0.09	Chipping Sparrow	0.42
			American Goldfinch	0.63			Black-capped Chickadee	0.39
			Song Sparrow	0.49			Common Grackle	0.36
NY	Black-capped Chickadee	0.37	American Robin	3.83	House Sparrow	0.39	American Robin	4.68
	House Sparrow	0.37	Baltimore Oriole	1.58	American Goldfinch	0.28	Chipping Sparrow	1.52
	Blue Jay	0.25	Song Sparrow	1.00	Eastern Bluebird	0.28	Cedar Waxwing	1.24
	Palm Warbler	0.12	European Starling	0.50	Chipping Sparrow	0.23	Gray Catbird	1.13
	American Robin	0.06	Common Grackle	0.50	Blue Jay	0.17	European Starling	0.68
PNW	House Finch	4.76	American Robin	1.84	House Finch	1.33	American Robin	5.33
	American Goldfinch	3.87	American Goldfinch	0.25	American Robin	0.56	Cedar Waxwing	0.76

Table 1.3 (cont'd)

American Robin	3.73	Dark-eyed Junco	0.25	Dark-eyed Junco	0.41	House Finch	0.70
Brewer's Blackbird	1.33	White-crowned Sparrow	0.18	Yellow-rumped Warbler	0.36	Western Kingbird	0.60
European Starling	1.16	House Finch	0.14	Northern Flicker	0.10	American Goldfinch	0.57

^a MI=Michigan, NY = New York, PNW = Pacific Northwest

^b Birds that are important fruit consumers for each region and crop are shown in bold; this classification was based on the bird species being both frequently sighted and recorded as a high consumer of fruit (see Methods).

Model results

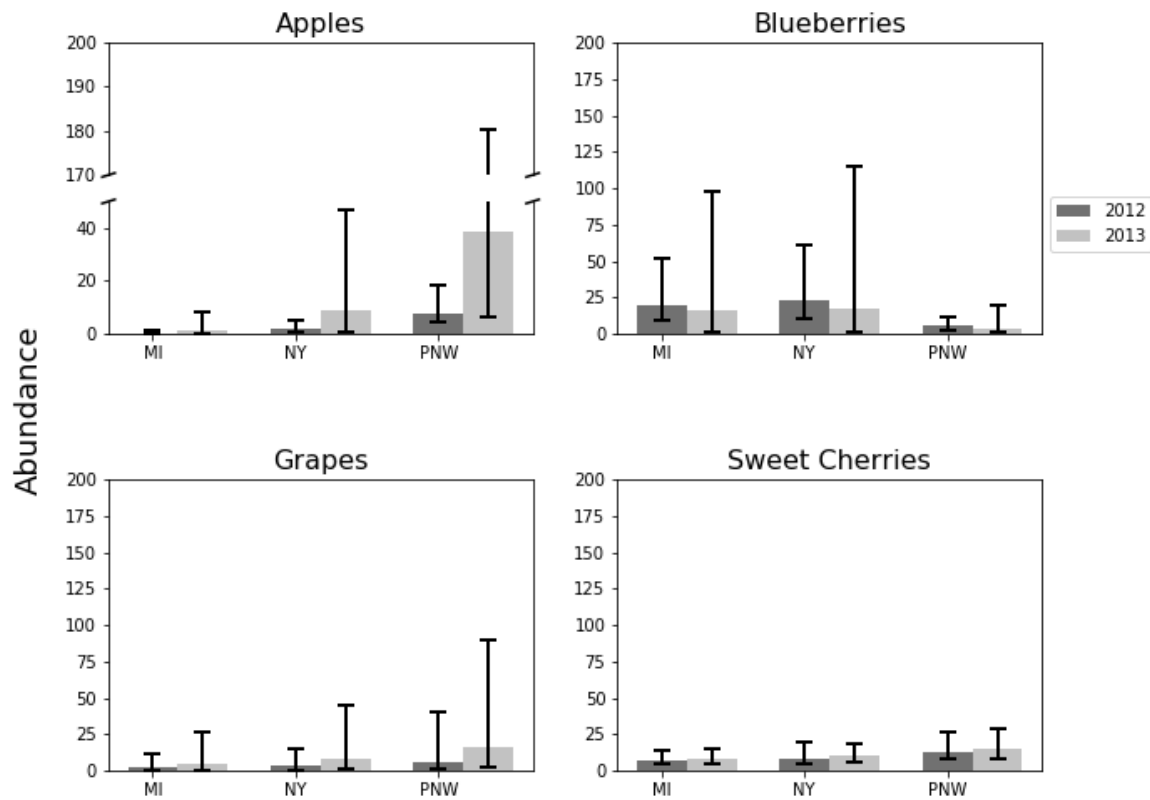
Our results for the fruit-eating bird models show that abundance varied across regions in all crops except grapes; the 95% credible interval (CI) for parameter values for region in each of the crop models with the exception of grapes did not include zero. Land-cover heterogeneity did not significantly influence fruit-eating bird abundance in any of the crop models, as the 95% CI for the heterogeneity parameter in each model included zero. Our separate models for the effectiveness of bird management showed that with the exception of blueberries, bird management did not significantly reduce bird abundance.

Abundance estimates

Abundance estimates from the n-mixture models for fruit-eating birds and robins varied among crops (Figure 1.1). For all fruit-eating birds, estimated mean abundance was highest in apples in the Pacific Northwest in 2013, and lowest in apples in Michigan in 2012. Abundance

estimates did not differ across the three regions in the grape model. For blueberries, the highest mean abundances were in Michigan for both 2012 and 2013. Sweet cherries showed consistently high abundances of fruit-eating birds across all 3 regions, although they did differ among regions and years. Pacific Northwest sweet cherries had the highest means for bird abundance for both years of the study, compared to New York and Michigan.

Figure 1.1. Abundance estimates from the fruit-eating bird models, shown as mean number of birds per point count area, comparing within crops among regions in Michigan (MI), New York (NY), and the Pacific Northwest (PNW) during 2012 and 2013. Error bars represent 95% credible intervals.



DISCUSSION AND CONCLUSION

Waxwings were designated as important fruit consumers in Michigan blueberries, and sweet cherries in New York and the Pacific Northwest. This pattern is surprising, given that waxwings are common in Eastern regions of the United States, and have been recorded as frequent fruit consumers. We expected them to be important fruit consumers in all small-fruit

crops, particularly in the Eastern study regions (Lindell et al., 2012a; Rodewald, 2015). House finches were important in blueberries, apples, and sweet cherries only in the Pacific Northwest; they are more abundant in western regions of the United States than in the east (Rodewald, 2015). Robins were important fruit consumers in sweet cherries and blueberries for all regions, in addition to grapes in the Pacific Northwest. American goldfinches were found to be important in blueberries in both Michigan and the Pacific Northwest. Relatively few bird species were deemed important fruit consumers in grapes; this does not support our prediction that the smaller fruits in our study would have both high abundances and numbers of fruit-eating species and runs counter to literature showing high bird damage in grape vineyards (Stevenson and Virgo, 1971; Somers and Morris, 2002a). We were also surprised by the relatively low number of starlings detected, especially in grapes, as starlings have been shown to cause damage to grapes (Somers and Morris, 2002b).

Land-cover heterogeneity was not a significant influence on fruit-eating bird abundance, in contrast to the results of other studies that have shown that increases in land-cover heterogeneity lead to increased bird abundance in agricultural fields (Guerrero et al., 2012). There could be characteristics of our study system that masked any effects land-cover heterogeneity had on bird abundance. Bird damage in Pacific Northwest apples is low (Lindell et al., 2016), even though abundance estimates for fruit-eating birds in Pacific Northwest apples from this study were higher than for other regions. The Pacific Northwest had much larger orchard sizes than the other two regions; this could lead to damage being 'diluted' in the larger orchards, despite higher bird abundances. This was demonstrated in sweet cherries where larger orchards exhibited lower overall rates of bird damage (Leigh, 2015).

Results from this study have important implications for fruit growers, who can have misconceptions about which species are problematic in their crops. A study by Anderson et al., (2013) conducted surveys of fruit growers in the same regions and crops as our study, asking them to identify bird species responsible for fruit damage. Robins were correctly identified as damaging to fruit in many crops; however, waxwings were never listed as problematic, even though we found them to be important in blueberries and sweet cherries (Anderson et al., 2013). Additionally, starlings were listed as problematic in every fruit category in the surveys (Anderson et al., 2013), yet were only ranked as important fruit consumers in the present study in Pacific Northwest blueberries.

These misconceptions can lead to missed opportunities to implement effective species-specific management strategies. One such bird-management technique is the use of unmanned aircraft systems (drones). Preliminary information suggests that drones could be used in areas predated by larger fruit-eating birds, and birds that are not strongly territorial (Mulero-Pázmány et al., 2017). This could include birds outside of their breeding season, or species such as waxwings that typically defend a small area around a colonial nest (Tracey et al., 2007; Rodewald, 2015). Drones have also shown promise against flocks (Mulero-Pázmány et al., 2017), which could be beneficial in crops that often host large flocks of fruit-eating birds in the fall, such as starlings in New York blueberries. Species-targeted strategies such as decoy trapping can be effective against some species such as starlings (Conover and Dolbeer, 2007).

Our study found that bird management measures did not decrease bird abundance in any crop except blueberries. Another study in the same crop systems found that bird deterrents did not reduce bird damage (Elser et al., under review). A study in grape and blueberry crops found that inflatable tubemen may be effective deterrents, but only in contexts, and that methyl

anthranilate sprays are ineffective (Lindell et al., 2018). Many scaring techniques are effective at first, but lose effectiveness due to habituation (Baxter and Robinson, 2007). Integrated pest management (IPM), which is a combination of pest management practices, is likely the optimal way to deter pest bird populations. IPM can incorporate techniques that have shown to be effective on certain species or in particular situations. For example, it has been shown that ‘sonic nets’ can disrupt starlings’ ability to communicate, and therefore displaces them from an area (Swaddle et al., 2016). In parts of the U.S. where American kestrels breed, putting up kestrel nest boxes in cherry orchards has been shown to greatly reduce the number of fruit-eating birds (Shave et al., 2018).

Dolbeer (1990) suggested IPM as a solution to red-winged blackbird (*Agelaius phoeniceus*, hereafter blackbirds) corn consumption. Blackbirds only feed on corn for a short period during the year; the rest of the time they consume insects. Dolbeer (1990) suggested that a combination of planting different cultivars, harvesting a few days earlier, and targeted scaring techniques during a short critical period can mitigate damage caused by blackbirds in corn fields, while also using the pest control services they provide.

In our study there are several important fruit consumers that could provide beneficial ecosystem services. Robins spend a good deal of time foraging on fruit that has fallen to the ground (Eaton, 2016) which may remove fruit that would otherwise serve as a reservoir for pests and diseases. Other preliminary work suggests that birds foraging on the ground may remove insect crop pests directly (Lindell et al., unpubl. Data). Juvenile robins have a higher proportion of fruit in their diet than adults (Rodewald, 2015) – targeted scaring of juveniles could prevent crop loss, while also allowing them to provide pest control services during other parts of the year. The Baltimore oriole, found to be an important fruit consumer in New York blueberries, is

another omnivorous species that could be potentially be beneficial to crops during parts of its life cycle. Baltimore orioles switch from an insect-based diet during the summer to a fruit-rich diet in the fall (Rodewald, 2015). Planting earlier ripening cultivars of blueberries could lessen the extent of fruit consumption caused by this species, while still allowing them to consume insects during the summer. IPM strategies that use species-specific ecology have the potential to mitigate crop damage, while also harnessing potential ecosystem services.

As a final note, we suggest that more research be conducted on the effectiveness of point counts as a sampling method for flocking species. Several results that we found surprising may be due to point counts not capturing large flocks, as flocks move around frequently and often scare when approached (Melissa Hannay, Michigan State University, personal observation). This could be one cause of the lack of starlings seen in our study; starlings tend to gather in large flocks in the fall, when some fruits such as certain grape cultivars are harvested (Rodewald, 2015).

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CHAPTER 2:

NEST BOXES INCREASED PRESENCE OF AMERICAN KESTRELS IN A BLUEBERRY PRODUCTION REGION DESPITE LOW BOX OCCUPANCY

Melissa L. Brady, Megan E. Shave, Olivia J. Utley, Sarah A. Groendyk, Catherine A. Lindell

ABSTRACT

Landscape enhancements, like nest boxes, can attract birds to agricultural areas to provide ecosystem services such as pest reduction through their deterrence and consumption of crop pests. However, there are large gaps in knowledge about how birds respond to enhancements. From 2014 to 2018 we installed American Kestrel (*Falco sparverius*; hereafter kestrel) nest boxes in a blueberry production region in western Michigan. From 2015 to 2018 we conducted surveys to monitor kestrel presence in 1.6-km transect segments to estimate kestrel occupancy with and without boxes. We also monitored box occupancy and reproductive success. Kestrel presence increased over time in the study area although there was some uncertainty in this trend. The presence of a box in a site did not increase kestrel presence in sites, but boxes in neighboring sites did increase presence. This indicates that enriching an area with boxes increases kestrel presence. Box occupancy rates were positively influenced by occupancy of the same box the previous year. Percent successful nests ranged from 75 to 100 percent, and mean numbers of fledglings produced was approximately 4 per box. Our results show that nest boxes can serve as effective landscape enhancements to attract kestrels to agricultural landscapes, but the degree to which kestrels occupy boxes can vary geographically. Local-scale studies can provide information about the potential benefits and challenges of using nest boxes as a pest management tool.

INTRODUCTION

Birds can provide ecosystem services to agricultural operations, from pest control to pollination (Whelan et al. 2015, Garcia et al. 2020). Birds that provide these services, hereafter “beneficial birds”, can be attracted to agricultural areas by providing resources, or landscape enhancements, such as artificial perches, roosts, or nest boxes (reviewed in Lindell et al. 2018).

Such enhancements attract beneficial birds to specific places in the landscape, for example crop fields, and so can facilitate the delivery of ecosystem services. For example, installing boxes for Western Bluebirds (*Sialia mexicana*) in California, USA vineyards decreased abundance of a sentinel prey arthropod pest (Jedlicka et al. 2014); using nest boxes to attract Great Tits (*Parus major*) to apple orchards in the Netherlands resulted in less fruit damage by caterpillars (Mols and Visser 2007).

For landscape enhancements to increase the provisioning of ecosystem services, they must direct organisms to places where they can deter pests (e.g., Kross et al. 2016). If nest boxes are occupied and produce young, adult activities are focused for a sustained period in an area where they can deter or consume pests while crops are susceptible (e.g., Shave et al. 2018). In a cherry-growing region in northern Michigan, USA, placing nest boxes in and near cherry orchards increased the presence of American Kestrels, (*Falco sparverius*; hereafter, kestrel), in sites along transects that traversed orchards (Shave and Lindell 2017b). Kestrels consume a variety of organisms that could be considered crop pests, including fruit-eating birds such as European Starlings (*Sturnus vulgaris*; hereafter starling; Shave 2017).

Our study had several objectives. First, we investigated if the addition of nest boxes increased kestrel site presence in a blueberry-growing region in western Michigan. We predicted that boxes would increase kestrel presence, defined as an increased occupancy 1.6-km transect segments (hereafter, sites). Second, we investigated rates of box occupancy and reproductive success. If kestrels successfully use boxes for nesting, this information would be useful for growers trying to manage crop pests deterred and consumed by kestrels (Bardenhagen et al. 2020). Additionally, if box occupancy and reproductive success were high, these findings would

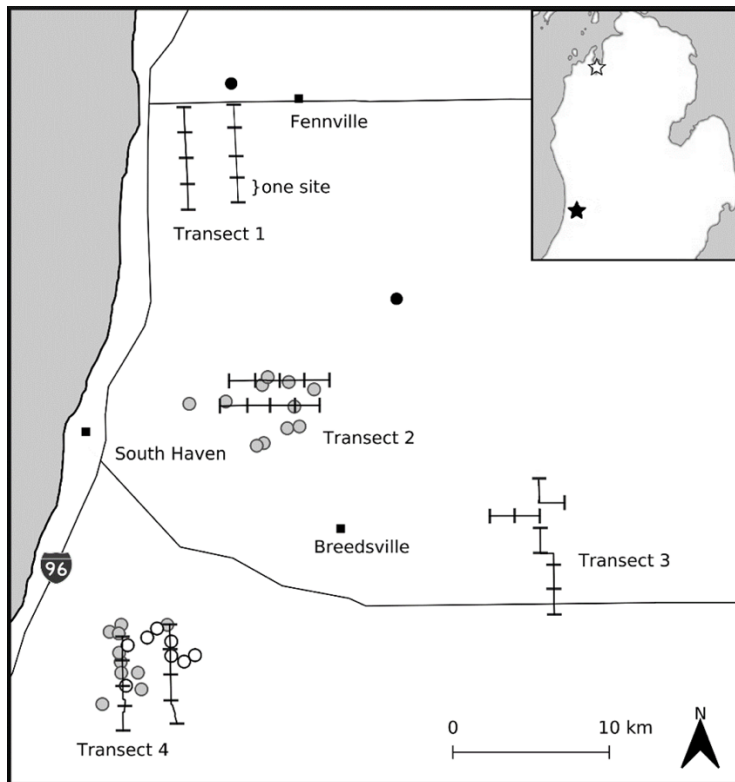
indicate that nest boxes potentially provide benefits to local kestrel populations, which have been declining in many regions of North America for decades (McClure et al. 2017).

METHODS

Study area and nest box installation

We conducted the study from 2015 to 2018 in Allegan, Van Buren, and Berrien counties in western Michigan, USA, in an area that included forest patches, rural residential areas, and multiple highbush blueberry (*Vaccinium corymbosum*) growing operations (Figure 2.1).

Figure 2.1. **Map of the Michigan blueberry study area.** The inset shows the location of our study areas in Michigan, USA. The black star represents the location of the blueberry production region; the white star represents the sweet cherry production region. Circles represent boxes; black were installed in 2014, gray prior to the 2016 nesting season, and white prior to the 2017 nesting season. Lines represent transects, while the tick marks along the transects denote the boundaries of the 1.6 km sites.



Previous work in northern Michigan had shown that kestrels readily use artificial nest boxes installed in fruit orchards and are tolerant of human activity (Shave and Lindell 2017a). We installed nest boxes on 5.5-m wooden towers (design in Shave and Lindell 2017a) in or within 10 m of blueberry fields. We installed two boxes in 2014 as part of a pilot study; these

boxes were located far from our transects, and therefore not included in our site occupancy study. However, they were included in our box occupancy analysis. We installed 21 boxes prior to the 2016 nesting season, and eight more boxes prior to the 2017 nesting season (Figure 2.1). Boxes were spaced at least 800 m apart from other boxes. We worked with the growers to install boxes where they would not interfere with the growing operation. Boxes used in the site occupancy analysis were placed within 0.8 km of a transect segment. At the end of each nesting season, boxes were cleaned and filled with about 2 cm of wood shavings. All boxes were installed with the opening facing southeast, as this has been shown to be optimal for kestrel use (Balgooyen 1990, Butler et al. 2009). Blueberry plants in fields ranged in height from less than 1 m to approximately 2 m, depending on the age of the blueberry bushes and level of pruning. Kestrels prefer nesting in open areas away from tall vegetation (Bird and Palmer 1988).

Kestrel surveys and site occupancy

We surveyed kestrels along four 12.8-km (8-mile) transects in western Michigan; kestrel nest boxes were installed around two of these transects. Each transect comprised eight 1.6-km (1-mile) segments, for a total of 32 transect segments (sites) that were used to estimate site occupancy. Transects were established in 2015; no sites had boxes in 2015. In 2016, 10 sites had boxes and in 2017 and 2018, 12 sites had boxes. For boxes to be considered “present” in a site or a neighboring site in the site occupancy model, they had to be within 0.8 km of the site, described below. However, all boxes were included in the box use analysis and when reporting reproductive measures.

We chose transects that followed roads through landscapes with blueberry operations and were at least 10 km apart (Figure 2.1). Kestrel breeding territory size is estimated to be about 1 km²; thus 10 km is distant enough to reduce the likelihood of individual kestrels being detected

on more than one transect (Smallwood et al. 2009a). Transects passed through open areas without forest cover, which kestrels prefer, (Bird and Palmer 1988) although some of the transects included short (approximately 50 m) stretches with woody vegetation. Each of the four transects was broken into two sections to avoid patches of heavily forested areas in the study region.

We recorded all visual and aural detections of kestrels within 250 m of either side of the transect. We performed kestrel surveys from 2015-2018, on days without heavy precipitation or fog. In 2015 surveys were conducted in July and August. From 2016 to 2018, surveys were conducted from May to August. We conducted surveys in the morning between 0800 and 1200, or in the evening between 1600 and 2000. Weather permitting, we surveyed each transect in one day (one half in the morning, the other half in the evening). During each visit, a transect was surveyed twice by walking each 1.6-km site once (the initial survey), waiting five minutes, then walking the 1.6-km site in the opposite direction (the return survey). We then drove to the start of the next 1.6-km site and surveyed that site similarly. We rotated the survey time and start direction for each survey. Each transect was surveyed multiple times each year.

Model for site occupancy

We estimated kestrel presence by constructing a site occupancy model, analyzed in a Bayesian framework. A ‘site’ was defined as a transect segment. The model assumes that kestrels remain in their territories during the breeding season, i.e., that the population is closed. This assumption is not held between years. The site occupancy model is as follows, broken into an ecological process and observation process, i.e. factors that could affect detection of kestrels during surveys (Kéry and Schaub, 2012):

Ecological process:

$$z_{i,t} \sim \text{Bernoulli}(\psi_{i,t})$$

where z represents the estimated true occupancy status of a site

Observation process:

$$y_{i,k,t} | z_i \sim \text{Bernoulli}(z_{i,t} * p_{i,k,t}),$$

where y represents the observed occupancy status of a site and p represents the probability of detecting a kestrel if the site is occupied. Further, i , t , and k denote the site, year and survey (initial or return).

Ecological effects that could influence kestrel site occupancy were modeled as follows:

$$\text{logit}(\psi_{i,t}) = \alpha_1 + \alpha_2 * \text{box}_{i,t} + \alpha_3 * \text{neighbor box}_{i,t} + \alpha_4 * \text{occupancy status of site previous year}_{i,t-1} + \text{transect}_{i,t}$$

where ‘box’ denotes the presence of a box at the site, ‘neighbor box’ specifies if there was a box present at a neighboring site (defined as an adjacent site on the same transect), and ‘transect’ represents the effect of individual transects.

Observation effects that could affect kestrel detection were modeled as follows:

$$\text{logit}(p_{i,k,t}) = \beta_1 + \beta_2 * \text{date}_{i,k,t} + \beta_3 * (\text{date}_{i,k,t})^2 + \beta_4 * \text{survey}_{i,k,t}$$

where ‘date’ represents the date of the survey, ‘date2’ represents a nonlinear effect of date, and ‘survey’ represents whether the survey was an initial or return survey.

Date is included in the model to capture differences in kestrel movement patterns that may occur throughout the season and that may affect detection. In previous work, morning vs. evening time periods did not affect kestrel detection in a sweet cherry production region so we did not include time-of-day in our model (Shave et al. 2018). In support of this decision, our kestrel detections were about evenly split between morning and evening survey periods

(unpublished data). Estimates for the number of sites occupied by a kestrel each year were based on results (or output) of the site occupancy model.

We analyzed the model in R 3.6.2 (R Core Team 2018), using package R2jags. We checked model convergence by visually inspecting the MCMC chains, and by ensuring that all Rhat values were within +/- .01 of 1 (Kéry and Schaub 2012). We ran the model with three chains for 150,000 iterations, with a burn in of 20,000.

Box occupancy and reproductive success

We considered a box to be occupied if one or more kestrel eggs were found in the box on any nest check. We began to check kestrel boxes in mid-April each year, using a pole-mounted camera. We checked boxes once a week until an egg was seen, in which case we checked the box more frequently, until the egg/eggs hatched, and then every few days after hatching. In a few cases other species used our boxes; native species (such as tree swallows, *Tachycineta bicolor*) were left in the box, while starling eggs and/or nesting material were removed. We considered young to be fledged if they survived to 22 days of age (Steenhof and Peterson 2009a, Shave and Lindell 2017a). We considered a nesting attempt to be successful if the box produced at least one fledgling (Eschenbauch et al. 2009). Kestrels are tolerant of nest monitoring; nest checks have not been shown to affect box occupancy or reproductive success (Smallwood 2016, Shave and Lindell 2017a). We used all boxes in the analysis of box occupancy and reproduction, regardless of the year in which they were installed or their location in relation to transects.

Model for box occupancy

To determine if nest boxes were more likely to be occupied if the box had been occupied the previous year, we constructed the following model:

$$y_{i,t} \sim \text{Bernoulli}(\psi_{i,t})$$

$$\text{logit}(\psi_{i,t}) = \alpha_1 + \alpha_2 * \text{box status previous year}_{i,t-1}$$

where ‘box status previous year’ represents whether the box was occupied by kestrels the previous year. We analyzed the model in R 3.6.2 (Core Team R 2018), using package R2jags and checked model convergence as described above for the site occupancy model.

RESULTS

Kestrel site occupancy

We conducted a total of 1136 site surveys from 2015 to 2018. In 2015, before boxes were installed, we surveyed each site at least twice, with 24 sites surveyed four times. We surveyed each site eight times in 2016, and 12 times each in 2017 and 2018. Overall, kestrels were detected at 2 sites in 2015, 6 sites in 2016, 13 sites in 2017, and 11 sites in 2018, with approximately equal kestrel detections at sites with boxes compared to sites without boxes in 2017 and 2018 (Table 2.1).

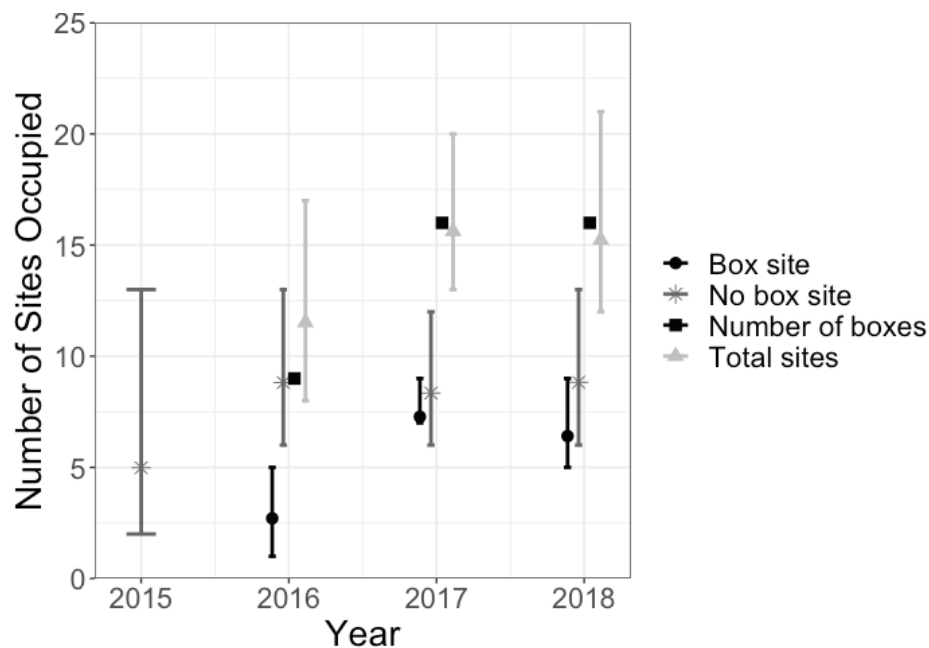
Table 2.1. **The number of sites with at least one kestrel detection for each year 2015-2018.**

The percentage of sites in parentheses.

Year	Sites with boxes	Sites without boxes	All sites
2015	NA (n=0)	2 (6%, n=32)	2 (6%, n=32)
2016	1 (10%, n=10)	5 (23%, n=22)	6 (19%, n=32)
2017	7 (58%, n=12)	6 (30%, n=20)	13 (41%, n=32)
2018	5 (42%, n=12)	6 (30%, n=20)	11 (34%, n=32)

The site occupancy model provides estimates with confidence intervals for site occupancy with and without boxes for each year (Figure 2.2).

Figure 2.2. **American Kestrel site occupancy estimates from model for 2015 to 2018.** Error bars represent the 95% credible intervals (CI). Number of occupied sites was higher for sites without boxes compared to sites with boxes in 2016. Number of occupied sites with boxes increased from 2016 to 2017, (the 95% CIs do not overlap). The black squares represent the number of boxes present each year.



There was an apparent increase in occupancy for all sites between 2015 and 2018, although it did not quite reach statistical significance, i.e. non-overlapping confidence intervals. This is likely because of the large confidence intervals in year 2015, before boxes were installed, when 160 miles of transect surveys resulted in only two kestrel detections (Figure 2.2). Kestrel

site occupancy was estimated to be 6-41% in 2015. After boxes were installed, site occupancy estimates were 25-53% in 2016, 41-63% in 2017 and 38-66 % in 2018. Sites with boxes had an increase in kestrel presence from 2016-2017, based on non-overlapping confidence intervals. Parameter estimates from our site occupancy model show that only the presence of a box in a neighboring site had a positive effect on site occupancy (Table 2.2). All detection probability covariates had 95% credible intervals that overlapped zero (Table 2.2), indicating that kestrel detection was not affected by date or if surveys were initial or return surveys (Kéry and Schaub 2012), similar to Shave and Lindell 2017b.

Table 2.2. **Parameter values from site occupancy model.** Statistically significant parameters (i.e. the 95% credible interval does not overlap zero) are in bold.

Parameter		Mean	SD	95% CI	
Ψ: Site occupancy	α_1 : Intercept	-1.96	0.94	-2.51	-0.25
	α_2 : Box	-1.57	2.48	-7.59	2.51
	α_3 : Neighbor box	6.36	2.45	1.20	9.84
	α_4 : Occupancy previous year	1.09	1.52	-1.27	4.66
	Transect 1	1.27	1.23	-0.94	3.76
	Transect 2	-4.27	2.81	-9.17	1.79

Table 2.2 (cont'd)

	Transect 3	0.61	1.22	-1.72	3.03
	Transect 4	1.40	2.52	-2.67	8.40
p: Detection	β_1 : Intercept	-1.90	0.29	-2.48	-1.35
	β_2 : Date	0.26	0.16	-0.06	0.57
	β_3 : Date squared	-0.32	0.18	-0.68	0.03
	β_4 : Survey	0.43	0.28	-0.12	0.99

Box occupancy and reproductive success

Our results show that if the box was occupied in the previous year, this had a positive effect on the box occupancy, according to our parameter estimates (Table 2.3).

Table 2.3. **Parameter results from box occupancy model.** Significant parameters (i.e. the 95% credible interval does not overlap zero) are in bold.

Parameter	Mean	SD	95% CI	
α_1 : Intercept	-1.17	0.31	-1.78	-0.60
α_2 : Box occupancy previous year	1.36	0.62	0.15	2.64

About one third of nest boxes were occupied each year from 2016 to 2018 (Table 2.4). The percentage of successful nests was 75% or higher each year and the mean number of fledglings per successful nest each year was approximately 4 (Table 2.4).

Table 2.4. **Box occupancy and mean clutch size.** A nesting attempt was successful if it produced at least one fledgling. We calculated mean clutch size from occupied boxes.

Year	# And % Boxes Occupied	Mean Clutch Sizes +/- SE	#And % Successful Nesting Attempts	Mean Fledglings +/- SE
2016	7 (30%)	4.7 +/- 0.2	3 (75%)	4.0 +/- 0
2017	11 (35%)	4.7 +/- 0.3	8 (89%)	4.0 +/- 0.5
2018	9 (29%)	5.0 +/- 0	8 (100%)	3.9 +/- 0.6

DISCUSSION AND CONCLUSION

Site occupancy

Our data strongly suggest installing nest boxes increased the presence of kestrels in the blueberry production region. Although the trend toward increased site occupancy over the 3 years of the study did not quite reach statistical significance, this is likely because of large confidence intervals in year one, before boxes were installed.

These results are similar to those for our study region in northern Michigan where we installed boxes in sweet cherry orchards and site occupancy was estimated to be 46-54%, 61-68%, and 57-64% in the first, second, and third years after boxes were installed (Shave and Lindell 2017b), compared to site occupancy of 25-53%, 41-63%, and 38-66%, respectively, in the present study. The wider confidence intervals in the present study indicate significant uncertainty as to the magnitude of the box effect on site occupancy and may result, in part, from the lower box use in the blueberry region compared to the sweet cherry region. In the cherry region, the presence of boxes within sites and in neighboring sites both positively influenced the likelihood of a site being occupied (Shave and Lindell 2017b). However, in the present study only having a box in a neighboring site positively influenced occupancy, perhaps a result of the assumed lower abundance of kestrels in the blueberry study region. Interestingly, the one year (2016) in which we detected a significant difference in site occupancy between box and no-box sites, estimated occupancy in the no-box sites was higher. We believe this is because the boxes increase kestrel presence in the area and not only within the arbitrarily assigned boundaries of our sites. In support of this idea, our results showed that site occupancy was positively affected by box occupancy in a neighboring site, indicating that box effects were not contained to within our 1.6-km sites but spread beyond that, likely because the activities of individual kestrels overlapped the boundaries of sites. Another nest box study in Florida, USA, showed an increase in kestrel surveys with the placement of nest boxes. Smallwood and Collopy (2009) installed kestrel boxes at sites in Florida and found an increase in kestrel density, lending more proof that installing kestrel boxes can increase kestrel presence in an area.

To maximize the number of surveys we could complete each season, sites in the same transect were adjacent to each other. This could lead to spatial dependence, since one kestrel

territory could overlap multiple sites. However, we did not find an effect of transect on site occupancy, indicating a lack of spatial effects. We also found that there was no significant influence of detecting a kestrel on the initial vs. return survey, suggesting that our surveying activity did not alter kestrel behavior along transects.

Box occupancy and nest success

Box occupancy rates were relatively low, varying between 29 to 35 percent from 2016 to 2018. These rates are lower than those reported for American Kestrels in landscapes comprising rangeland, agriculture, and exurban areas (approximately 48%; Steenhof and Peterson 2009a) and temperate grasslands (approximately 60%; Eschenbauch et al. 2009). The rate also was at the low end of American Kestrel box occupancy rates reported for several nest box programs in North America (Smallwood et al. 2009b). However, other studies have shown that box occupancy rates can be low for the first few years after the establishment of a nest box system (Smallwood et al. 2009b). Box occupancy rates in our sweet cherry study region in northern Michigan were substantially higher than in the blueberries in western Michigan, varying between 83 to 100 percent in 2013-2015 (Shave and Lindell 2017a). However, our box occupancy rates in blueberries were comparable to those reported for Barn Owls, *Tyto alba*, in the agricultural Central Valley of California (approximately 42%; Kross et al. 2016) and a wine grape-growing region of California (approximately 33%; Wendt and Johnson 2017). Thus, the high rate of box occupancy for kestrels in our sweet cherry study region (Shave and Lindell 2017a) may be somewhat of an anomaly. It could be that most agricultural contexts are not ideal habitat for natural avian predators but are acceptable if enhancements like nest boxes are installed.

In this study, a box was significantly more likely to be occupied by kestrels if it was occupied the previous year, although kestrels exhibit low breeding site fidelity in other study

regions (Steenhof and Peterson 2009b). And, in contrast to the box occupancy rates, the nest success rates in blueberries were comparable to, or higher than, that reported for American Kestrels in other areas (e.g Gault et al. 2004, Steenhof and Peterson 2009a, Eschenbauch et al. 2009) and in our sweet cherry region (Shave and Lindell 2017a). Taken together, our results suggest that nest boxes are an important resource that can improve the value of agricultural landscapes for kestrels and allow for successful reproduction, although box occupancy rates vary substantially among landscapes (discussed in more detail below).

Geographic variability in site and box occupancy

The present study, in conjunction with our earlier work in sweet cherries, illustrates substantial geographic variability in nest box use, with substantially higher box occupancy in the cherry region. There could be several reasons for the difference. First, kestrel nest boxes have been in place in the sweet cherry region for several decades, and there appears to be an established kestrel population (Shave and Lindell 2017a). However, there is little evidence of a history of kestrel box installation in the blueberry region. Second, the landscapes of the two areas differ. Both regions comprise a mix of agriculture, woodlands, and small residential areas, but the cherry region (Leelanau County) has some pastureland (6.3% of land in farms), while the blueberry region (Van Buren and Allegan counties) has none reported (USDA 2014). Pastureland, with short grass and few trees, provides good hunting habitat for kestrels (Sheffield et al. 2001). Thus, there may be more kestrels in the cherry region than in the blueberry region. There is some eBird evidence to support higher kestrel abundance in the cherry region. For the months of April through July 2015 – 2018, the percentage of completed checklists that had a kestrel present was 4.1% out of 2919 lists for Leelanau County (cherry region), with only 0.9%

out of 1290 lists for Van Buren County (blueberry region), and 3.6% out of 3489 lists for Allegan County (blueberry region; eBird, 2017).

Additionally, there were many nesting attempts in kestrel boxes by starlings in the blueberry region yet very few in the cherries (C. Lindell, 2016-2018, unpubl. Data). Starlings began nesting attempts in the boxes earlier in the blueberry region, which is further south, compared to the cherry region; first starling nesting attempts were observed in April for the blueberry region, and mid-May for the cherry region (C.Lindell, 2016-2018, unpubl. Data). Kestrels can out compete starlings for nest boxes (McClure et al. 2015, C. Lindell 2016-2018, unpubl. Data). However, because starlings are attracted to the boxes in the blueberry region and begin early nesting, this may have deterred kestrels from using the boxes in some cases. Later starling nesting in the cherry region may prevent this type of situation. Given that starlings are a well-known fruit pest (Hannay et al. 2019), their nesting in boxes in fruit production regions could have a negative impact on the surrounding crops. Therefore, nest boxes installed in some contexts, like our blueberry study region, will require more management by growers to monitor and remove starlings when they attempt to nest, compared to the cherry region. In evaluating the effectiveness of landscape enhancements like nest boxes in attracting natural predators, it is important to consider all the species that may use them, and the additional work that may be required to discourage use by non-target species.

Finally, highbush blueberry bushes have a dense structure with foliage close to the ground; kestrels in mature blueberry fields appear to hunt mostly in the grassy areas separating blueberry fields (M. Hannay, O. Utley, S. Groendyk, 2016-2018, pers. Comm.). Cherry trees, in contrast, have a more open structure with significant open space between the ground and the lowest level of foliage at 1-2 m above ground. Based on data from GPS loggers, Shave (2017)

found that kestrels regularly hunt in sweet cherry orchards. Thus, sweet cherry orchards may be more hospitable habitat for kestrels than blueberries.

Implications for using nest boxes to attract natural predators to agricultural regions

Consumers are willing to pay more for fruit grown with pest management techniques like nest boxes for natural predators, compared with chemical sprays (Oh et al. 2015). Recent work shows that American Kestrels deter fruit-eating birds from orchards, and potentially provide significant economic benefits for fruit-growing regions (Shave et al. 2018). Other work also demonstrates the value of natural predators in agriculture (e.g. Kross et al. 2012, Murano et al. 2019, Garfinkel et al. 2020). In addition, a national USA-based survey of blueberry and sweet cherry farmers showed that they perceive nest boxes for predators to be a useful pest management technique and are interested in installing them (Bardenhagen et al. 2020). Finally, some natural predators, like American Kestrels, have been declining for decades (Smallwood et al. 2009b, Sauer et al. 2017) and nest boxes programs may aid in conservation efforts. Thus, there are many reasons to investigate how to use nest box programs for predatory birds to improve ecosystem service provisioning in agricultural areas (Lindell et al. 2018).

Our results show that nest boxes vary in the likelihood of attracting beneficial species by region and/or crop. While kestrel presence increased in both our study regions over the years, the presence of boxes showed a stronger positive effect on site occupancy in the sweet cherry region. Other studies (e.g. Kross et al. 2016, Wendt and Johnson 2017) have also shown varying box use rates and reproductive success of raptors in agricultural areas. Thus, the effectiveness of nest boxes in increasing ecosystem service provisioning depends on the context in which they are installed. Future research should investigate the factors and contexts that influence the effectiveness of landscape enhancements in a range of agricultural landscapes and for different

beneficial species (Lindell et al. 2018). Regional species abundances, land-cover types, preferred prey abundance, farm management practices, and crop structure could all influence the likelihood of nest boxes attracting raptors and providing pest management services. Local studies will be key to informing researchers and farmers about the potential benefits and challenges of using nest boxes as a pest management tool in a region.

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CHAPTER 3:

EFFECT OF AMERICAN KESTRELS ON FRUIT-EATING AND NON-FRUIT-EATING BIRDS IN BLUEBERRY FIELDS IN MICHIGAN

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INTRODUCTION

Natural predators can provide ecosystem services such as pest regulation in agriculture (MEA 2005, Power 2010). Interest in how the natural world can improve agricultural productivity has spurred multiple studies in attracting natural predators to regulate and deter agricultural pests (reviewed in Lindell et al., 2018). Encouraging predators to take up residence near an agricultural operation can reduce pest presence and crop damage. For example, introducing New Zealand falcons (*Falco novaeseelandiae*) into vineyards significantly reduced the abundance of fruit-consuming passerines and the number of grapes removed by 95%, (Kross et al., 2012). Incorporating natural predators into agricultural operations can potentially reduce use of chemical deterrents for pest control (Lindell et al., 2018). Chemical deterrents can be expensive and are unappealing to many consumers who show a preference for natural pest control methods (Herrnstadt et al., 2016). Other deterrents, such as scaring, often lose effectiveness as pests habituate (Steensma et al., 2016, Gilsdorf et al., 2002).

Birds of prey are effective at deterring crop pests, including vertebrate pests such as fruit-eating birds and rodents. For example, the American kestrel (*Falco sparverius*; hereafter ‘kestrel’) deters and consumes vertebrate pests and is readily attracted to nest boxes (Shave and Lindell, 2017a). One study estimated that active kestrel nest boxes could provide benefits to the state of Michigan of \$2.6-\$2.8 million USD over 5 years by reducing fruit-eating birds in the sweet cherry orchards surrounding nest boxes (Shave et al., 2018). Owls may also prove beneficial; one study found that over 99 percent of barn owls’ (*Tyto alba*) prey items were agricultural pests and likely confer benefits to the agricultural operations in which they are present (Kross et al., 2016).

However, the net effect that birds have on a crop can be positive or negative and only a limited number of studies have tried to estimate net effects (e.g. Olimpí et al. 2020). Birds can have a negative effect on crops by consuming and/or damaging crops, or by decreasing beneficial species (Mooney, 2010; Anderson et al., 2013) . Birds can have a positive effect on crops by reduce pests by consuming and deterring crop pests (e.g. Whelan et al. 2008). Therefore, calculating the net effects of birds in agroecosystems (benefits – costs) is important to determining the true economic value of bird activity (Peisley et al. 2015, Pejchar et al. 2018). For example, birds in California strawberry fields both caused fruit damage and consumed arthropod pests, with overall slight negative effects of birds on berry production (Olimpí et al. 2020). An introduced predatory bird may consume or deter not only pests but also beneficial species, such as insectivores that consume pest insects, lessening pest control benefits of the predatory bird (Martin et al., 2013).

Surrounding land cover can influence the strength of ecosystem services provided to a growing operation by influencing habitat availability to bird species that may provide services and/or disservices (Heath et al., 2017; Garcia et al., 2020). One study found a higher bird abundance and species richness in field or orchard margins that contained tree lines; some studies have linked higher biodiversity to greater ecosystem services provisioning (Power, 2010; Heath et al., 2017). Another study found that fruit-eating birds crossed into sweet cherry orchards more often when the orchards were bordered by forest compared to orchards bordered by other orchards, with forest cover potentially providing a safe staging ground for the frugivorous birds (Lindell et al., 2016).

Different fruit cultivars and fruit ripeness may also affect the number of birds using an orchard or field. Some bird species show a preference for higher sugar fruits, such as a

preference for sweet cherries vs tart cherries (Lindell et al., 2012). Additionally, birds are more attracted to ripe fruit than unripe fruit; since cultivars have different ripening timelines, the date that an observation is performed in a fruit orchard or field will likely influence the number of birds observed. For example, in blueberries in Michigan, the Earliblue variety produces fruit in early July, while Elliot produces fruit into September. (Hancock and Hanson, 2001).

We investigated if kestrel presence could provide pest control to blueberry growers by deterring fruit-eating birds from blueberry fields in western Michigan. We also wanted to investigate potential negative effects of kestrels via the deterrence of non-fruit-eating birds, which may in consume and/or deter pest insects, thus influencing the net effects provided by kestrels. We installed kestrel nest boxes in or near blueberry growing operations from 2015-2018. In 2017 and 2018, we performed bird surveys of blueberry fields both with and without a nest box in use by a nesting kestrel pair. We predicted that the presence of nesting kestrels in or near a blueberry field would decrease bird abundance, both in fruit-eating and non-fruit-eating birds. We also predicted that an increase in tree cover would increase the number of all birds, since tree cover could serve as a refuge from kestrels and supplementary habitat for many species. Additionally, we predicted that sweeter varieties of blueberries would attract more birds. We also predicted that the interaction term of month and variety would affect the number of birds observed in the fields, as ripe fruit should attract birds more than unripe fruit.

METHODS

Kestrel nest boxes and study area

We conducted this study in Van Buren and Allegan Counties in western Michigan (Figure 3.1). Land cover in these counties is mostly cropland, with some remnant forest and rural residential areas; Van Buren County comprises 71% cropland, 15% woodland, and 14% other

uses, while Allegan is 83% cropland, 8% woodland, and 10% other uses (USDA, 2012). We installed kestrel nest boxes in or near blueberry fields prior to the 2017 nesting season, within 200 m of observation blocks. We placed nest boxes on a 5.5-m wooden tower (box and tower design in Shave and Lindell, 2017). We placed boxes at least 800 m apart and faced the entrance of the box toward the southeast, which kestrels prefer and leads to higher nest success rates (Balgooyen, 1990; Butler et al., 2009).

Nest boxes were checked with a pole-mounted camera (Shave and Lindell, 2017a) at least once per week. Kestrels show high tolerance towards nest monitoring; checks were not associated with nest failure (Shave and Lindell, 2017a). A kestrel box was considered active during a date range, starting when an incubating female or ≥ 1 egg was found in the box during a nest check. We defined the active range as ending 2 weeks after the estimated fledging date for a box, because kestrel fledglings stay in the immediate area around their nest site for several weeks following fledging (Smallwood and Bird, 2020). The fledging date was when the nestling/s were estimated to be 28 days old; since the last nest check typically occurred at 22-25 days old, this date was estimated from the last nest check using the estimated nestling age (Steenhof and Peterson, 2009).

Bird surveys

In 2017 we surveyed blueberry blocks from 7 June to 3 August, and in 2018 from 27 May to 9 August. We surveyed blocks during four different time-of-day intervals: 06:30-09:30, 09:30-12:30, 12:30-15:30, and 15:30-18:30. Blueberry fields contained different varieties: Aurora, Jersey, Bluejay, Bluecrop, Blueray, Bluetta, Rubel, Weymouth, Duke, Earliblue, Elliot, and Liberty. Typically, there was one dominant variety per study block. These varieties vary in sugar content and harvest date, ranging from early July to mid-September (Hancock and Hanson,

2001). Each observation block was defined as a 50 m² area within a blueberry field. We rotated the time that each block was observed throughout the field season. We conducted observations when there was little to no precipitation or fog. Each survey was 10 minutes long. Two surveys were conducted on each visit to an observation block, with at least a 5-minute period in between surveys.

We conducted dependent double-observer surveys at our observation blocks, with no communication between observers during the survey. Two observers were present for each survey, one designated the primary observer, the other the secondary observer. The primary observer recorded all birds detected, while the secondary observer only recorded birds missed by the primary observer (Forcey et al., 2006). For analysis, the observations of the two observers were combined per survey period. We conducted observations from step ladders at a corner of the block, choosing the corner that had the most visibility of the block. We recorded all birds that entered the block, using only visual cues. The surveyed blocks were assigned to one of two treatments: blocks with an active kestrel nest box adjacent to the study block, and those without an active nest box.

Landcover analysis

We investigated the effect of tree cover by using the proportion of tree cover within a 500-m radius of the center of the study block; this size represents the approximate home range size of many of the species in our study. For example, during the breeding season, American robins will quest up to 300 m from their nests (Knupp et al., 1977). We used satellite imagery from the National Agricultural Imagery Program from 2017 (NAIP; Lindell et al., 2016). We measured tree cover visually using ArcGIS polygon measurement tools, delineating tree cover by hand. Corrections to the image layer were made based on field visits and observations.

Modeling

We constructed two separate N-mixture abundance models to estimate bird abundance in our study. N-mixture models are used to estimate abundance when there are temporal and spatial replicates (Kéry and Schaub, 2012). First, we constructed a model to investigate the abundance of fruit-eating birds in our observation blocks and investigated if the presence of an active kestrel box decreased fruit-eating birds. We then constructed a separate model to investigate if non-fruit-eating birds were deterred by active kestrel boxes. For this model, we assumed that bird populations were closed during the observation period. We also assumed that observers had the same level of skill, since there were too many different observers to calculate an individual observer effect.

We used the same construction for each of the two models:

$$N_{i,k} \sim \text{Poisson}(\lambda_{i,k})$$

Covariates for our abundance model are as follows:

$$\text{Log}(\lambda_{i,k}) = \alpha_0 + \alpha_1 * (\text{tree cover}_i) + \alpha_2 * (\text{blueberry variety}_i) + e_i,$$

where tree cover is the amount of tree cover within a 500-m radius of the observation block, and variety is the variety of blueberry found in the observation block.

The covariate for our observation model is structured as follows:

$$y_{i,j,k} | N_{i,k} \sim \text{Binomial}(N_{i,k}, p_{i,j,k})$$

$$\text{Logit}(p_{i,j,k}) = \beta_0 + \beta_1 * (\text{active box}_{i,j,k}) + \beta_2 * (\text{time}_{i,j,k}) + \beta_3 * (\text{month} * \text{blueberry variety}_{i,j,k}) + e_{i,j,k},$$

where active box is the presence or absence of an active box, time represents the time of day that the survey was conducted (morning or afternoon/evening), and month*blueberry variety is the interaction between the month that the survey was conducted in and the variety of blueberry in

the observation block. The subscript k represent year, i represents the site replicates, and j represents the temporal replicates. Random variables for site and replicate are included to account for overdispersion (e_i and $e_{i,j,k}$). Active box was placed in the observation part of the model because the boxes were not active for the entire length of the study; this varied by survey.

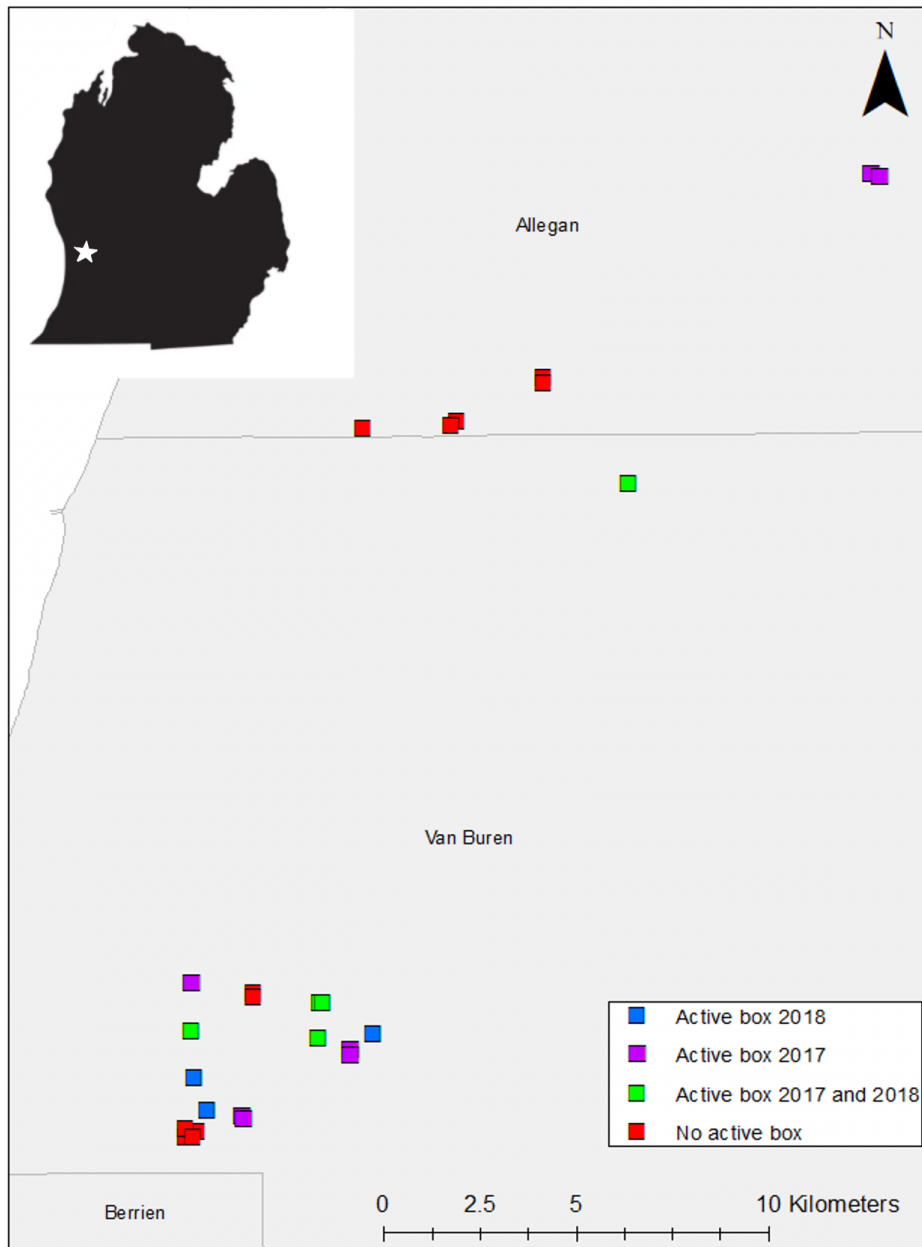
We analyzed these models in a Bayesian framework. We used uninformative priors, and ran three Markov chains for 150,000 iterations, discarding the first 20,000 iterations as burn in. We ensured model convergence by inspecting the mixing of the three Markov chains, and by checking that R_{hat} values for all models were within 0.1 of 1 (Kéry, 2010).

RESULTS

Kestrel boxes

In 2017, 8 active kestrel boxes were associated with observation blocks, with 7 active boxes in 2018 (Figure 3.1). In 2017 only one box failed to produce fledglings; all boxes produced fledglings in 2018. Boxes were active for a mean of 65 days ($SD \pm 15.6$) in 2017, and 72 days ($SD \pm 3.3$) in 2018. The shorter mean active period and larger SD for 2017 were due to an early nest failure. The first date that a box was declared active was 13 April in 2017, and 28 April in 2018. The last date that a box was declared active was 9 August in 2017, and 29 July in 2018. The furthest active box from the centroid of an observation block was 196m; the closest was 39m. On average, boxes were 80.1 ($SD \pm 45.6$) m from the centroid of the observation blocks.

Figure 3.1. Location of observation blocks, and whether the blocks were associated with an active kestrel nest box, for 2017-2018. Inset shows study location within Michigan.



Bird observations

We conducted 59.3 and 59.7 hours of observations at 20 observation blocks in 2017 and 2018, respectively. There were 12 and 8 observation blocks with active kestrel boxes in 2017 and 2018, respectively. Some boxes had 2 observations blocks associated with the box (Figure 1). Each observation block was surveyed 16 to 20 times; in 2017, blocks had a mean of 17.8 surveys and in 2018 a mean of 18.1 surveys. In 2017 34 bird species were detected during surveys, and 29 species were detected in 2018. The list of species observed between the two years is contained in Table 3.1. Shave et al. (2018) classified fruit-eating species in a cherry production region in northern Michigan; these classifications were used in this study and some additional fruit-eating species were detected in the blueberry study system.

Table 3.1. **Species detected in observations blocks from 2017-2018, and if the species consumes fruit.** Fruit-eating species listed in Shave et al. 2018 denoted by *.

Common Name	Scientific Name	Consumes fruit
American Goldfinch	<i>Spinus tristis</i>	Yes*
American Robin	<i>Turdus migratorius</i>	Yes*
Baltimore Oriole	<i>Icterus galbula</i>	Yes*
Barn Swallow	<i>Hirundo rustica</i>	No
Black-capped Chickadee	<i>Poecile atricapillus</i>	No
Brown-headed Cowbird	<i>Molothrus ater</i>	No
Blue Jay	<i>Cyanocitta cristata</i>	Yes*

Table 3.1 (cont'd)

Brown Thrasher	<i>Toxostoma rufum</i>	Yes
Cedar Waxwing	<i>Bombycilla cedrorum</i>	Yes*
Chipping Sparrow	<i>Spizella passerina</i>	No
Common Grackle	<i>Quiscalus quiscula</i>	Yes*
Eastern Bluebird	<i>Sialia sialis</i>	No
Eastern Kingbird	<i>Tyrannus tyrannus</i>	No
Eastern Phoebe	<i>Sayornis phoebe</i>	No
Eastern Towhee	<i>Pipilo erythrophthalmus</i>	Yes
European Starling	<i>Sturnus vulgaris</i>	Yes*
Field Sparrow	<i>Spizella pusilla</i>	No
Great Crested Flycatcher	<i>Myiarchus crinitus</i>	No
Gray Catbird	<i>Dumetella carolinensis</i>	Yes
Hairy Woodpecker	<i>Dryobates villosus</i>	No
House Finch	<i>Haemorhous mexicanus</i>	Yes
House Sparrow	<i>Passer domesticus</i>	No
Indigo Bunting	<i>Passerina cyanea</i>	No
Killdeer	<i>Charadrius vociferus</i>	No

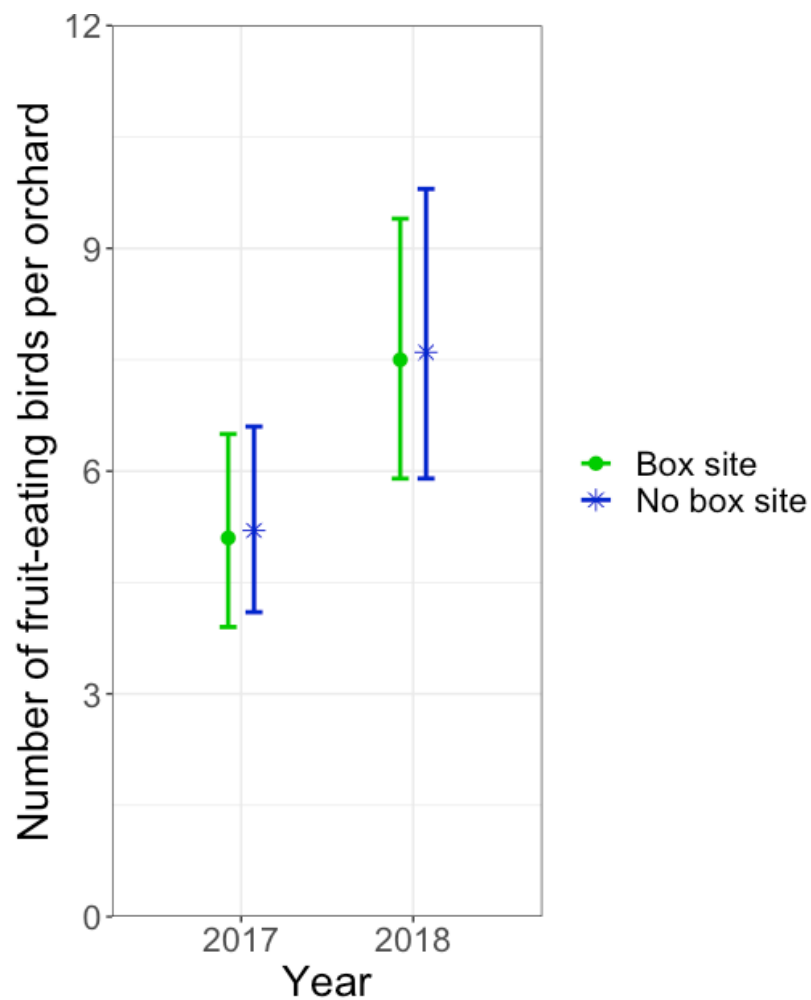
Table 3.1 (cont'd)

Mourning Dove	<i>Zenaida macroura</i>	No
Northern Cardinal	<i>Cardinalis cardinalis</i>	Yes
Northern Flicker	<i>Colaptes auratus</i>	Yes*
Orchard Oriole	<i>Icterus spurius</i>	Yes
Red-bellied Woodpecker	<i>Melanerpes carolinus</i>	No
Ruby-throated Hummingbird	<i>Archilochus colubris</i>	No
Red-winged Blackbird	<i>Agelaius phoeniceus</i>	No
Song Sparrow	<i>Melospiza melodia</i>	Yes*
Tree Swallow	<i>Tachycineta bicolor</i>	No
Willow/Alder Flycatcher	<i>Empidonax</i> <i>traillii/alnorum</i>	No
Yellow Warbler	<i>Setophaga petechia</i>	No

Model results: fruit-eating birds

The presence of an active kestrel box had no effect on the number of fruit-eating birds estimated to be in the orchard during the survey season, measured by the growing-season abundance estimated from the model (Figure 3.2). There was also no effect on the number of fruit-eating birds observed at the individual survey level, shown by the covariate for active box not being significant in the model (Table 3.2).

Figure 3.2. **Model estimates of fruit-eating bird abundance for the survey season per orchard in 2017 and 2018.**



Parameter results from the model show that the only covariate that had a statistically significant effect was time-of-day; afternoon surveys had less detections (Table 1).

Table 3.2. **Parameter values for fruit-eating bird model.** Statistical significance denoted by bold.

Parameter	Mean	SD	95% CI	
			2.5%	97.5%
a ₁ (tree cover)	1.0	0.9	-0.6	2.8
a ₂ (variety bluecrop)	0.1	0.9	-1.7	1.9
a ₃ (variety bluejay)	0.3	0.9	-1.5	2.2
a ₄ (variety blueray)	0.3	1.0	-1.6	2.1
a ₅ (variety bluetta)	-0.3	1.0	-2.3	1.6
a ₆ (variety duke)	0.4	0.9	-1.6	2.4
a ₇ (variety earliblue)	0.5	1.0	-1.3	2.4
a ₈ (variety 65lliot)	0.3	1.0	-1.6	2.3
a ₉ (variety liberty)	-0.2	0.9	-2.1	1.6
a ₁₀ (variety mixture)	0.2	0.9	-1.6	2.0
a ₁₁ (variety weymouth)	0.9	0.9	-0.9	2.8
b ₁ (active box)	-0.4	0.3	-0.9	0.1
b₂ (time-of-day)	-0.7	0.2	-1.1	-0.3
b ₃ (month*variety)	0	0	0	0

Model results: non-fruit-eating birds

The presence of an active box did not have an effect on the number of non-fruit-eating birds estimated to be in the orchard during the season, measured by the growing-season abundance estimated from the model (Figure 3.3). However, the presence of an active kestrel box had a negative effect on the number of non-fruit-eating birds observed at the individual survey level (Table 3.3). Time of day also had a significant effect; afternoon survey periods had less sightings (Table 3.3).

Figure 3.3. Model estimates of non-fruit-eating bird abundance for the survey season per orchard in 2017 and 2018.

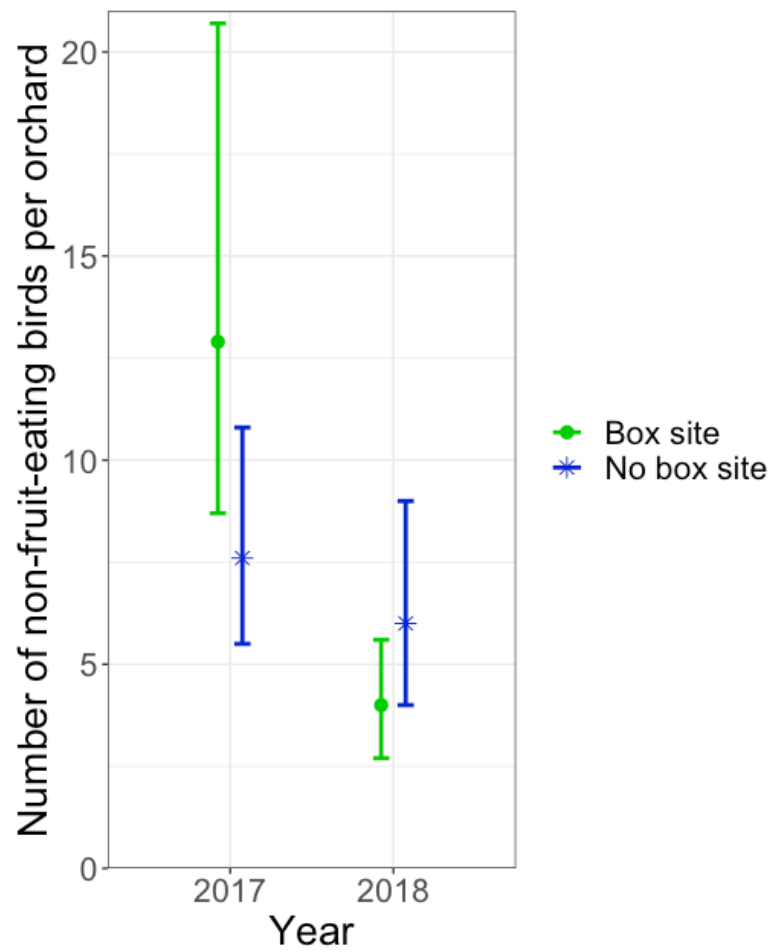


Table 3.3. **Parameter values for non-fruit-eating bird model.** Statistical significance denoted by bold.

Parameter	Mean	SD	95% CI	
			2.5%	97.5%
a ₁ (tree cover)	0.2	1.6	-3.0	3.4
a ₂ (variety bluecrop)	0.2	1.0	-1.7	2.1
a ₃ (variety bluejay)	1.4	1.1	-0.8	3.6
a ₄ (variety blueray)	0.6	1.1	-1.5	2.8
a ₅ (variety bluetta)	-0.1	1.2	-2.5	2.3
a ₆ (variety duke)	0.6	1.2	-1.7	3.0
a ₇ (variety earliblue)	-0.6	1.1	-2.7	1.6
a ₈ (variety elliot)	-0.1	1.3	-2.6	2.4
a ₉ (variety liberty)	1.1	1.1	-1.0	3.2
a ₁₀ (variety mixture)	0	1.0	-1.9	1.9
a ₁₁ (variety weymouth)	-0.4	1.1	-2.5	1.7
b₁ (active box)	-1.0	0.4	-1.8	-0.3
b₂ (time-of-day)	-0.6	0.3	-1.2	-0.1
b ₃ (month*variety)	0	0	0	0

DISCUSSION AND CONCLUSION

We found that active nest boxes had no effect on fruit-eating birds. This is contrary to results in a nearby sweet cherry study system, where active nest boxes had a strong negative impact on numbers of fruit-eating birds (Shave et al., 2018). However, we did find that active nest boxes did have a negative effect on non-fruit-eating birds in blueberry fields. If the non-fruit-eating birds eat detrimental insects, the kestrels potentially have a negative effect on pest abundance in these fields. However, it's also likely that the non-fruit-eating birds eat some beneficial insect species. Thus, we cannot estimate the effect of kestrels on insect pest control through their deterrence of non-fruit-eating birds without more detailed diet data from non-fruit-eating birds.

There are two ways in which our models estimated a change in the number of birds. First, the models estimated the total abundance of fruit-eating and non-fruit-eating birds throughout the season. Second, the models estimated if the presence of an active box had an effect on the number of birds (fruit-eating and non-fruit-eating) at each individual survey. The presence of an active box only had an effect at the individual survey level and only on non-fruit-eating birds; surveys when the box was active showed fewer non-fruit-eating birds, but there was not a decrease in the estimates of abundance of non-fruit-eating birds over the study season. Thus, the study suggests that even when a kestrel box decreases the number of non-fruit-eating birds, the effect may be ephemeral and may dissipate when kestrel activity decreases, such as once the kestrels fledge and move out of the immediate area.

The kestrel-mediated decrease in the number of non-fruit-eating birds may have a negative effect on pest control. Many blueberry pests are insects; for example, the spotted winged drosophila (*Drosophila suzukii*) is an introduced pest in the United States that can cause

large amounts of damage to blueberry growing operations (Bolda et al., 2010). When cages were used to exclude birds (and potentially mammals) from blueberry bushes, more larvae of the spotted winged drosophila were found; this indicates that birds may provide pest control by consuming spotted winged drosophila larvae (Ballsman et al., 2017).

However, non-fruit-eating birds may also consume or deter beneficial insect species as well. For example, the Japanese beetle (*Popillia japonica*) is another introduced blueberry pest that can cost blueberry growers significant amounts of money (Szendrei and Isaacs, 2006). Assassin bugs and multiple spider species will consume Japanese beetles; many insectivorous birds prey on these insects, such as Eastern bluebirds, which were present in our study (Pinkowski, 1978). If kestrels deter species that consume these beneficial insects, this could be a kestrel-mediated benefit for pest control. More work is needed to unravel the complex food webs that are influenced, in both positive and negative ways, when introducing a predator.

One reason that kestrels may have affected non-fruit-eating but not fruit-eating birds is body size. Many of the non-fruit-eating birds in our study had small body sizes, and therefore may have seen a kestrel as more of a threat than some of the larger fruit-eating birds like American robins (*Turdus migratorius*) and common grackles (*Quiscalus quiscula*). Kestrels have been documented consuming a wide size range of bird prey species including most of the species detected in our study; however, their typical diet items tend to be small organisms (such as arthropods, small mammals). The most detected fruit-eating bird in our study was the American Robin (hereafter, robin). While robins have been recorded as a prey item for kestrels, they have a larger body size than field sparrows and chipping sparrows, which were common non-fruit-eating birds in our study. More work needs to be done on how the response to a predator varies by body size of the prey in the context of ecosystem services. For example, one study found that

the presence of European kestrel (*Falco tinnunculus*) nests in Finnish farmland decreased the density of both small-bodied and migratory bird species but had no effect larger-bodied and resident bird species (Suhonen et al., 1994). A study in Florida found playing eastern screech owl (*Megascops asio*) calls decreased the abundance of smaller-bodied species of birds significantly more than larger-bodied species (Hua et al., 2013). In some ecosystems beneficial insectivores tend to be small-bodied passerines, such as Great Tits (*Parus major*) that reduce caterpillar damage in apple orchards, or warblers that consume insects that damage coffee plants (Mols and Visser, 2007; Johnson et al., 2010). A shift in the bird assemblage away from smaller-bodied birds may lead to fewer insectivores present, because of the presence of a predator.

There are differences between the present study site and our study site in northern Michigan cherry orchards that could have led to the differences in the impact of an active kestrel box on fruit-eating birds, i.e. no effect in the present study and reduced abundance of fruit-eating birds in cherries. First, cherry orchards are open, and may provide less cover from predation. This may force birds out of the orchards to seek cover, which would lead to a lower number of fruit-eating birds in orchards with active boxes. Mature high bush blueberry is very dense and may provide enough cover from predation so that prey birds do not need to exit the blueberry fields to find cover when a kestrel is nearby. Second, kestrels were detected actively hunting in cherry orchards, while kestrels mainly hunted in the grassy margins surrounding the blueberry fields, or in neighboring open areas (personal obs; comm Megan Shave). This corresponds to kestrel hunting habitat which tends to be open with short grass (Bird and Palmer, 1988). Therefore, kestrels may have spent less overall time in the blueberry fields during nesting, exerting less of a threatening presence.

Tree cover had no effect on the abundances of either fruit-eating or non-fruit-eating birds. Some studies have found that tree cover (i.e. treelines) is associated with an increase in bird abundance and diversity (Heath et al., 2017). In our study, the lack of an effect might be due to highbush blueberry being dense enough to provide birds with cover from predation, decreasing the need for nearby tree cover.

Our results show that there are many layers of complexity to the issue of how to incorporate natural predators into agroecosystems to confer pest control benefits. Pest control benefits that are observed in one crop and/or area may not transfer to a different crop or area. Also, the presence of an introduced predator may have unintended effects, such as decreasing the number of potentially helpful bird species. Net effects must also be taken in totality. The present study suggests that in blueberry fields American kestrels may reduce non-fruit-eating bird abundance, with potential effects on the abundance of the prey items of non-fruit-eating birds. More detailed data on the proportions of beneficial and detrimental insects in the diets of these non-fruit-eating birds would help to understand whether kestrels might have net negative effects on ecosystem services in this context.

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