EFFECTS OF NON-NATIVE WOODY PLANT SPECIES ON SHRUBLAND BIRDS OF CONSERVATION CONCERN

BY

KAITLYN RIPPLE

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Natural Resources and Environmental Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2019

Urbana, Illinois

Master's Committee:

Adjunct Assistant Professor Kirk Stodola Co-Advisor
Research Associate Thomas J. Benson Co-Advisor
Associate Professor Jeffrey W. Matthews
Dr. Loren Merrill
Dr. David N. Zaya

ABSTRACT

Shrubland birds are among the fastest declining groups of birds over the past 50 years. Habitat loss and degradation are proposed as being major drivers, but the underlying causes of these declines are unknown. I investigated some of the potential factors driving population declines in three species listed by the Illinois Department of Natural Resources as Species in Greatest Need of Conservation (Bell's Vireo (*Vireo bellii bellii*), Yellow-breasted Chat (*Icteria virens*), and Field Sparrow (*Spizella pusilla*)). I visited 112 shrubland sites across Illinois to gather information on the bird and vegetation community over a three-year period. I looked at how habitat characteristics at different scales of habitat selection influenced birds' occupancy dynamics, as well as how the three most abundant non-native shrub in Illinois (autumn olive (*Elaeagnus umbellata)*, honeysuckle (*Lonicera spp.*) and multiflora rose (*Rosa multiflora*)), influenced birds' physiological health and condition. I found that non-native plant species, specifically multiflora rose, negatively associated with shrubland bird occupancy dynamics, especially for Bell's Vireo and Yellow-breasted Chat. Field Sparrows were found on nearly all shrubland sites I surveyed, and appeared to utilize shrublands regardless of their composition or context on the landscape. Additionally, I found that autumn olive, honeysuckle and native plant species had a relationship with the stress (corticosterone), diet quality (triglyceride and β-hydroxybutyrate), and immune function (bacteria-killing ability) of all three species. Bell's Vireos had higher corticosterone concentrations in relation to increasing prevalence of autumn olive. Yellow-breasted Chats and Field Sparrows had lower triglyceride concentrations in relation to increasing prevalence of honeysuckle, and all three species had decreasing concentrations of β-hydroxybutyrate in relation to honeysuckle as well. Finally, increasing percentages of native plant species had a positive influence on bacteria killing-ability of the three shrubland obligate species. My results suggest that increasing the number of shrubland habitats

in combination with the replacement of non-native woody shrubs with native plants would benefit these three shrubland obligate birds.

ACKNOWLEDGEMENTS

First, I would like to thank Dr. Kirk Stodola and Dr. Loren Merrill who worked closely with me throughout this project. Dr. Stodola, not only provided technical expertise but also provided moral support throughout this project. Thank you for always being there to answer all of my questions and for always keeping things light and positive no matter how many mistakes I made. Dr. Merrill introduced me to the field of conservation physiology and mentored me throughout the entire project. Thank you for the countless meetings, help in the lab (even when it didn't work), and for all of the advice and encouragement.

I would also like to thank the rest of my committee Dr. David N. Zaya, Dr. T.J. Benson, and Dr. Jeffrey W. Matthews for all of their guidance and input. Without their contributions and expertise, this project would not have been possible.

I would also like to thank all of my technicians; Taylor Joray, Amber Ring, Dan Brown, Billy Nixon, Lauren Rudloff, Justine Brumm, Cat Werth, and Lake White. I could not have collected all of the data without your help and support. Though the work was tough and the hours were long, you all made it so much fun and I will always look back fondly on our field days.

Thank you to all of my lab mates; Maureen Hurd, Ben Williams, Emily Ospina-Jones, Claire Johnson, and Ian Souza-Cole, for all of your moral support, input, and most importantly comic relief. Thank you for dealing with my endless questions and constant distractions. I am so grateful to have had such great lab-mates.

And finally, thank you to all of my family and friends who supported and encouraged me throughout this program.

To My Family

TABLE OF CONTENTS

CHAPTER 1: GENERAL INTRODUCTION

Shrubland birds in North America have experienced population declines over the past 50 years (Dettmers 2003) and are one of the fastest declining bird groups, while receiving less conservation attention than other species (Stanton *et al.* 2018). Habitat loss and degradation are typically cited as the main drivers of decline (Rosenberg *et al.* 2016), yet the mechanisms driving the declines are poorly understood. Many obligate shrubland bird species are now "species of conservation concern." Landscape changes such as decreased shrubland abundance as well as encroachment of non-native plant species have left the quality of the remaining shrublands in question. To help conserve these declining bird species in this poorly understood habitat, we must first understand the underlying mechanisms influencing the declining shrubland bird populations.

To do this, I took a multi-tiered approach towards understanding the causes of population declines of shrubland birds in Illinois. First, I investigated the factors influencing the occupancy dynamics of shrubland birds in Greatest Need of Conservation. I adopted Johnson's (1980) site selection hierarchy concept as the framework for investigating the mechanisms influencing the occupancy dynamics of shrubland birds. Under this framework, the context in which a shrubland occurs on the landscape must first be considered. Birds will often choose to breed in areas based on the size of the habitat (Robinson *et al.* 1994) and the composition of the surrounding landscape (Knick and Rotenberry 1995). Next, the physical make-up of the vegetation within a habitat will determine its suitability. For instance, the physical structure of the vegetation can influence nesting (Brawn *et al.* 2001) and roosting locations (Hinsley and Bellamy 2000) and ultimately determine habitat suitability (Chapin *et al.* 2000). Finally, under the hierarchical selection process, the resources within a habitat are weighed. The plant species identity within a site can influence resources via food availability (Litt *et al.* 2014, Burghardt *et al.* 2009) and protection from nest predators (Rodewald *et al.* 2010). Using these three spatial scales, I investigated how the composition of the landscape may potentially be influencing the patterns of population declines in shrubland birds considered in Greatest Need of Conservation in Illinois.

In addition to investigating the occupancy dynamics, I used physiological biomarkers to further illuminate potential underlying factors that may be linking changes in habitat to declining populations. Many studies investigating the effects of non-native plants on birds focus on how non-native plants influence various population dynamics, such as abundance, survival, and fecundity. However, these measurements may be a misleading indicator of habitat quality (Van Horne 1983) and there is little benefit to high reproductive output if it significantly increases mortality (Sæther and Bakke 2000) or if those individuals produced fail to survive to reproductive age (Heppel *et al.* 2000). By using physiological markers, I can get a better understanding of how the individuals within a site are being directly influenced by various environmental factors such as encroachment by non-native plant species. These results can then be scaled up and applied to the population level.

My thesis focuses on how these potential underlying mechanisms may influence site selection and physiological health in three shrubland obligate avian species considered in Greatest Need of Conservation in the Illinois Wildlife Action Plan (IWAP 2005); Field Sparrow (*Spizella pusilla*), Yellow-breasted Chat (*Icteria virens*), and Bell's Vireo (*Vireo bellii bellii*). All three species breed exclusively in early successional habitat, though at different successional stages (Carey *et al.* 2008, Kus *et. al* 2010, Thompson and Nolan 2016). The Field Sparrow, a member of the family Emberizidae, prefers to nest in open shrubland habitat while avoiding areas near development (Carey *et al.* 2008). The Yellow-breasted Chat, the sole member of the

Icteriidae family, prefers to nest in dense, early successional shrubby habitat (Thompson and Nolan 2016). Bell's Vireo, a member of the Vireonidae family, also prefers to nest in dense, shrubby, early successional habitat. All three species have experienced population declines over the past 50 years in Illinois (Pardieck *et al.* 2017).

In Chapter 2, I investigate how landscape context, the physical structure of the shrubland, and the plant species present within the shrubland influence the occupancy dynamics of the three focal species. Following the hierarchical site selection process described by Johnson (1980), I investigate the role that patch size and the proportion of cropland surrounding a shrubland has on the occupancy dynamics of the three focal species to better understand the role of landscape context. I also investigate the role that vegetation structure plays to better understand how heterogeneity of a habitat influences the perception of habitat quality. Finally, I examine the influence of the three most pervasive non-native woody shrubs (autumn olive (*Elaeagnus umbellata*), honeysuckle (*Lonicera spp.*) and multiflora rose (*Rosa multiflora*)) in relation to the occupancy dynamics of the three shrubland obligate bird species of conservation concern.

In Chapter 3, I investigate the physiological responses of the three focal bird species in relation to the prevalence of the three most ubiquitous non-native woody shrubs plants and native shrubs using four biomarkers. Specifically, I assess circulating plasma corticosterone concentration which is a common biomarker used to measure the impact of environmental factors on organisms' chronic stress levels (Wingfield *et al.* 1997). Additionally, I measure the association between these environmental factors and diet quality using two dietary metabolite assays (triglycerides and β-hydroxybutyrate). Triglycerides, a form of lipid stored in the plasma, are used as an energy reserve, and higher concentrations in the plasma typically indicate a higher diet quality. β-hydroxybutyrate is a form of ketone acid generated when an animal catabolizes fat; higher levels are generally indicative of an animal forced to use its energy reserves because food resources are of low quality. I investigate an aspect of the birds' immunocompetence using a bacteria-killing assay which reflects an individual's capacity to clear a bacterial infection. Finally, I assessed ectoparasite burdens on each bird. Birds in poor condition, or those that are forced to spend more time searching or food resources may not be able to allocate resources to preening and other behavioral defenses to manage ectoparasite infestations. By looking at the associations between habitat composition and these four biomarkers I hope to better understand if population declines in the three focal avian species are being driven by habitat-mediated changes in the physiologic condition of the birds.

The aim of this thesis is to better inform managers on how habitat characteristics are influencing shrubland birds considered to be of conservation concern. Understanding the mechanisms influencing the declining populations of shrubland birds is essential to their conservation. Investigating the mechanisms influencing occupancy patterns as well as the health and condition will help provide information that can be used to help facilitate population growth as well as prevent further decline of shrubland bird species.

1.1 REFERENCES

Brawn, J. D., S. K. Robinson, and F. R. Thompson III. 2001. The role of disturbances in the ecology and conservation of birds. Annual Review Ecological Systems 32:251-76.

Burghardt, K. T., D. W. Tallamy, and W. G. Shriver. 2009. Impact of native plants on bird and butterfly biodiversity in suburban landscapes. Conservation Biology 23:219–224.

Carey, M., D. E. Burhans and D. A. Nelson. 2008. Field Sparrow (Spizella pusilla), The Birds of North America (P. G. Rodewald, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America: https://birdsna.org/Species-Account/bna/species/fiespa

Chapin III, F. S., E. S. Zavaleta, V. T. Eviner, R. L. Naylor, P. M. Vitousek, H. L. Reynolds, D. U. Hooper, S. Lavorel, O. E. Sala, S. E. Hobbie, M. C. Mack, and S. Díaz. 2000. Consequences of changing biodiversity. Nature 405:234–42.

Dettmers, R. 2003. Status and conservation of shrubland birds in the northeastern US. Forest Ecology and Management 185:81–93.

Heppel, S. S., H. Caswell, and L. B. Crowder. 2000. Life histories and elasticity patterns: perturbation analysis for species with minimal demographic data. Ecology 81:654–665.

Hinsley, S. A. and P. E. Bellamy. 2000. The influence of hedge structure, management and landscape context on the value of hedgerows to birds: A review. Journal of Environmental Management 60:33-49.

Illinois Department of Natural Resources. 2005. The Illinois comprehensive wildlife conservation plan and strategy. Retrieved from: https://www.dnr.illinois.gov/conservation/IWAP/Documents/IllinoisCWCP.pdf

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Knick, S. T., and J. T. Rotenberry. 1995. Landscape characteristics of fragmented shrubsteppe habitats and breeding passerine birds. Conservation Biology 9:1059-1071.

Kus, B., S. L. Hopp, R. R. Johnson and B. T. Brown. 2010. Bell's Vireo (Vireo bellii), The Birds of North America (P. G. Rodewald, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America: https://birdsna.org/Species-Account/bna/species/belvirDOI: 10.2173/bna.35

Litt, A. R., E. E. Cord, T. E. Fulbright, and G. L. Schuster. 2014. Effects of invasive plants on arthropods. Conservation Biology 28:1532-1549.

Pardieck, K. L., D. J. Ziolkowski Jr., M. Lutmerding and M. A. R. Hudson. 2018. North American Breeding Bird Survey Dataset 1966 - 2017, version 2017.0. U.S. Geological Survey, Patuxent Wildlife Research Center. https://doi.org/10.5066/F76972V8.

Robinson, S. K., E. J. Heske, and J. D. Brawn. 1994. Factors affecting the nesting success of edge and shrubland birds. Illinois Natural Survey Technical Reports W-125-R.

Rodewald, A.D., D.P. Shustack, and L.E. Hitchcock. 2010. Exotic shrubs as ephemeral ecological traps for nesting birds. Biological Invasions 12:33-39.

Rosenberg, K. V., J. A. Kennedy, R. Dettmers, R. P. Ford, D. Reynolds, J.D. Alexander, C. J. Beardmore, P. J. Blancher, R. E. Bogart, G. S. Butcher, A. F. Camfield, A. Couturier, D. W. Demarest, W. E. Easton, J.J. Giocomo, R.H. Keller, A. E. Mini, A. O. Panjabi, D. N. Pashley, T. D. Rich, J. M. Ruth, H. Stabins, J. Stanton, T. Will. 2016. Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee. 119 pp.

Sæther, B. E., and Ø. Bakke. 2000. Avian life history variation and contribution of demographic traits to the population growth rate. Ecology 81:642–653.

Stanton, R. L., C. A. Morrissey, and R. G. Clark. 2018. Analysis of trends and agricultural drivers of farmland bird declines in North America: A review. Agriculture, Ecosystems and Environment 254:244-254.

Thompson, C. F., and V. Nolan Jr. 1973. Population biology of the Yellow-Breasted Chat (Icteria virens L.) in Southern Indiana. Ecological Monographs 43:145–171.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893–901.

Wingfield, J. C., K. Hunt, C. Breuner, K. Dunlap, G. S. Fowler, L. Freed, and J. Lepson. 1997. Environmental stress, field endocrinology, and conservation biology. J. R. Clemmons, R. Buchholz (Eds.), Behavioral Approaches to Conservation in the Wild, Cambridge University Press, Cambridge, UK, pp 95-131.

CHAPTER 2: LANDSCAPE CONTEXT, VEGETATION STRUCTURE, OR PLANT IDENTITY? INVESTIGATING POTENTIAL MECHANISMS BEHIND OCCUPANCY DYNAMICS OF SHRUBLAND BIRDS

2.1 ABSTRACT:

Many shrubland bird species have suffered population declines over the past 50 years (Dettmers 2003), and habitat loss and degradation are proposed to be a major contributor to these declines. With increases in row-crop agriculture and urbanization, natural areas are disappearing and many remaining shrublands have been colonized by non-native plant species. I investigated potential mechanisms influencing the occupancy dynamics of shrubland birds at varying scales of site selection. Specifically, I investigated the occupancy dynamics of three shrubland obligate species considered to be of conservation concern in Illinois (Bell's Vireo (*Vireo bellii bellii*), Yellow-breasted Chat (*Icteria virens*), and Field Sparrow (*Spizella pusilla*)) in relation to landscape characteristics, habitat structure, and plant community identity. I visited 112 shrubland sites during the breeding seasons of 2016-2018. At each site I recorded bird community, as well as the vegetation composition and structure. Additionally, I used land cover datasets in ArcGIS to calculate landscape level information around each of the sites. I used a multi-season occupancy modeling approach to analyze the relationships between these habitat characteristics and the bird species' site selection and fidelity. I found that plant species identity, specifically the percentage of multiflora rose (*Rosa multiflora*), had a significant influence on site selection by Bell's Vireo and site fidelity of both Bell's Vireo and Yellow-breasted Chat. Field Sparrows were ubiquitous throughout my sites, which suggested that they were utilizing sites regardless of the habitats' context or composition. My results suggest that the identity of the plant species in a shrubland has the largest influence on the occupancy dynamics shrubland bird species. However,

because shrublands are so uncommon, increasing the abundance of shrublands has the potential to benefit all shrubland obligate species.

2.2 INTRODUCTION:

Shrubland bird species have experienced population declines over the past 50 years (Dettmers 2003), making them one of the fastest declining groups of birds (Stanton *et al.* 2018). Shrubland birds are declining nationally, and many of the species are of conservation concern (Sauer *et al.* 2017). The primary cause of these population declines has been attributed to habitat loss and degradation (Rosenberg *et al.* 2016). Over the past century, shrublands have been converted into pastures, row crop agriculture, and urban areas, while the remaining shrublands have been degraded by the colonization of non-native plant species (Askins 1993, Rosenberg *et al.* 2016). Additionally, the natural disturbances that created and maintained shrublands, like wildfires, have been suppressed, which has further decreased the number of naturally occurring shrublands (Askins 2000). With shrublands becoming less common, and shrubland obligate bird species declining, it is important to understand the processes linking habitat loss and degradation to population declines to better manage for these species of conservation concern.

Shrubland habitat in the Midwestern U.S. is uncommon, and little is known about the species that use it (Illinois Department of Natural Resources 2005). Shrublands were often viewed as wastelands, but were also described as having "the richest summer habitat" for birds and were utilized by many species, at least in Illinois (Graber and Graber 1963). Historically, early successional or shrubland habitats were more common on the landscape (estimated 500,000 acres in 1907 (Graber and Graber 1963)), but changes in farming practices have decreased their prevalence drastically (17,907 acres 2015 (USDA NASS 2015)). Furthermore, disturbance suppression has caused many shrublands to become overgrown and structurally homogenous and increased prevalence of non-native woody shrubs (e.g. multiflora rose, honeysuckle, and autumn olive) which has led to shifts in the species composition. While habitat loss may be largely responsible for population declines (Dettmers 2003), changes in habitat quality may be only exacerbating the declines.

Habitat quality and selection of breeding areas for shrubland birds are determined by multiple factors acting on different spatial scales (Johnson 1980). First, the locations of the shrubland within the broader landscape context may be important. Lager patches of contiguous habitat may be more desirable for breeding birds (Robinson *et al.* 1994) and birds will likely select sites surrounded by more potentially suitable habitat (Knick and Rotenberry 1995). Second, the physical structure of the vegetation influences an area's suitability (Cody 1981, James 1971, Wiens 1969), by affecting reproductive success (Brawn *et al.* 2001) and foraging locations (Brooks *et al.* 2004). Third, vegetation composition can affect habitat suitability (Chapin *et al.* 2000); specifically, non-native plants can decrease site quality (Crooks 2002) by altering the soil chemistry, invertebrate communities (Litt *et al.* 2014, Burghardt *et al.* 2009), microclimates, and outcompeting native species (Carter *et al.* 2015). Understanding how habitat characteristics at different spatial scales influence habitat selection in shrubland birds is an important first step towards reversing population declines.

I investigated how landscape context, vegetation structure, and the presence of non-native woody plant species influence site selection for conservation priority shrubland birds in Illinois. I focused my efforts on three shrubland birds considered to be in Greatest Need of Conservation (Illinois Department of Natural Resources 2005), Bell's Vireo (*Vireo bellii bellii*), Yellow-breasted Chat (*Icteria virens*), and Field Sparrow (*Spizella pusilla*). I visited 112 sites located throughout Illinois over a three-year period from 2016 to 2018. At each location, I documented the presence of the three focal species, described vegetation structure, and quantified the prevalence of non-native woody plant species. I investigated occupancy patterns of the three species in Greatest Need of Conservation in relation to the three site selection metrics; landscape context, habitat structure, and species identity, using dynamic occupancy models (MacKenzie et al. 2003). I expected that the occupancy dynamics of the three focal species would be influenced by 1) the proportion of row-crop agriculture surrounding a shrubland, 2) the homogenization of habitat structure, and 3) the percentages of non-native woody shrubs.

2.3 METHODS:

Focal Species

I focused my efforts on three shrubland obligate species, Bell's Vireo, Yellow-breasted Chat, and Field Sparrow. All three species have experienced population declines in Illinois over the past 50 years (Walk *et al.* 2010) and are listed as Species in Greatest Need of Conservation in the Illinois Wildlife Action Plan (Illinois Department of Natural Resources 2005).

Study Areas

I visited 112 publicly owned shrublands located throughout the state of Illinois between late May and early July 2016, 2017 and 2018 (Figure 2.1). I visited 109 sites in 2016, 85 in 2017, and 109 in 2018. Shrublands were located throughout the entire state, although lack of suitable shrubland habitat in the west-central part of Illinois led to underrepresentation in this region (Figure 2.1).

Field Methods

I conducted vegetation and bird surveys at each shrubland site. Sites were visited over multiple years and were surveyed between one and five times over the course of the study.

Landscape variables

I calculated the proportion of agriculture within 1 km of each shrubland patch. I focused on 1 km because I believed that birds were unlikely to interact with areas outside of that buffer and that it was a more realistic scale for land managers. Site coordinates were overlaid onto the National Agricultural Statistics Service's Cropland Data Layer (CDL 2015) raster file (USDA NASS 2015) in ArcGIS 10.5.1, and I used the Geospatial Modeling Environment (Beyer 2012) to determine the proportion of the surrounding landscape devoted to row-crop agriculture. I focused on surrounding agriculture because it is the dominant landscape feature in Illinois and correlated with other land-cover types (development $r^2 = 0.11$ and forest $r^2 = 0.26$) The extent each shrubland was determined using ArcGIS 10.5.1.

Vegetation surveys

Vegetation surveys consisted of 100-m transects laid out in a random direction from the approximate center of a site. I defined sites as the extent of the entire shrubland patch. Sites I surveyed had to fit a 100 m transect within the shrubland patch, and there were no maximum requirements for size of the site. Five 10 × 10 m plots were located every 20 m along the 100-m transect. I recorded all woody species present in each 10 × 10 m plot, along with the percent cover of each species in three vertical strata, 0-1 m, 1-3 m, and >3 m. Percent cover was recorded by estimating the total percentage each plant species covered in the 10 x 10 m area. I combined all non-native honeysuckle spp. (*Lonicera maackii*, *Lonicera x bellii*, *Lonicera japonica*, and

Lonicera morrowii) which I will refer to as honeysuckle, with the majority of them being *L. maackii*. Dead woody species that were still standing were included because they provide physical structure which plays an important role in the territory establishment of birds (Bulluck and Buehler 2006).

Site Structure – I quantified vegetation structural characteristics using average woody plant cover, and horizontal and vertical heterogeneity. I calculated the average woody plant cover by averaging the total cover in all three strata (0-1, 1-3 m, >3 m) in each plot and then averaging across the five plots to represent the density in woody plant cover. Horizontal heterogeneity was calculated by averaging the percent cover of all woody species among the three strata in each plot and then taking the variance among all 5 plots, thereby representing the 'patchiness' of a shrubland. Vertical heterogeneity was calculated by averaging the percent cover across all 5 plots in each of the three strata categories, and then calculating the variance among all three strata categories.

Plant identity – Autumn olive (*Elaeagnus umbellata*), multiflora rose (*Rosa multiflora*), and honeysuckle (*Lonicera spp.*) are the most abundant and widespread non-native woody shrubs in shrublands in Illinois (unpublished data, Invasive Species Campaign 2017). Percent cover of all three non-native species, along with total percent native species were calculated using the cover data collected in the vegetation surveys. The percent cover of each species was calculated by taking the mean cover among the first two strata (0-1 m and 1-3 m) and then taking the mean cover across the five plots. I used the first two strata because the vegetation rarely exceeded 3 meters. I also combined the three non-native species to investigate the cumulative effect of their encroachment.

Bird surveys

I conducted point count and targeted callback surveys at all shrublands. Two 10-min point count surveys were conducted 50 m away from the center of each vegetation survey transect and 100 m away from each other. Each point count was treated as a replicate survey of the center of shrubland and a minimum of 5 minutes elapsed between each point count. I recorded all focal species seen or heard within a 100-m radius. I followed the 10-minute point counts with targeted callback surveys that used a mixture of calls and songs to detect Bell's Vireos, Yellow-breasted Chats, and Field Sparrows. An observer walked the 100 m transect playing a broadcast of each of the three species every 25 m. Call broadcasts consisted of a playback period that began with 15 seconds of call and song for a focal species followed by 10 seconds of silence before the next focal species recording began. After the 75-second long call playback, the observer remained at each point for an additional 30 seconds to detect any individuals that did not respond immediately before moving to the next point. Sites were sampled 1-2 times per year.

Statistical Analyses

I investigated the presence/absence of Yellow-breasted Chats, Bell's Vireos, and Field Sparrows, in relation to the landscape, site structure, and plant identity characteristics using the dynamic occupancy model described by MacKenzie *et al.* (2003). I fit ten models that represented my hypotheses on the influence of landscape features (shrubland patch size, surrounding agriculture), habitat structure (average shrub coverage, vertical heterogeneity, horizontal heterogeneity), and plant species identity (percent multiflora rose, percent honeysuckle, percent autumn olive, percent non-native woody plant species and percent native woody plant species) on presence/absence of my focal species. I made detection a function of observation type (callback or point count) for each model and included year in the colonization and extinction parameters to account for yearly population fluctuations. I used Akaike's Information Criterion (Akaike 1974) to compare model performance. All analyses were performed using the "*colext*" function in the package *Unmarked* (Fiske and Chandler 2011) in program R version 3.5.1 (R Core Team 2018).

2.4 RESULTS:

Landscape – While there are a variety of landcover types in Illinois (e.g. forest, development, and wetlands), I focused on row crop agriculture because it is considered to be a large contributor to the loss of natural habitat. The dominant landcover surrounding the shrublands sites were forests (mean: 36% and range: 0–86%), however many of the shrublands in Illinois are forest edges and therefore would inherently increase the proportion of forest surrounding these sites. Row-crop agriculture was the second most dominant feature surrounding the shrubland sites with an average of 26% (range: 0-81%), followed by grassland and shrubland habitats (mean: 15% and range: 0–55%) and development (mean: 11% and range: 0–62%). The average patch size for each shrubland was 0.267 km^2 (range: 0.007 to 5.081 km^2).

Site structure – The physical structure of the shrublands did not vary substantially (Figure 2). The average standard deviation of horizontal structural heterogeneity was 10.5 (range: 0.4-32.6%). Average standard deviation of vertical structural heterogeneity was 10.1% (range: 0.5-43.7%). The average density of woody plant species was 20% (range: 0-96%).

Plant identity – Multiflora rose, honeysuckle, and autumn olive, were the most prevalent woody plant species I found on the shrublands throughout Illinois. Their distributions were spread evenly across the state. The average percent cover for each of the non-native shrubs were

1% multiflora rose (range: 0-17%, present at 57 sites), 2% honeysuckle (range: 0-42%, present at 64 sites), and 5% autumn olive (range: 0-41%, present at 64 sites). The average percent of native woody species was 11% (range: 0-34%).

Occupancy

Bell's Vireos were observed (naïve occupancy) at 19% of sites in 2016, 24% of sites in 2017, and 17% of sites in 2018. Detection of Bell's Vireo was greater for callback survey compared to the passive point count (callback survey $\beta = 1.056$ and point count $\beta = 0.599$). Percentage of multiflora rose best predicted the occupancy dynamics of Bell's Vireo. Bell's vireo were 2.4 times less likely to occupy a site for each be occupied by Bell's Vireo (Table 2.1, Table 2.2, Figure 2.3). Additionally, multiflora rose influenced the probability an occupied site would become unoccupied in the following year. Specifically, for every percent increase in multiflora rose, occupied sites were 4.4 times less likely to be occupied in the following year (Table 2.2, Figure 2.4). Average percent of woody cover was the next best fitting model, but the confidence intervals for its effects on initial occupancy, colonization, and extinction were large and the effect it had on the dynamic occupancy patterns of Bell's Vireos (Table 2.2) was unclear.

Yellow-breasted Chats were observed at 51% sites in 2016, 81% of sites in 2017, and 75% of sites in 2018. Yellow-breasted Chats had the highest detection probability using point count surveys (callback survey $\beta = 0.550$ and point count $\beta = 1.380$). Percentage of multiflora rose best predicted the occupancy dynamics for Yellow-breasted Chat (Table 2.1). Initial occupancy of Yellow-breasted Chats was not strongly influenced by the percentage of multiflora rose. However, with every increase in the percentage of multiflora rose, the site was 1.5 times more likely to become unoccupied the following year by a Yellow-breasted Chat (Table 2.2, Figure 2.5). Percent native woody plant species was the next best fitting model (Table 2.1).

However, the confidence intervals for its effects on initial occupancy, colonization, and extinction were large and therefore its effect on Yellow-breasted Chat was unclear (Table 2.2).

Field Sparrows were observed at 91% of sites in 2016, 95% of sites in 2017, and 95% of sites in 2018. Field Sparrows had the highest probability using point count surveys (callback survey $\beta = 0.962$ and point count $\beta = 2.000$). Percent multiflora rose was the best indicator or the likelihood of Field Sparrows occupying a site, but the confidence intervals were large and therefore its influence on Field Sparrow occupancy dynamics was not clear (Table 2.2). Percent honeysuckle and percent non-native woody plant species were the next best predictors (Table 2.1), but their effects on initial occupancy, colonization, and extinction were unclear. (Table 2.2).

2.5 DISCUSSION:

The three species of conservation concern that we focused on varied substantially in their use of shrublands throughout Illinois. Bell's Vireos were present at <25% of the sites over the three-year period, Yellow-breasted Chats were present at a majority of the sites, and Field Sparrows were present at almost all sites. Multiflora rose appears to influence site selection as well as the probability of a site remaining occupied for two of the three species. Shrublands where multiflora rose was most prevalent were less likely to be selected by Bell's Vireo and the presence of multiflora rose increased the probability of an occupied site becoming unoccupied for both Bell's Vireo and Yellow-breasted Chat. None of the habitat characteristics explained the variation in Field Sparrows' occupancy patterns, probably because they were ubiquitous at shrublands throughout Illinois.

The presence of multiflora rose at a shrubland may deter individuals of certain species, such as Bell's Vireo, from settling at a location. Multiflora rose may be altering the perception of food availability. Non-native plant species, such as multiflora rose, have an earlier leaf phenology than most native plant species (Gleditsch and Carlo 2014), which can influence the timing of food availability. Consequently, migratory species, such as Bell's Vireo, may perceive sites with multiflora rose as being lower in quality when selecting a site because they may not be able to rear young when food is most abundant (Visser *et al.* 2006). Additionally, multiflora rose may deter some species from settling by reducing the availability of adequate nesting sites. Multiflora rose often grows into trees, which inevitably changes the locations where shrub nesting bird species can place their nests. Bell's Vireo, for instance, nest in the forks of low-lying branches (Barlow 1962), which may no longer be present at a site if multiflora rose is abundant. Thus, it is possible that Bell's Vireo, or other similar shrub-nesting species, may perceive the shrubland sites with multiflora rose as being less desirable and may choose not to breed there.

The presence of multiflora rose at a shrubland also influenced site occupancy dynamics in both Bell's Vireo and Yellow-breasted Chat. Site fidelity, which is tied to occupancy dynamics, in shrubland birds is tied to breeding success (Schlossberg 2009), with birds returning to sites where they were successful the previous year. Rodewald *et al.* (2010) found that nest survival was low for individuals that nested in non-native species, especially multiflora rose, compared to those that nest in native vegetation. Although multiflora rose plants have defensive structures, such as thorns, which may act as a natural defense against nest predators, nests in multiflora rose experience higher rates of predation by mammals than nests in plants without thorns (Borgmann and Rodewald 2004). Additionally, sites that are dominated with multiflora rose may have lower quality food resources, which may be deterring birds from returning to those cites the following year. For instance, Landsman and Bowman (2017) found that lower abundances of spiders, which are an important food resource for birds, were associated with higher prevalence of multiflora rose. Therefore, species like Bell's Vireo and Yellow-breasted Chat may be leaving sites with a greater prevalence of multiflora rose because of low breeding success as well as lower food availability.

Vegetation structure did not play a significant role in the occupancy patterns of the shrubland bird species I investigated. I found very little variation in structural characteristics between the shrubland sites I visited. Shrublands throughout Illinois shared a similar core group of plant species, including the three non-native species I focused on, which were present at a majority of the sites. Because the shrublands shared many of the same plant species in their communities, the physical structure of the shrubland sites I visited was relatively similar. Additionally, I found no strong correlations between any of the non-native shrub species on the structure of the shrubland (unpublished data), suggesting that the degree of invasion was not influencing the structure of these shrublands. Therefore, birds did not have much variation in habitat structure to choose from, and consequently, habitat structure was not an important predictor of occupancy dynamics for these shrubland bird species.

Landscape context also did not appear to be important for these three shrubland obligate species. Many of the publicly owned shrublands in Illinois are ephemeral habitats, meaning they are disturbance dependent and are generally composed of early successional vegetation. Species whose populations are abundant and widespread like the Field Sparrow, are using these habitats whenever they appear on the landscape, regardless of where they are located. Furthermore, the majority of Illinois is row-crop agriculture and shrublands are rare. With so few available shrublands, these individuals have limited choices in breeding sites and appear to use those available regardless of their size and location on the landscape (Schlossberg and King 2008).

Conservation Implications

Many shrubland obligate species are in decline, and understanding the mechanisms influencing their site selection and use is essential to their conservation. Less common shrubland bird species, similar to Yellow-breasted Chat and Bell's Vireo, appear to be sensitive to plant species identity. Non-native plant species, especially multiflora rose, may be influencing site quality and consequently site selection and use. Consequently, targeted removal of multiflora rose may help increase the prevalence of uncommon shrubland bird species. However, shrubland obligate species that are more tolerant to a wider range of shrubland conditions, such as the Field Sparrow, appear to be less sensitive to non-native shrub encroachment and may be taking advantage of shrubland habitats as they become available on the landscape regardless of their surroundings (Askins *et al.* 2007). Therefore, increasing the number of shrublands should benefit those common species, as well as those less common.

2.6 TABLES AND FIGURES:

Table 2.1. Model selection table ranking models of occupancy dynamics in relation to habitat characteristics for Bell's Vireo, Yellow-breasted Chat, and Field Sparrow. Ten models were run for each species as covariates on the initial occupancy, colonization, and extinction probabilities and were ranked according to their AIC value.

Species	**Model**	**K**	**AIC**	**ΔAIC**	**AIC_w**
Bell's Vireo	*% Multiflora Rose*	10	524.7	0.00	0.69
	Average % Woody Cover	10	527.3	2.56	0.19
	Vertical Structural Heterogeneity	10	530.1	5.42	0.05
	Patch Size	10	531.1	6.43	0.03
	Horizontal Structural Heterogeneity	10	531.9	7.18	0.02
	Null	5	533.4	8.70	0.01
	Proportion of Crops within 1km	10	533.7	9.01	0.01
	% Native Woody Plant Species	10	534.3	9.61	0.01
	% Autumn Olive	10	536.3	11.56	0.00
	% Non-native Woody Plant Species	10	536.9	12.18	0.00
	% Honeysuckle	10	537.4	12.71	0.00
Yellow-breasted Chat	*% Multiflora Rose*	10	1029.3	0.00	0.62
	% Native Woody Plant Species	10	1031.9	2.56	0.17
	Null	5	1033.1	3.75	0.10
	% Honeysuckle	10	1035.3	5.95	0.03
	% Non-native Woody Plant Species	10	1035.5	6.15	0.03
	Horizontal Structural Heterogeneity	10	1036.2	6.87	0.02
	Patch Size	10	1037.6	8.29	0.01

Table 2.1 cont.

	Proportion of Crops within 1km	10	1038.4	9.09	0.01
	% Autumn Olive	10	1038.9	9.54	0.01
	Vertical Structural Heterogeneity	10	1038.9	9.58	0.01
	Average % Woody Cover	10	1040.2	10.90	0.00
Field Sparrow	*% Multiflora Rose*	10	710.4	0.00	0.60
	% Honeysuckle	10	711.7	1.25	0.32
	% Non-native Woody Plant Species	10	714.5	4.11	0.07
	% Autumn Olive	10	721.2	10.80	0.00
	Null	5	731.8	21.35	0.00
	Vertical Structural Heterogeneity	10	739.7	29.30	0.00
	Proportion of Crops within 1km	10	740.2	29.76	0.00
	Horizontal Structural Heterogeneity	10	797.0	86.57	0.00
	% Native Woody Plant Species	10	864.5	154.12	0.00
	Average % Woody Cover	10	864.5	154.13	0.00
	Patch Size	10	864.6	154.16	0.00

Table 2.2. Top ranking models of occupancy dynamics for Bell's Vireo, Yellow-breasted Chat, and Field Sparrow from 2016-2018. Ten parameters were tested for each species, and the models within 5 AIC values of the top model were chosen as top models. Standard errors for each estimate are in parenthesis.

Species	**Parameter**	**Parameter Estimates**								
			Initial occupancy		Colonization			Extinction		
		AIC	Intercept	Parameter	Intercept	Parameter	Year	Intercept	Parameter	Year
Bell's Vireo	*% Multiflora Rose*	524.7	-0.87 (0.30)	-0.86 (0.40)	-2.25 (0.44)	0.11 (0.15)	-0.06 (0.56)	-1.79 (0.69)	1.49 (0.71)	1.60 (0.76)
	Average % Woody Cover	527.3	-1.64 (0.34)	0.01 (0.01)	-2.13 (0.47)	0.00 (0.01)	-0.02 (0.55)	0.08 (0.71)	-0.07 (0.03)	1.82 (0.79)
Yellow-breasted Chat	*% Multiflora Rose*	1029.3	0.20 (-0.11)	-0.11 (0.10)	0.04 (0.41)	0.58 (0.36)	-0.78 (0.66)	-2.90 (0.58)	0.40 (0.15)	0.69 (0.63)
	% Native Plant Species	1031.9	-0.24 (0.03)	0.03 (0.03)	-1.48 (1.19)	0.21 (0.13)	-0.60 (0.66)	-1.73 (0.72)	-0.05 (0.05)	0.69 (0.62)
Field Sparrow	*% Multiflora Rose*	710.4	2.32 (0.40)	0.10 (0.23)	0.43 (0.82)	0.00 (0.30)	0.12 (1.24)	-3.00 (0.77)	-1.43 (1.08)	-0.01 (1.02)
	% Honeysuckle	711.7	2.40 (0.37)	0.01 (0.08)	-0.07 (0.89)	0.72 (0.74)	0.01 (1.25)	-3.39 (0.76)	-0.28 (0.41)	-0.02 (1.02)
	% Non-native Plant Species	714.5	2.12 (0.43)	0.06 (0.06)	-7.61 (31.40)	16.98 (79.50)	6.95 (31.40)	-3.46 (0.79)	-0.02 (0.06)	0.07 (0.94)

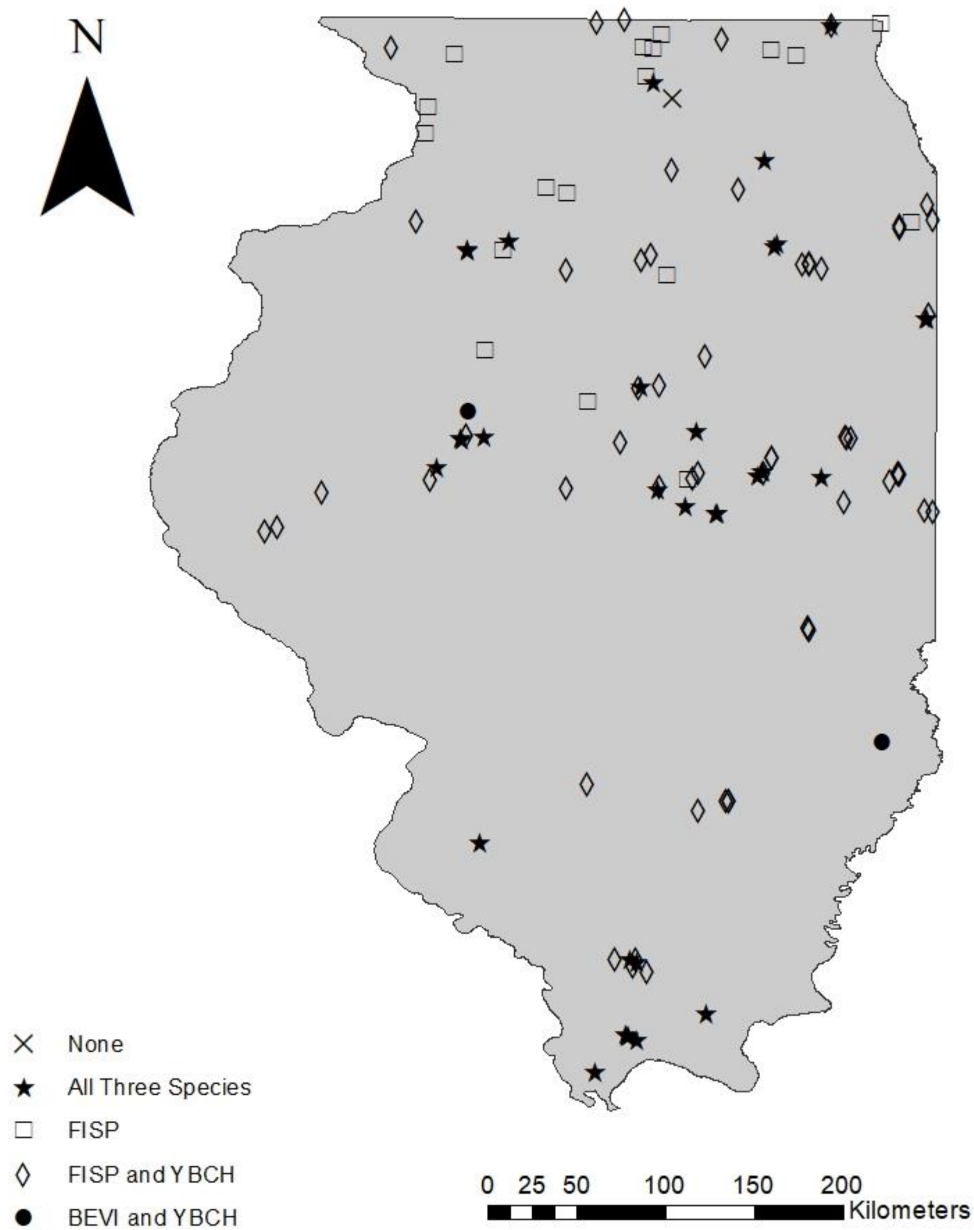

Figure 2.1. Publicly owned shrublands that were surveyed over the course of 2016-2018. 109 surveyed in 2016 with, 85 surveyed in 2017, and 109 surveyed in 2018. Symbols represent the species present at each of the sites of the three-year period.

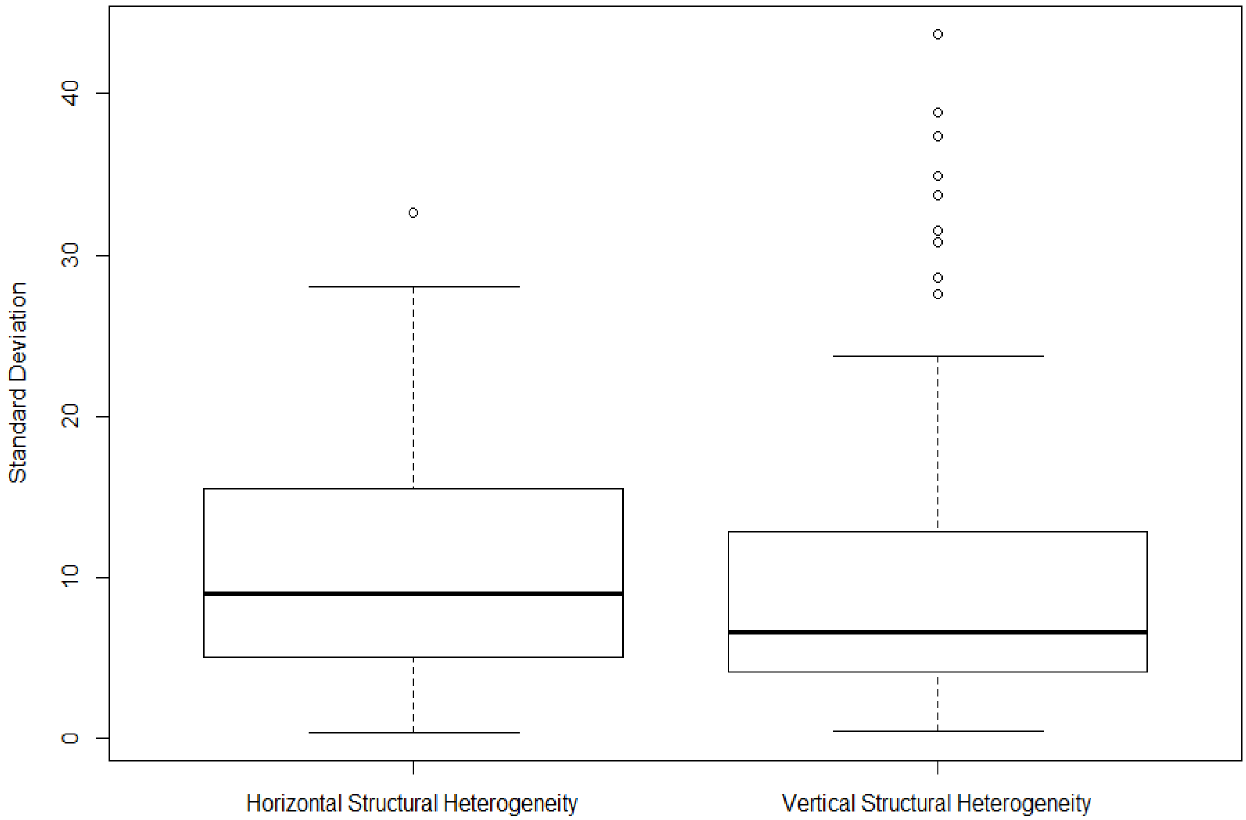

Figure 2.2. Distribution of the sites' horizontal and vertical structural heterogeneity.

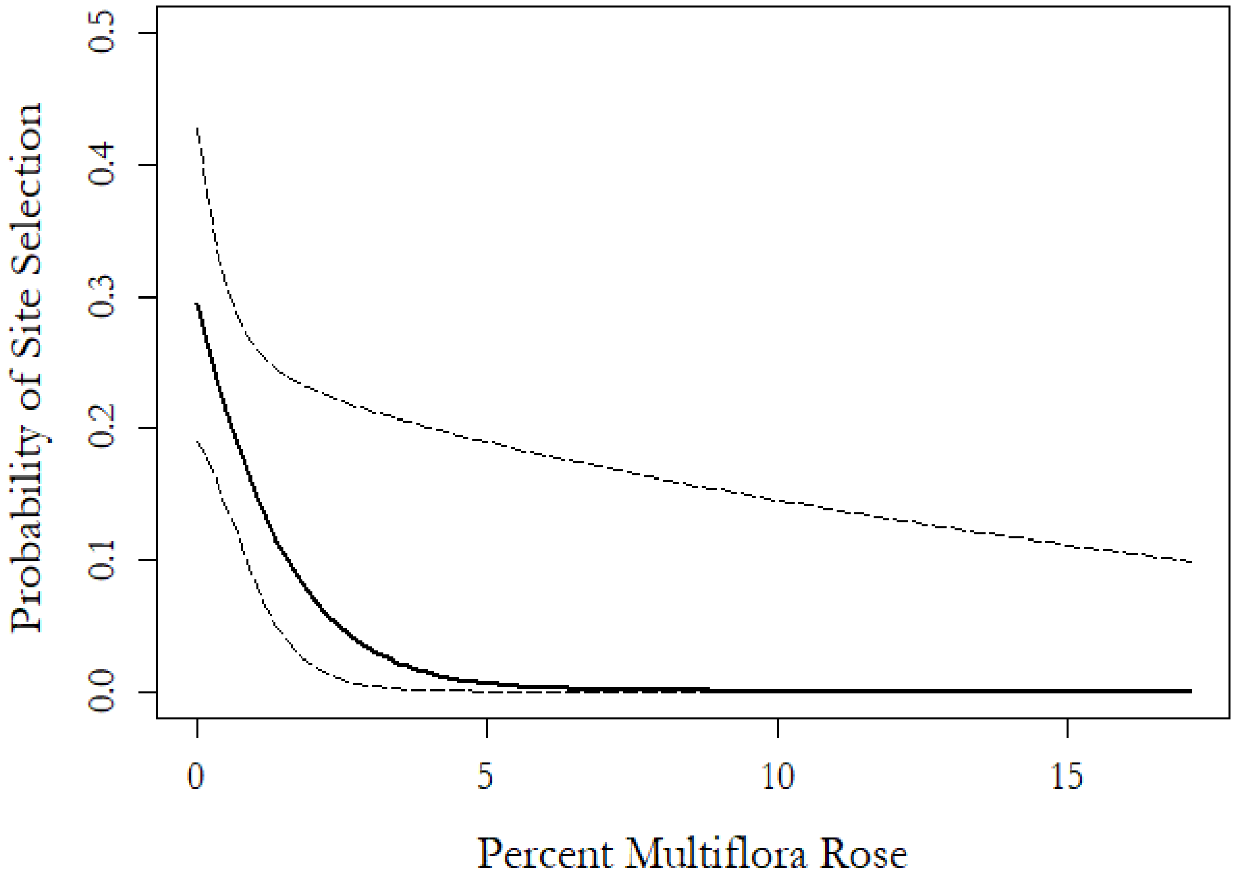

Figure 2.3. Predicted probability of initial site selection (with 95% confidence intervals) for Bell's Vireo with increasing percentages of multiflora rose in a site.

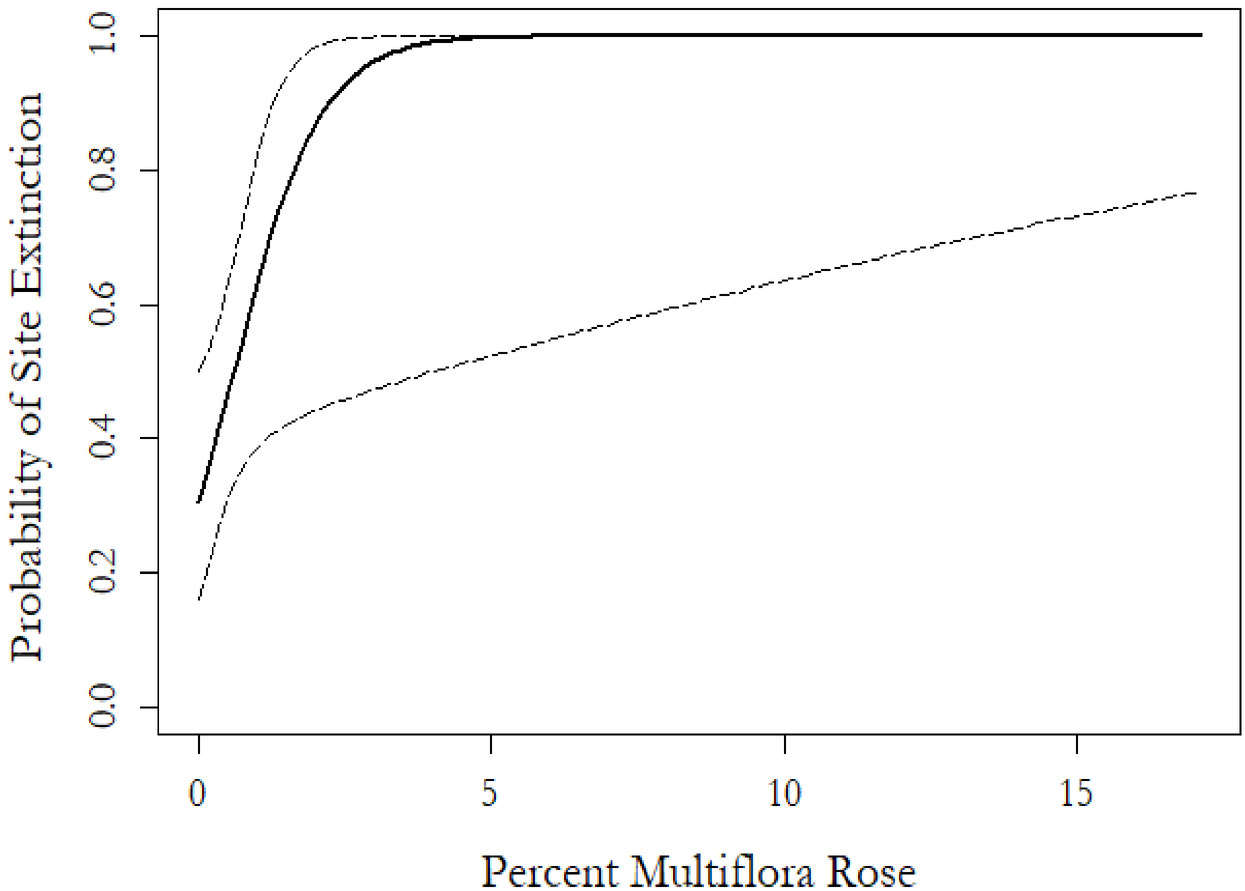

Figure 2.4. Predicted probability of a site becoming extinct the following year (with 95% confidence intervals) by Bell's Vireo with increasing percentages of multiflora rose.

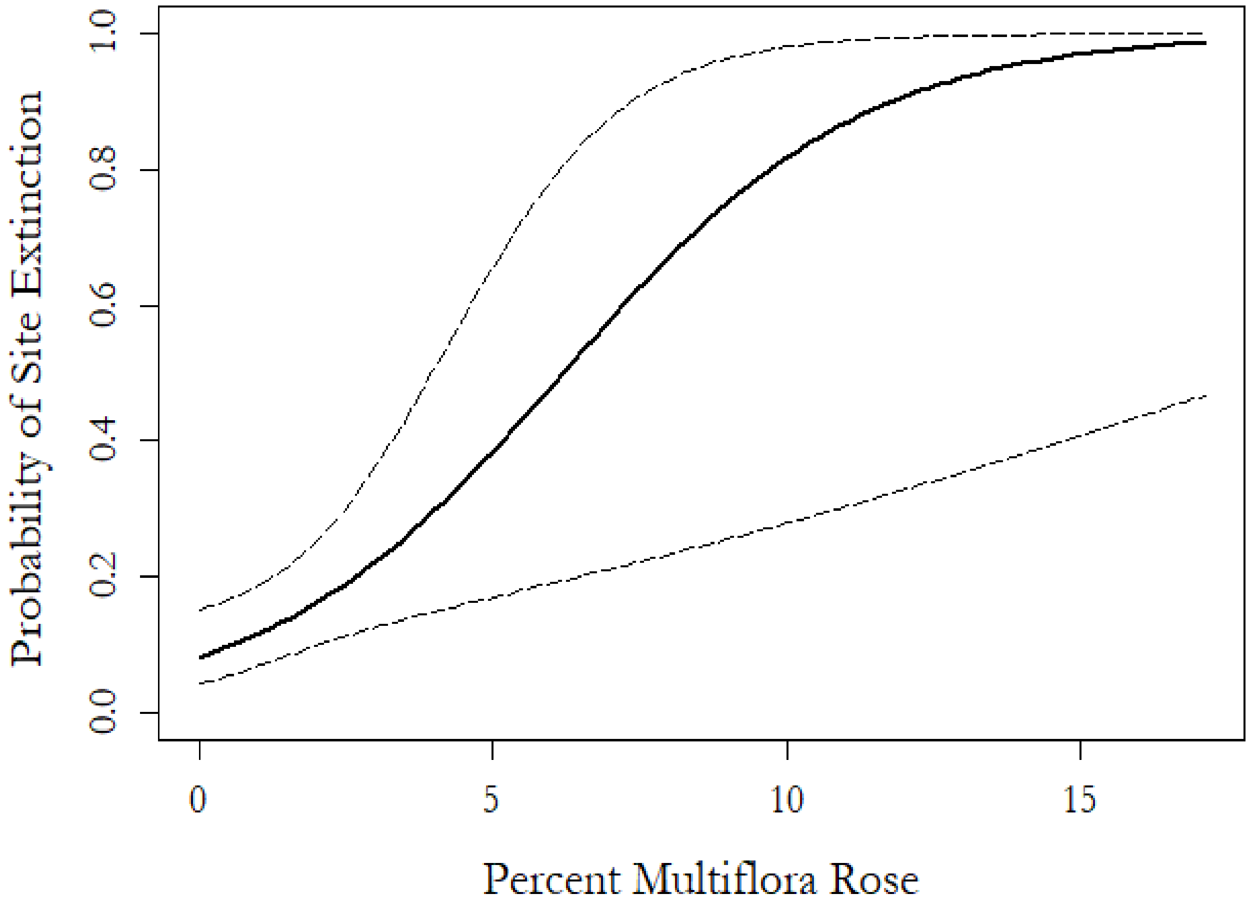

Figure 2.5. Predicted probability of a site becoming extinct the following year (with 95% confidence intervals) for Yellow-breasted Chat as the percentage of multiflora rose increases.

2.7 REFERENCES

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control 19:716-723.

Askins, R. A. 1993. Population trends in grassland, shrubland, and forest birds in eastern North America. Current Ornithology 11:1-34.

Askins, R. A. 2000. Restoring North America's birds: Lessons from landscape ecology. Yale University Press, New Haven, CT.

Askins, R. A., B. Zuckerberg, and L. Novak. 2007. Do the size and landscape context of forest openings influence the abundance and breeding success of shrubland songbirds in southern New England? Forest Ecology and Management 250:137-147.

Barlow, J. C. 1962. Natural History of the Bell Vireo, Vireo belli Audubon. University of Kansas Publications, Museum of Natural History, Lawrence Kansas 12:241-296.

Brawn, J. D., S. K. Robinson, and F. R. Thompson III. 2001. The role of disturbances in the ecology and conservation of birds. Annual Review Ecological Systems 32:251-76.

Beyer, H. L. 2012. Geospatial Modelling Environment (Version 0.7.2.1). URL http://www.spatialecology.com/ gme.

Borgmann, K. L., and A. D. Rodewald. 2004. Nest predation in an urbanizing landscape: The role of exotic shrubs. Ecological Applications 14:1757-1765.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of Invasive Alien Plants on Fire Regimes. Bioscience 54:677–688.

Bulluck, L. P., and D. A. Buehler. 2006. Avian use of early successional habitats: Are regenerating forests, utility right-of-ways and reclaimed surface mines the same? Forest Ecology and Management 236:76–84.

Burghardt, K. T., D. W. Tallamy, and W. G. Shriver. 2009. Impact of native plants on bird and butterfly biodiversity in suburban landscapes. Conservation Biology 23:219–224.

Carter, E. T., B. C. Eads, M. J. Ravesi, and B. A. Kingsbury. 2015. Exotic invasive plants alter thermal regimes: implications for management using a case study of a native ectotherm. Functional Ecology 29:683-693.

Chapin III, F. S., E. S. Zavaleta, V. T. Eviner, R. L. Naylor, P. M. Vitousek, H. L. Reynolds, D. U. Hooper, S. Lavorel, O. E. Sala, S. E. Hobbie, M. C. Mack, and S. Díaz. 2000. Consequences of changing biodiversity. Nature 405:234–42.

Cody, M. L. 1981. Habitat selection in birds: The roles of vegetation structure, competitors, and productivity. BioScience 31:107-113.

Crooks, J. A. 2002. Characterizing ecosystem-level consequences of biological invasions: the role of ecosystem engineers. Oikos 97:153–166.

Dettmers, R. 2003. Status and conservation of shrubland birds in the northeastern US. Forest Ecology and Management 185:81–93.

Fiske, I., and R. Chandler. 2011. unmarked: An R package for fitting hierarchical models of wildlife occurrence and abundance. Journal of Statistical Software, 43(10), 1-23. URL http://www.jstatsoft.org/v43/i10/.

Gleditsch, J. M., and T. A. Carlo. 2014. Living with aliens: Effects of invasive shrub honeysuckles on avian nesting. PLoS ONE 9:e107120.

Graber, R. R., and J. W. Graber. 1963. A Comparative Study of Bird Populations in Illinois, 1906-1909 and 1956-1958. Illinois Natural History Survey Bulletin 28:383–528.

Invasive Species Campaign. 2017. Retrieved from: https://www.dnr.illinois.gov/conservation/IWAP/Documents/IWAPPlan2015/InvasiveSpecies.pdf

Illinois Department of Natural Resources. 2005. The Illinois Comprehensive Wildlife Conservation Plan and Strategy. Retrieved from: https://www.dnr.illinois.gov/conservation/IWAP/Documents/IllinoisCWCP.pdf

James, F. C. 1971. Ordinations of habitat relationships among breeding birds. The Wilson Bulletin 83:215-236.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65-71.

Knick, S. T., and J. T. Rotenberry. 1995. Landscape characteristics of fragmented shrubsteppe habitats and breeding passerine birds. Conservation Biology 9:1059-1071.

Landsman, A. P., and J. L. Bowman. 2017. Discordant response of spider communities to forests disturbed by deer herbivory and changes in prey availability. Ecosphere 8: e01703. 10.1002/ecs2.1703

Litt, A. R., E. E. Cord, T. E. Fulbright, and G. L. Schuster. 2014. Effects of invasive plants on arthropods. Conservation Biology 28:1532-1549.

MacKenzie, D. I., J. D. Nichols, J. E. Hines, M. G. Knutson, and A. B. Franklin. 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. Ecology 84:2200-2207.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Robinson, S. K., E. J. Heske, and J. D. Brawn. 1994. Factors affecting the nesting success of edge and shrubland birds. Illinois Natural Survey Technical Reports W-125-R.

Rodewald, A. D., D. P. Shustack, and L. E. Hitchcock. 2010. Exotic shrubs as ephemeral ecological traps for nesting birds. Biol Invasions 12:33-39.

Rosenberg, K. V., J. A. Kennedy, R. Dettmers, R. P. Ford, D. Reynolds, J. D. Alexander, C. J. Beardmore, P. J. Blancher, R. E. Bogart, G. S. Butcher, A. F. Camfield, A. Couturier, D. W. Demarest, W. E. Easton, J. J. Giocomo, R. H. Keller, A. E. Mini, A. O. Panjabi, D. N. Pashley, T. D. Rich, J. M. Ruth, H. Stabins, J. Stanton, T. Will. 2016. Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee. 119 pp.

Sauer, J. R., D. K. Niven, J. E. Hines, D. J. Ziolkowski, Jr, K. L. Pardieck, J. E. Fallon, and W. A. Link. 2017. The North American Breeding Bird Survey, results and analysis 1966-2015. Version 2.07.2017 USGS Patuxtent Wildlife Research Center, Laurel, MD.

Schlossberg, S. and D. I. King. 2008. Are shrubland birds edge specialists? Ecological Applications, 18: 1325-1330.

Schlossberg, S. 2009. Site fidelity of shrubland and forest birds. The Condor, 111: 238-246.

Stanton, R. L., C. A. Morrissey, and R. G. Clark. 2018. Analysis of trends and agricultural drivers of farmland bird declines in North America: A review. Agriculture, Ecosystems and Environment 254: 244-254.

USDA National Agricultural Statistics Service Cropland Data Layer. 2015. Published crop-specific data layer [Online]. Available at https://nassgeodata.gmu.edu/CropScape/. USDA-NASS, Washington, DC.

Visser, M. E., L. J. M. Holleman, and P. Geinapp. 2006. Shifts in caterpillar biomass phenology due to climate change and its impact on the breeding biology of an insectivorous bird. Oecologia 147: 164-172.

Walk, J. W., M. P. Ward, T.J. Benson, J. L Deppe, S. A. Lischka, S. D. Bailey, and J. D. Brawn. 2010. Illinois birds: a century of change. Illinois Natural History Survey Special Publication 31.

Wiens, J. A. 1969. An approach to the study of ecological relationships among grassland birds. Ornithological Monographs 8: 1-93.

CHAPTER 3: THE INFLUENCE OF SHRUBLAND HABITAT COMPOSITION ON THE PHYSIOLOGICAL HEALTH OF THREE CONSERVATION PRIORITY BIRD SPECIES

3.1 ABSTRACT:

Shrubland birds have experienced population declines across the U.S. for the past 50 years. Habitat loss and degradation are proposed as likely drivers for these declines, yet, the mechanistic processes behind them is unclear. One potential source of habitat degradation is invasion by non-native plant species. Many studies investigating the effects that non-native plant species have on bird populations have focused on measures of population abundance or reproductive success, but have neglected the effects on the physiological health and condition of birds. I investigated the association between non-native shrubs and physiological measurements of health and condition in three shrubland obligate birds of conservation concern: Bell's Vireo (*Vireo bellii bellii*), Yellow-breasted Chat (*Icteria virens*), and Field Sparrow (*Spizella pusilla*). The non-native shrub species that I investigated (autumn olive (*Elaeagnus umbellata*), honeysuckle (*Lonicera spp.*), and multiflora rose (*Rosa multiflora*)) are three of the most abundant non-native plant species found in shrublands in the Midwestern U.S. I used five different physiological biomarkers: circulating plasma corticosterone, which is an indicator of environmental stress; triglyceride and β-hydroxybutyrate, which are dietary metabolites indicative of short-term diet quality; bacteria killing ability (BKA) of the blood plasma, which reflects the organism's ability to clear a bacterial infection; and finally, ectoparasite burdens. I expected non-native plant species to have a negative effect on all aspects of physiological condition in the focal bird species but the results were mixed and varied by species. Corticosterone concentrations of Bell's Vireos increased with higher prevalence of autumn olive. Yellow-breasted Chat and Field Sparrow triglyceride and β-hydroxybutyrate concentrations were

inversely related to the prevalence of honeysuckle. Higher percentages of native plant species were associated with higher levels of bacteria killing-ability in all three species. In general, higher levels/proportion/percentage of non-native woody species were associated with reduced physiological condition in the birds. These results suggest that managers should consider including some level of non-native species reduction or control to benefit shrubland obligate avian species.

3.2 INTRODUCTION:

Shrubland birds have experienced population declines across North America for the past few decades, and many of these species are now of conservation concern (Sauer *et al.* 2017). Habitat loss and degradation are thought to be major drivers of these declines (Rosenberg *et al.* 2016), although the mechanisms underlying the population declines remain unclear. Shrublands are transitional habitats, and historically they were maintained across the landscape by a suite of natural events such as fires, floods, and windfalls. Over the past century, many of these natural processes have been suppressed (Askins 2000), and most of the areas in which shrublands formerly existed have been turned into pasture, converted to row-crop agriculture, or been lost to suburban sprawl. Many shrubland birds have subsequently been relegated to a fraction of the landscape they previously occupied, and much of the remaining habitat has become degraded by the colonization of non-native plant species (Askins 1993, Rosenberg *et al.* 2016). Consequently, as a result of these habitat changes, the bird communities that depend on these shrublands for breeding have felt the ramifications (Keane and Crawley 2002, DeGraaf and Yamasaki 2003). With the decreasing availability of shrublands and increased encroachment by non-native plant species, it is important to understand how variation in site-level characteristics such as habitat composition and structure can influence the health and condition of shrubland birds, so that conservation efforts can be tailored accordingly.

Despite the fact that increasing prevalence of non-native plant species has been implicated in bird population declines (Rosenberg *et al.* 2016), the connection between these population declines and encroachment of non-native plants remains speculative. With shrubland habitats being uncommon and understudied in the Midwest, it is important to understand how encroaching non-native plant species are influencing shrubland birds. Most studies investigating the effects of non-native plant species on birds have focused on population measurements (e.g. presence/absence, abundance, richness, or reproductive output) but have found mixed results (Nelson *et al.* 2017). However, while these studies examine the end point measures of population decline, there is a lack of understanding of how and why these populations are declining. With the increasing prevalence of non-native species, there is a need to better understand how these changes in habitat composition can lead to population declines. One way to provide insight into the underlying causes of these declines is to incorporate measures of physiological condition. Non-native plant species could be influencing bird populations in numerous ways, which may all be linked to an individual's physiological condition. For instance, they may be influencing birds stress levels through changes in availability of nesting substrates (Brawn *et al.* 2001) as well as nesting success (Tremblay *et al.* 2005, Rodewald *et al.* 2010, Budnik *et al.* 2016). Additionally, they could influence the diet quality by dictating energy stores available through changes in food resource availability (Brooks *et al.* 2004, Litt *et al.* 2014, Burghardt *et al.* 2009) and resource competition (Narango *et al.* 2017). And finally, they could also affect the immune competence of individuals through changes in exposure to disease borne vectors (Gardner 2016) as well as the changes in stress levels and diet quality as mentioned above. Therefore, understanding how non-native plant species encroachment into shrubland habitats can influence the physiological health can provide a link between habitat quality and bird condition, thereby providing insight into the mechanisms driving population declines.

For this work I used four health-linked biomarkers to examine the effects of non-native plant species encroachment on the health and condition of three shrubland bird species of conservation concern. Changes in habitat composition through encroachment of non-native plant species can affect these physiological biomarkers through increased predation (Tremblay *et al.* 2005, Rodewald *et al.* 2010, Budnik *et al.* 2016), changes in food resources (Burghardt *et al.* 2009, Smith *et al.* 2013, Litt *et al.* 2014), increased competition with conspecifics and heterospecifics (Peiman and Robinson 2010), changes in habitat structure and micro-climates (Carter *et al.* 2015), as well as higher prevalence of vector-borne diseases (Gardner 2016). I examined circulating levels of the glucocorticoid hormone, corticosterone, two dietary metabolites (triglyceride and β-hydroxybutyrate), and the bacteria-killing ability (BKA) of the birds' blood plasma. Baseline corticosterone is a good measure of environmental stress, as prolonged exposure to environmental stressors can lead to chronically elevated levels of corticosterone and cause wear and tear on the body (Busch and Hayward 2009, McEwen and Wingfield 2003). Triglyceride and β-hydroxybutyrate are good measures of short-term diet quality and indicators of food availability (Jenni-Eiermann and Jenni 1994). Triglyceride is a form of stored lipid in the plasma and higher concentrations typically indicate that there are higher quality and more abundant food resources available (Dietz *et al.* 2009). B-hydroxybutyrate, a type of ketone acid produced as a byproduct of fat catabolism, is used to measure the degree to which an individual is burning through their fat stores (Jenni-Eiermann and Jenni 1997). Higher concentrations of β-hydroxybutyrate indicate that the bird is fasting, likely due to less abundant and lower quality food resources. Bacterial-killing ability (BKA) of the blood plasma is a good indicator of an individual's ability to fight off bacterial infections. Furthermore, BKA is linked to many life history components, sexual signals, survival, and other physiological traits such as corticosterone (Tieleman *et al.* 2005, Wilcoxen *et al.* 2010, Ellis *et al.* 2012, Merrill *et al.* 2012, 2013). Changes in habitat composition to non-native plant species could affect BKA directly by increasing the density of disease vectors (Gardner 2016), or indirectly through changes in dietary metabolites and corticosterone concentrations. Finally, heavy ectoparasite loads are one factor that may be linked to the immune function of individuals. Individuals whose immune systems are challenged with fighting off infections or other threats to the body may not be able to allocate the necessary resources managing ectoparasite infestations through grooming or other behavioral methods. Initiating immunological responses as well as behavioral defenses, such as grooming, can be energetically costly, and individuals will likely prioritize managing immediate threats to their well-being in lieu of less immediate threats (Owen *et al.* 2010). Therefore, birds with higher ectoparasite loads may be reflective of a lower functioning immune system.

If non-native shrubs are negatively impacting the health and condition of shrubland obligate birds, I expect that as the proportion of each non-native shrub species at a site increases, 1.) corticosterone concentrations will increase, 2.) triglyceride concentrations will decrease and β-hydroxybutyrate concentrations will increase, 3.) BKA will decline, and 4.) ectoparasite burdens will increase. These connections have the potential to provide important conservation implications which may then help better inform future management decisions.

3.3 METHODS:

Study Species – I focused my efforts on three shrubland obligate species currently listed as species in Greatest Need of Conservation in Illinois (IWAP 2005): Bell's Vireo (*Vireo bellii bellii*), Yellow-breasted Chat (*Icteria virens*), and Field Sparrow (*Spizella pusilla*). All three species use shrublands of various successional stages (Carey *et al.* 2008, Kus *et al.* 2010, Thompson and Nolan 2016). Bell's Vireo, a long-distance migrant, prefers to breed in dense early successional habitat, and habitat fragmentation and loss of this early successional habitat, along with parasitism by the Brown-headed Cowbird (*Molothrus ater*), have contributed to their population decline (Barlow 1962, Kus *et al.* 2010). Yellow-breasted Chat, another long-distance migrant, also prefers to breed in dense shrubby early successional habitat. Loss of habitat to agriculture and forest succession as well as increased predation may be primary causes of population declines in this species (Thompson and Nolan 2016). Unlike the other two species, the Field Sparrow is a short distance migrant that prefers to nest in more open early successional habitat. All three species are open-cup nesting species considered to be socially monogamous. Declines in Illinois are most likely due to the loss of habitat with increased row-crop agriculture and development, as well as increased brood parasitism by Brown-headed Cowbirds, and nest predation (Carey *et al.* 2008).

Study Sites – I collected blood samples from birds at 29 sites (7 resampled) in 2017 and 36 sites (2 resampled) in 2018 in central Illinois (Figure 3.1). Sites were selected based on data I gathered in 2016 and 2017, where I systematically surveyed woody vegetation and the bird communities at 112 sites throughout Illinois (Chapter 2). Specifically, I targeted sites where the three focal bird species were present, and that had varying degrees of invasion by the three focal non-native shrubs.

Vegetation surveys – At each site I quantified the total woody plant species cover, the percentage of native species woody cover, and the percentage of three non-native woody species, autumn olive (*Elaeagnus umbellata*), honeysuckle (*Lonicera* spp.), and multiflora rose (*Rosa multiflora*). I chose to focus on autumn olive, honeysuckle, and multiflora rose because they were the most prevalent and widespread non-native woody plants in the shrublands I visited in 2016 and 2017 (Chapter 2). Vegetation surveys consisted of 100-m transects laid out in a random direction from the approximate center of a shrubland. Five 10 × 10 m plots were located every 20 m along the 100-m transect. I recorded all woody species present in each plot, along with the percent cover of each species in three vertical strata, 0-1 m, 1-3 m, and >3 m off the ground. Percent cover of each of the plant species was recorded by estimating what percentage of the 10 x 10 m plot each species covered. I calculated the percent cover of each of three focal non-native woody plant species and native woody plant species by averaging the percent cover in the 0-1 m and 1-3 m strata for each plot and then took the average of those calculations between all five plots. I left out the >3 m stratum because woody shrub plants are rarely >3 m.

Sample collection – Birds were captured using mist nets and lured into the net using a recording of each focal species' call or song. I recorded the time playback started and time from when an individual hit the net until bleeding. Individuals were generally bled within 3 minutes of hitting the net, which is approximately the time it takes for the avian stress response to activate (Romero and Reed 2005). The brachial vein was pricked using sterile needles and <1% of the bird's body weight in blood was collected in capillary tubes and immediately stored on ice for 4-6 hours. Blood samples were spun down in a centrifuge to separate the red blood cells from the plasma. Plasma was pulled off and stored at -80°C until it was used for the various assays. Samples were stored for a maximum of 9 months in 2017 and 4.5 months in 2018.

Corticosterone assay – I sent the corticosterone samples up to a collaborator at the Lincoln Park Zoo to be analyzed. They assessed corticosterone levels in individuals using 5 µL of plasma combined with 5 µL of a dissociation reagent (Arbor Assays, Ann Arbor, MI), which was incubated for a minimum of 5 minutes. Next, 490 µL of phosphate-buffered saline (pH 7.0) was added to make a 1:100 dilution. Plasma glucocorticoid production was analyzed using a corticosterone EIA with previously described methods (e.g., Munro and Stabenfeldt 1984; Santymire and Armstrong 2010). The corticosterone antiserum (CJM006) and horseradish peroxidase (provided by C. Munro, University of California, Davis, CA, USA) were diluted to 1:225,000 and 1:200,000, respectively. Antiserum cross-reactivities for corticosterone are: corticosterone, 100%; desoxycorticosterone, 14.25%; tetrahydrocorticosterone, 0.9%; 11-deoxycortisol. 0.03%; prednisone, < 0.01%; prednisolone, 0.07%; cortisol, 0.23%; cortisone, < 0.01%; progesterone, 2.65%; testosterone 0.64% and estradiol 17β, < 0.01% (Santymire and Armstrong 2010; Narayan *et al.* 2010). Mean intra-assay coefficient of variation (CV) was less than 10% and inter-assay CV was less than 12%.

Triglyceride and β-hydroxybutyrate assays – I used colorimetric assay kits from Cayman Chemical (#700190 and # 10010303) to assess triglyceride and β-hydroxybutyrate levels in the birds' plasma. I identified the optimal plasma volume that yielded a metabolite measurement that fell in the center of the standard curve of known concentrations for each of the species.

Eight standards of known triglyceride concentrations were used to create a standard curve to which I compared each individual's triglyceride concentrations. Field Sparrow, Bell's Vireo, and my control samples (a mix of multiple species of birds) were diluted in 5.5 µL of plasma into 16.5 µL of standard assay reagent, and Yellow-breasted Chat samples were diluted using 3 µL of plasma into 19 µL of standard reagent. I then added a triglyceride enzyme mixture to the dilution using a multichannel pipet to start the reaction, and the plate was incubated at room temperature for 15 minutes. Following incubation, plates were read with a plate reader (Biotek Epoch Microplate Spectrophotometer) at 540 nanometers. Samples were run in duplicate and mean intra-assay CV was 5% and the mean inter-assay CV was 9%.

I compared β-hydroxybutyrate levels of individuals against a standard curve of eight known β-hydroxybutyrate standard concentrations. We diluted all species' samples at the same ratio (6.8 μL plasma in 95.2 μL standard buffer) and ran each in duplicate with developer solution added to start the reaction. Plates were then covered in foil, incubated at 25°C for 30 minutes, and read at 450 nanometers. Mean intra-assay CV was 5% and the mean inter-assay CV was 6%

Bacteria-killing ability assay – I measured the BKA of the blood plasma of each species following Matson *et al.* (2006), Millet *et al.* (2007), and Morrison *et al.* (2009). I identified the optimal plasma volume that yielded a 50% killing ability for each of the species. Plasma was thawed and 2.5 μL was added to a mixture of CO_2-independent medium (Gibco, Invitrogen) + 4mM L-glutamine (97.5 μL) and Escherichia coli broth (10 μL) and incubated at 41 degrees Celsius for 20 minutes. The strain of E. coli used in this assay (ATCC # 8739) is believed to be a novel strain for wild birds, and bacteria-killing is thought to be primarily complement dependent via the alternative pathway (Matson *et al.* 2006, Merrill unpublished data). In other words, to kill the bacteria, a protein (C3b) is bound to the surface of the bacteria which, once bound, then acts as an antibody to help facilitate the degradation of the bacteria by phagocytes and removal of immune complexes (Janeway *et al.* 2001). I used bacterial concentrations which resulted in 250-350 bacteria colonies per control plate and 50 μL of the mixture was pipetted in duplicate onto agar plates containing glass spreader beads. Plates with the mixture were shaken for 45-60 seconds to ensure an even spread of bacteria across the plate, at which point the beads were removed. Plates were then incubated for about 18 hours at 37°C, the optimal temperature for E. coli growth. I also created control plates for comparison. Control plates contained a mixture of 100 µL of phosphate-buffered saline and 10 µL of E. coli solution without plasma. BKA was calculated by subtracting the average number of bacteria colonies between the plates for each individual from the mean bacteria colonies from the control plates and dividing by the control mean. Duplicate samples with CVs greater than 20% were rerun, excluding samples with small absolute differences. Mean intra-assay CV was 13% and inter-assay CV was 6%.

Ectoparasite burden – Birds were screened for ectoparasites by manually combing through the head feathers using a toothpick to look for mites, lice, and/or ticks, and examining wings and the tail feathers. Wings and tail feathers were spread, backlit by angling feathers to the sun with the undersides facing the camera to highlight any ectoparasites by making the feathers appear translucent, and then photographed with a digital camera (Canon PowerShot SX610 HS). The digital images were later examined by four different observers. If objects were not able to be confidently identified by the observer, pictures were recorded and later checked by one observer (K. Ripple). All ectoparasites from the wings and tail were analyzed as one group instead of separating them into mites and lice because the pictures were often not clear enough to distinguish between them.

Statistical analyses – I used an information-theoretic approach (Burnham and Anderson 2002) to examine the effects of non-native woody plant species on the physiological measurements of the three focal bird species. All health markers measures were log-transformed except for ectoparasite burden. I excluded five samples (2 YBCH and 3 FISP) from the dietary metabolite (colorimetric) assays because the plasma was opaque or red likely due to cell lysing. I used the package "*lme4*" (Bates *et al.* 2015) in program R version 3.5.1 (R Core Team 2018) to fit linear mixed effects models examining the associations between site characteristics and the physiological markers (corticosterone, triglyceride, β-hydroxybutyrate, BKA), and ectoparasite burden. I first examined each biomarker to see whether year, date, time of day, time to bleed, and time to bleed since callback had an influence on them. I only found evidence for significant (p-value < 0.05) year and date effects. Therefore, year and date were included in all models as nuisance parameters along with species. I fit 9 different models, one that only included species, year and date, site as a random effect, and an additional eight that included the percentage of the three non-native woody plant species (autumn olive, honeysuckle, and multiflora rose) and percent native woody plant species, with and without a species-specific interaction effect using the focal species. The species interaction effect took into account the species' responses to each of the habitat characteristics to determine if the pattern was driven by all three birds or individual species. I compared model fit using the Akaike Information Criterion (Akaike 1974).

3.4 RESULTS:

I captured a total of 199 birds across the two years: 94 birds (8 Bell's Vireos, 57 Field Sparrows, 19 Yellow-breasted Chats) in 2017 and 105 birds (9 Bell's Vireos, 61 Field Sparrows, 35 Yellow-breasted Chats) in 2018. In 2017, Bell's Vireos were present at seven sites, Field Sparrows at 26 sites and Yellow-breasted Chats at 19 sites. In 2018, Bell's Vireos were present at six sites, Field Sparrows at 30 sites, and Yellow-breasted Chats at 22 of the 36 sites. Native woody plant species were more common than non-native woody plants, with autumn olive being the most common non-native woody plant species (Table 3.1).

Corticosterone – Bell's Vireos had the greatest corticosterone concentrations, followed by Field Sparrows, and Yellow-breasted Chats (Table 3.2). Corticosterone levels were generally greater in

2018 compared to 2017 for all three focal species (Table 3.2). A species-specific effect of percent cover of autumn olive best described the variability in corticosterone concentrations (Table 3.3). Percent autumn olive was positively associated with corticosterone concentrations in Bell's Vireos but appeared to have little effect on concentrations in Yellow-breasted Chats and Field Sparrows (Table 3.4, Figure 3.2).

Triglyceride – Field Sparrows had the greatest triglyceride concentrations followed by Yellow-breasted Chats, and Bell's Vireos (Table 3.2). Triglyceride concentrations in the focal species were generally greater in 2017 than in 2018 (Table 3.2). Percent cover of honeysuckle with a species-specific effect was the best-supported model describing triglyceride concentrations (Table 3.5). As the percentage of honeysuckle increased, the triglyceride levels of both Field Sparrows and Yellow-breasted Chats decreased (Table 3.6, Figure 3.3). Though the relationship was positive between percent cover of honeysuckle and Bell's Vireos' triglyceride concentrations, the standard error of those estimates was high (Table 3.6, Figure 3.3).

β-hydroxybutyrate – Yellow-breasted Chats had the greatest concentration of β-hydroxybutyrate followed by Field Sparrows and Bell's Vireos (Table 3.2). β-hydroxybutyrate concentrations in the focal species generally did not differ between years (Table 3.2). Percent cover of honeysuckle without a species-specific effect was the best-supported models describing β-hydroxybutyrate levels (Table 3.7) in which the proportion of honeysuckle was inversely associated with β-hydroxybutyrate concentrations (Table 3.8, Figure 3.4).

Bacteria-killing Ability –Bell's Vireos and Yellow-breasted Chats had the greatest BKA followed by Field Sparrows (Table 3.2). The BKA was generally greater in 2017 than in 2018 (Table 3.2). Percentage of native plant species was the best-supported model describing BKA

(Table 3.9) in which increasing percentage of native woody plant species was positively related to BKA (Table 3.10, Figure 3.6).

Ectoparasites- Field Sparrows had the greatest ectoparasite loads followed by Yellow-breasted Chats and Bell's Vireos (Table 3.2). Ectoparasites were present on 94% of Field Sparrows (88% in 2017 and 100% in 2018), 73% of Yellow-breasted Chats (64% in 2017 and 81% in 2018), and 62% of Bell's Vireos (75% in 2017 and 50% in 2018). Ectoparasite loads were greater in 2018 than in 2017 (Table 3.2). None of the models out-competed the model that only included species, year, and date (Table 3.11). Furthermore, parameter estimates for the effect of non-native woody plant species, total native species, and total woody cover, had large confidence intervals that overlapped zero (Table 3.12).

3.5 DISCUSSION:

I predicted that non-native plant species would negatively impact the physiological health of the three focal avian species of conservation concern. While I found some evidence to support this prediction, I did not find consistent negative effects. Stress levels, as measured through corticosterone, did not appear to be related to all non-native woody plant species. Instead, I found that corticosterone was best described by percent cover of autumn olive. Increasing percent cover of autumn olive resulted in greater concentrations of corticosterone in Bell's Vireos but had little effect on Yellow-breasted Chats' and Field Sparrows' corticosterone. The proportion of honeysuckle did appear to impact diet quality, as measured by triglyceride and β-hydroxybutyrate concentrations, but not in a consistent manner. Triglyceride concentrations for Field Sparrows and Yellow-breasted Chats were negatively related to proportion honeysuckle as predicted, but the inverse association between β-hydroxybutyrate concentrations and honeysuckle, was the opposite of what was expected. The immune response, as measured by

BKA did suggest that native plant species had a positive effect on all three focal species. This is likely due to a lack of negative features associated with non-native plants. Additionally, I found no effect of habitat features on the ectoparasite burdens on any of the focal species. Rather I found that Field Sparrows had higher ectoparasite numbers than both the Yellow-breasted Chat and Bell's Vireo. It is likely that the social structures rather than plant species present are influencing these numbers. Altogether, I found that non-native plant species appear to be linked to changes in physiological condition, though not always in the way that I expected.

The negative relationship between autumn olive and Bell's Vireos' corticosterone concentrations may be influenced by a number of factors. For instance, autumn olive may be increasing the stress response of Bell's Vireos by influencing the frequency of brood parasitism by the Brown-headed Cowbird, which is one of the largest threats to the Bell's Vireo (Kus *et al.* 2010). Stoleson and Finch (2001) found that birds that nested in Russian olive (*Elaeagnus angustifolia*), a close relative of autumn olive, suffered higher rates of brood parasitism that birds that nested in native plants. In Illinois, Bell's Vireos have been found to have high rates of parasitism by the Brown-headed Cowbird (Reiley 2017). Bell's Vireos will defend their nests from approaching female Brown-headed Cowbirds by scolding, biting, and aggressively attacking them (Mumford 1952, Budnik *et al.* 2001, Sharp and Kus 2004). Additionally, autumn olive may also be increasing foraging effort either through increased provisioning rates for parasitized nests as well as by decreasing the food quality and quantity in shrublands. When a Brown-headed Cowbird successfully parasitizes their nests, Bell's Vireos will raise the Brown-headed Cowbird chick. Brood parasite chicks have been found to alter parental habits through increased protection and provisioning, which increase corticosterone concentrations in parents (Mark and Rubenstein 2013). Another way in which increases in autumn olive might impact corticosterone concentrations may be through the quality of nesting substrate. Autumn olive may be providing lower quality nesting substrate and thereby increasing competition for these better-quality nest sites. Territory and nest defense have been linked to increased corticosterone concentration (Landys *et al.* 2010, Lobato *et al.* 2010). Furthermore, autumn olive may be providing a lowering the availability of high-quality food resources. With decreased diet quality, individuals would be experiencing increased foraging effort resulting in greater energy expenditure which would then be expressed as elevated baseline corticosterone concentrations. Therefore, autumn olive may be increasing corticosterone concentrations through a combination of increased rates of brood parasitism which leads to increases in foraging effort, increased competition for resources such as nesting substrate, and decreases in quality of food resources. However, we found little evidence to support that autumn olive is influencing food resource availability in our dietary metabolites, but instead found that increased prevalence of honeysuckle was influencing the diet quality.

I did find evidence that honeysuckle influenced short-term diet quality, although in apparently opposite ways. I predicted that β-hydroxybutyrate levels would be inversely related to triglyceride levels but did not find that to be the case. Yellow-breasted Chats’ and Field Sparrows’ triglyceride concentrations, as well as β-hydroxybutyrate concentrations for all species, were inversely related to percentages of honeysuckle. Higher concentrations of triglycerides are indicative of a higher quality food resource as individuals are able to store fat (Dietz *et al.* 2009), whereas higher concentrations of β-hydroxybutyrate are indicative of lower quality of food with birds burning through their energy stores (Jenni-Eiermann and Jenni 1997). This result highlights the importance of examining two dietary metabolites rather than just one as it is more informative of the influence that honeysuckle may be having on the diet quality of these birds. Increases in non-native species, such as honeysuckle, may alter the quantity and quality of the food available which could in turn have an effect on the foraging effort of individuals. As mentioned above, increased foraging effort could also result in higher corticosterone concentrations. However, if this was the case, it is likely that we would see a similar relationship with both corticosterone concentrations as well as the dietary metabolites being influenced by honeysuckle. Instead, this relationship with dietary metabolites may be due to the low-quality food resources that honeysuckle may be providing. First, many birds depend on invertebrates as a food source during the breeding season for themselves as well as for their young (Narango *et al.* 2017), and there is evidence that the abundance of larval leaf-chewers is lower on honeysuckle than native plants (Love 2006). While other research has indicated that honeysuckle may not dramatically influence invertebrate communities in a similar manner to many other non-native plants (Brooks *et al.* 2004, Litt *et al.* 2014, Burghardt *et al.* 2009), larval leaf chewers are an important resource for the development of chicks as well as adults because of their high nutritional value (Schowalter *et al.* 1981). Additionally, while honeysuckle provides an abundance of berries during the latter portion of the breeding period, these berries are low in nutritional content (Smith *et al.* 2013). Therefore, birds in areas with honeysuckle appear to have access to enough food resources, which is reflected in the negative relationship with β-hydroxybutyrate, but the quality of the nutrition available may be lower than areas without honeysuckle, which would lead to a negative relationship in triglycerides. This suggests that birds may not be having issues finding food, rather finding high-quality food in areas with more honeysuckle.

Finally, I found that native plant species had a positive influence on BKA. Fighting off infections and other threats to the immune system is energetically costly (Owen *et al.* 2010), and expending energy to deal with external stressors associated with non-native plant species could leave the immune system compromised. It appears that native plant species may be positively influencing bacteria killing likely because they lack the negative characteristics associated with non-native plant species. Native plants have been found to be associated with decreased disease prevalence (Gardner 2016), increased diet quality (Schowalter *et al.* 1981, Love 2006), and lower rates in nest predation (Borgmann and Rodewald 2004, Rodewald *et al.* 2010) and brood parasitism (Stoleson and Finch 2001). Furthermore, BKA had been linked to corticosterone (Merrill *et al.* 2012), and decreases in environmental stressors, such as Brown-headed Cowbird parasitism (Rodewald 2009, Budnik *et al.* 2016, Stoleson and Finch 2001), would be reflected in greater BKA. Therefore, the combination of these factors associated with native plant species may be positively influencing the immune function of all of the birds residing in those habitats.

Ectoparasites did not appear to be influenced by any of the non-native plant species that that I investigated. While I expected a similar relationship between BKA and ectoparasites in relation to habitat characteristics, I did not find this to be the case. The ectoparasites that I investigated do not feed on the blood supply but instead, feed on dead skin and feathers and therefore are not introducing pathogens. I expected that birds that had a lower BKA would have higher ectoparasite burdens because they were unable to spend time and energy in managing these infections, but my data did not support this. Instead, I found little evidence that the abundance of ectoparasite burdens was linked to any habitat characteristic, suggesting that other factors unrelated to habitat features are playing a role. While I did not see differences in ectoparasite abundances across sites, I did find differences in abundances between species. Field Sparrows had higher ectoparasite loads on average than the other two species. It is likely that more complex factors such as differences in preening behavior or social structures between the focal species are dictating these abundances. It is also possible that there could be a threshold effect, and the threshold at which results would be seen was not captured in this study. However, due to the differences in abundances between the species, it is likely the former.

3.6 CONCLUSION:

The impact of non-native plant species on native flora and fauna is recognized as a globally important problem. In spite of the considerable attention non-native plant encroachment has generated, this is among the first studies to examine the mechanisms linking the degree of non-native plant species encroachment to physiological biomarkers of wild bird populations. While I expected all non-native plant species to have an association with the health and condition of these birds, I did not find this to be the case. However, there is evidence that all three of the most abundant non-native shrub species have a negative association with shrubland obligate species to varying degrees. In addition to autumn olive and honeysuckle negatively associated with the physiological health of these birds, I also found in another study that multiflora rose negatively influenced the occupancy dynamics of Yellow-breasted Chat and Bell's Vireo (Chapter 2). The results of this study have important conservation implications, suggesting that these physiological markers can provide an important link between an individual bird's condition and habitat quality that can be scaled up to the population level (Albano *et al.* 2011, Jenni-Eiermann and Jenni 1997, Wikelski and Cooke 2006). Future studies investigating these proposed mechanisms would benefit conservation decisions by strengthening these links between non-native shrubs and physiological condition. In addition, looking at how non-native shrubs impact nestlings may be more informative; work examining the impact of landscape composition on a suite of immunological parameters in shrubland bird adults and nestlings found that nestlings were significantly more sensitive to landcover variation than adults (Merrill *et al.*

2019). However, I did find evidence that non-native shrubs are negatively associated with the physiological condition of these species of conservation concern, and efforts to reduce or remove non-native woody shrub species and to facilitate native shrubs will likely benefit shrubland obligate birds.

3.7 TABLES AND FIGURES

Table 3.1. Minimum, maximum, mean, and median values (%) of cover of the three most pervasive non-native plant species in my sites as well as the percentage of native plant species.

Parameter	Minimum	Maximum	Mean	Median
% Multiflora Rose	0.0	8.5	1.1	1.0
% Honeysuckle	0.0	12.6	1.8	1.0
% Autumn Olive	0.0	33.0	5.0	3.0
% Native Species	0.0	36.5	10.7	10.9

Table 3.2. Summary statistics for physiological and ectoparasite measurements for three focal bird species sampled in Illinois shrublands, 2017–2018.

Physiological Biomarker	**Species**	**2017**				**2018**			
		N	Min	Max	Mean	N	Min	Max	Mean
Corticosterone	*Field Sparrow*	48	50.3	108.3	72.0	60	78.4	128.5	99.5
(Ng/mL)	*Yellow-breasted Chat*	24	42.5	103.7	64.0	34	73.9	166.1	103.0
	Bell's Vireo	6	74.7	137	98.3	5	129.9	178.3	146.8
Triglyceride	*Field Sparrow*	41	92.1	920.7	212.5	59	58.7	444.1	182.1
(mg/dl)	*Yellow-breasted Chat*	28	101.4	597.2	214.4	34	41.7	360.5	118.2
	Bell's Vireo	6	110.2	464.7	207.6	5	64.1	206.4	116.6
β-hydroxybutyrate	*Field Sparrow*	41	0.1	3.0	1.2	58	0.7	2.7	1.7
(mM)	*Yellow-breasted Chat*	28	0.6	3.0	1.5	34	0.5	2.1	1.5
	Bell's Vireo	6	1.0	1.3	1.4	5.0	1.0	2.4	1.2
Bacteria Killing Ability	*Field Sparrow*	48	-40.8	98.9	50.4	61	-51.8	82.7	-10.3
(%)	*Yellow-breasted Chat*	29	12.7	99.7	81.3	35	-19.0	100.0	70.6
	Bell's Vireo	5	45.7	100	73.4	9	48.4	74.2	78.5
Ectoparasites	*Field Sparrow*	49	0	66	10.2	55	1	155	23.4
(#/individual)	*Yellow-breasted Chat*	28	0	59	6.4	32	0	156	20.7
	Bell's Vireo	8	0	16	4.9	8	0	18	3.4

Table 3.3. Model selection table examining the relationship between habitat characteristics and corticosterone concentrations of individuals ranked according to Akaike's Information Criterion, the number of associated parameters per model (*K*), change in AIC in relation to the top ranked model (ΔAIC), and the weight of each model (w_i). Linear mixed effect models were used to analyze the relationships. Models with "× *Species"* denote the models that include Bell's Vireo, Yellow-breasted Chat, and Field Sparrow as an interaction effect. All models were run with "species", "year" and "date" as covariates.

Model	**AIC**	**K**	**ΔAIC**	w_i
% Autumn Olive × Species	-466.0	10	0.0	0.659
Null	-461.8	7	4.2	0.081
% Honeysuckle × Species	-460.7	10	5.3	0.047
% Autumn Olive	-460.7	8	5.3	0.046
% Honeysuckle	-460.4	8	5.6	0.039
% Native Plant Species	-460.2	8	5.8	0.036
% Multiflora Rose	-460.0	8	6.0	0.032
% Native Plant Species × Species	-459.6	10	6.0	0.032
% Multiflora Rose × Species	-456.3	10	6.4	0.028

Table 3.4. Parameter estimates with standard error in parentheses for top-ranked AIC models comparing habitat characteristics to log transformed corticosterone concentrations using linear mixed effects models. FISP refers to Field Sparrow, YBCH refers to Yellow-breasted Chat, and BEVI refers to Bell's Vireo. Species-specific effects were included into the models to determine if each of the focal species had differing responses to the habitat characteristics. Date had a significant influence on corticosterone concentrations and was included in the model as a nuisance parameter to control for its effect.

Model	**AIC**	**Estimates**							
		Intercepts					Slopes		
		Species					*Species-specific Effects*		
		BEVI	*FISP*	*YBCH*	*Date*	*Year*	*BEVI*	*FISP*	*YBCH*
% Autumn Olive × Species	-466.0	1.999 (0.024)	1.874 (0.011)	1.847 (0.013)	-0.001 (0.000)	0.165 (0.009)	0.010 (0.003)	-0.003 (0.001)	0.002 (0.001)
Null	-461.8	2.031 (0.022)	1.871 (0.011)	1.854 (0.013)	-0.001 (0.000)	0.166 (0.010)	----	----	----

Table 3.5: Model selection table examining the relationship between habitat characteristics and triglyceride concentrations of individuals ranked according to Akaike's Information Criterion, the number of associated parameters per model (*K*), change in AIC in relation to the top ranked model (ΔAIC), and the weight of each model (w_i). Linear mixed effect models were used to analyze the relationships. Models with "× *Species*" denote the models that include Bell's Vireo, Yellow-breasted Chat, and Field Sparrow as an interaction effect. All models were run with "species", and "year" as covariates.

Model	**AIC**	**K**	**ΔAIC**	w_i
% Honeysuckle × Species	-17.5	9	0.0	0.511
% Honeysuckle	-14.6	7	2.9	0.120
Null	-14.4	6	3.1	0.108
% Native Plant Species × Species	-12.8	9	4.7	0.049
Average % Woody Cover	-12.5	7	4.9	0.042
% Native Plant Species	-12.5	7	5.0	0.042
% Multiflora Rose	-12.6	7	4.9	0.044
% Autumn Olive	-12.4	7	4.9	0.044
% Multiflora Rose × Species	-10.7	9	5.4	0.040

Table 3.6. Parameter estimates with standard error in parentheses for top-ranked AIC models comparing habitat characteristics to log transformed triglyceride concentrations using linear mixed effects models. FISP refers to Field Sparrow, YBCH refers to Yellow-breasted Chat, and BEVI refers to Bell's Vireo. Species-specific effects were included into the models to determine if each of the focal species had differing responses to the habitat characteristics. Date had a significant influence on triglyceride concentrations and was included in the model as a nuisance parameter to control for its effect.

Model	**AIC**	**Estimates**						
		Intercepts				Slopes		
		Species				*Species-specific Effects*		
		BEVI	*FISP*	*YBCH*	*Year*	*BEVI*	*FISP*	*YBCH*
% Honeysuckle × Species	-17.5	2.082 (0.094)	2.331 (0.033)	2.241 (0.043)	-0.126 (0.035)	0.039 (0.021)	-0.017 (0.010)	-0.027 (0.015)
Null	-14.4	2.208 (0.070)	2.312(0.031)	2.204 (0.035)	-0.140 (0.035)	----	----	----

Table 3.7. Model selection table examining the relationship between habitat characteristics and β-hydroxybutyrate concentrations of individuals ranked according to Akaike's Information Criterion, the number of associated parameters per model (*K*), change in AIC in relation to the top ranked model (ΔAIC), and the weight of each model (w_i). Linear mixed effect models were used to analyze the relationships. Models with "× *Species"* denote the models that include Bell's Vireo, Yellow-breasted Chat, and Field Sparrow as an interaction effect. All models were run with "species" and "date" as covariates.

Model	**AIC**	**K**	**ΔAIC**	w_i
% Honeysuckle	-161.9	7	0	0.387
% Honeysuckle × Species	-160.0	9	2.0	0.150
Null	-159.7	6	2.2	0.129
% Multiflora Rose	-159.2	7	2.7	0.100
% Multiflora Rose × Species	-158.4	9	3.4	0.067
% Autumn Olive	-157.7	7	4.2	0.047
% Native Plant Species	-157.7	7	4.2	0.047
% Native Plant Species × Species	-156.3	9	5.6	0.047
% Autumn Olive × Species	-156.2	9	5.7	0.024

Table 3.8. Parameter estimates with standard error in parentheses for top-ranked AIC models comparing habitat characteristics to log transformed β-hydroxybutyrate concentrations using linear mixed effects models. FISP refers to Field Sparrow, YBCH refers to Yellow-breasted Chat, and BEVI refers to Bell's Vireo. Species-specific effects were included into the models to determine if each of the focal species had differing responses to the habitat characteristics. Date had a significant influence on β-hydroxybutyrate concentrations and was included in the model as a nuisance parameter to control for its effect.

Model	**AIC**	**Estimates**						
		Intercepts				Slopes		
		Species				*Species-specific Effects*		
		BEVI	*FISP*	*YBCH*	*Date*	*BEVI*	*FISP*	*YBCH*
% Honeysuckle	-161.9	0.223 (0.052)	0.217 (0.025)	0.139 (0.027)	-0.002 (0.001)	-0.012 (0.005)	----	----
% Honeysuckle × Species	-160.0	0.165(0.065)	0.221 (0.267)	0.145 (0.030)	-0.002 (0.001)	-0.008 (0.014)	-0.013 (0.006)	-0.015 (0.010)
Null	-159.7	0.191 (0.050)	0.197 (0.025)	0.117 (0.027)	-0.002 (0.001)	----	----	----

Table 3.9. Model selection table examining the relationship between habitat characteristics and BKA of individuals ranked according to Akaike's Information Criterion, the number of associated parameters per model (*K*), change in AIC in relation to the top ranked model (ΔAIC), and the weight of each model (w_i). Linear mixed effect models were used to analyze the relationships. Models with "× *Species"* denote the models that include Bell's Vireo, Yellow-breasted Chat, and Field Sparrow as an interaction effect. All models were run with "species", "year". and "date" as covariates.

Model	**AIC**	**K**	**ΔAIC**	$\boldsymbol{w_i}$
% Native Plant Species	-255.2	8	0.0	0.202
Null	-254.9	7	0.3	0.174
% Autumn Olive × Species	-254.8	10	0.4	0.166
% Honeysuckle	-253.8	8	1.4	0.101
% Multiflora Rose	-253.7	8	1.5	0.096
% Multiflora Rose × Species	-253.5	10	1.7	0.087
% Autumn Olive	-253.1	8	1.7	0.071
% Honeysuckle × Species	-251.6	10	3.0	0.071
% Native Plant Species × Species	-251.6	10	3.6	0.033

Table 3.10. Parameter estimates with standard error in parentheses for top-ranked AIC models comparing habitat characteristics to log transformed BKA using linear mixed effects models. FISP refers to Field Sparrow, YBCH refers to Yellow-breasted Chat, and BEVI refers to Bell's Vireo. Species-specific effects were included into the models to determine if each of the focal species had differing responses to the habitat characteristics. Date had a significant influence on BKA s and was included in the model as a nuisance parameter to control for its effect. For models without species-specific effects, BEVI refers to the slope of all combined species.

Model	**AIC**	**Estimates**							
		Intercepts					Slopes		
		Species						*Species-specific Effects*	
		BEVI	*FISP*	*YBCH*	*Date*	*Year*	*BEVI*	*FISP*	*YBCH*
% Native Plant Species	-255.2	2.396 (0.042)	2.180 (0.025)	2.380 (0.026)	-0.004 (0.001)	-0.139 (0.017)	0.002 (0.001)	----	----
Null	-254.9	2.423 (0.039)	2.204 (0.020)	2.403 (0.021)	-0.004 (0.001)	-0.142 (0.017)	----	----	----
% Autumn Olive × Species	-254.8	2.444 (0.045)	2.212 (0.020)	2.404 (0.022)	-0.004 (0.001)	-0.143 (0.017)	-0.005 (0.006)	-0.002 (0.001)	-0.001 (0.001)
% Honeysuckle	-253.8	2.432 (0.040)	2.208 (0.020)	2.408 (0.022)	-0.004 (0.001)	-0.139 (0.017)	-0.004 (0.004)	----	----
% Multiflora Rose	-253.7	2.425 (0.039)	2.202 (0.020)	2.400 (0.022)	-0.004 (0.001)	-0.144 (0.017)	0.004 (0.004)	----	----
% Multiflora Rose × Species	-253.5	2.404 (0.041)	2.211 (0.020)	2.397 (0.022)	-0.004 (0.001)	-0.146 (0.017)	0.138 (0.089)	-0.002 (0.006)	0.009 (0.006)
% Autumn Olive	-253.1	2.423 (0.039)	2.205 (0.020)	2.404 (0.022)	-0.004 (0.001)	-0.141 (0.017)	-0.001 (0.001)	----	----

Table 3.11. Model selection table examining the relationship between habitat characteristics and ectoparasite loads of individuals ranked according to Akaike's Information Criterion, the number of associated parameters per model (*K*), change in AIC in relation to the top ranked model (ΔAIC), and the weight of each model (w_i). Linear mixed effect models were used to analyze the relationships. Models with "× *Species*" denote the models that include Bell's Vireo, Yellow-breasted Chat, and Field Sparrow as an interaction effect. All models were run with "species", "year". and "date" as covariates.

Model	**AIC**	**K**	**ΔAIC**	w_i
Null	1641.8	7	0.0	0.323
% Native Plant Species	1643.4	8	1.6	0.145
% Multiflora Rose	1643.6	8	1.8	0.131
% Honeysuckle	1643.7	8	1.9	0.125
% Autumn Olive	1643.8	8	2.0	0.119
% Autumn Olive × Species	1644.5	10	2.0	0.084
% Honeysuckle × Species	1646.9	10	2.7	0.025
% Native Plant Species × Species	1647.2	10	5.1	0.025
% Multiflora Rose × Species	1647.6	10	5.8	0.022

Table 3.12. Parameter estimates with standard error in parentheses for top-ranked AIC models comparing habitat characteristics to ectoparasite loads using linear mixed effects models. FISP refers to Field Sparrow, YBCH refers to Yellow-breasted Chat, and BEVI refers to Bell's Vireo. Species-specific effects were included into the models to determine if each of the focal species had differing responses to the habitat characteristics. Date had a significant influence on ectoparasite loads and was included in the model as a nuisance parameter to control for its effect. For models without species-specific effects, BEVI refers to the slope of all combined species.

Model	**AIC**	**Estimates**							
		Intercepts					Slopes		
		Species						*Species-specific Effects*	
		BEVI	*FISP*	*YBCH*	*Year*	*Date*	*BEVI*	*FISP*	*YBCH*
Null	1641.8	6.301 (6.939)	16.268 (4.211)	13.282 (4.625)	11.305 (3.429)	-0.235 (0.117)	----	----	----
% Native Plant Species	1643.4	8.673 (7.967)	18.615 (5.682)	15.588 (5.953)	11.133 (3.437)	-0.235 (0.117)	-0.204 (0.332)	----	----
% Multiflora Rose	1643.6	6.112 (6.955)	15.993 (4.276)	12.981 (4.700)	11.095 (3.478)	11.095 (3.478)	0.430 (1.188)	----	----
% Honeysuckle	1643.7	5.759 (7.186)	15.903 (4.395)	12.889 (4.819)	11.107 (3.494)	-0.235 (0.117)	0.280 (0.963)	----	----
% Autumn Olive	1643.8	6.307 (6.948)	16.282 (4.280)	13.296 (4.690)	11.309 (3.438)	-0.234 (0.120)	-0.005 (0.286)	----	----
% Autumn Olive × Species	1644.5	9.191 (7.868)	14.884 (4.375)	16.174 (5.006)	11.188 (3.418)	-0.239 (0.120)	-0.818 (1.117)	0.288 (0.333)	-0.540 (0.444)

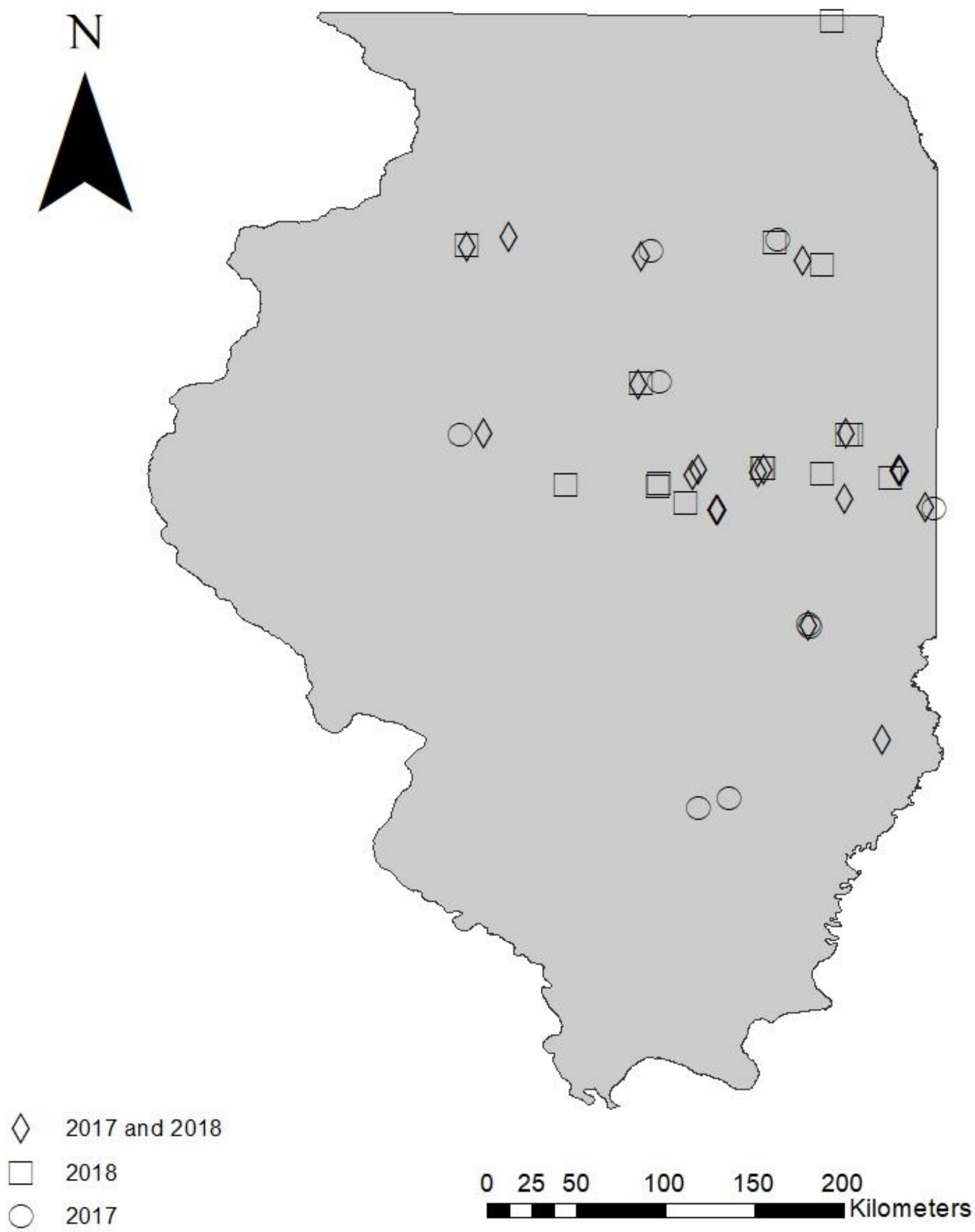

Figure 3.1. Map of sites visited during 2017 and 2018 from late May- mid-July. Twenty-nine sites were visited in 2017 with 7 revisits, and 35 sites were visited in 2018 with 2 revisits. Symbols represent which sites were sampled during 2017 and 2018.

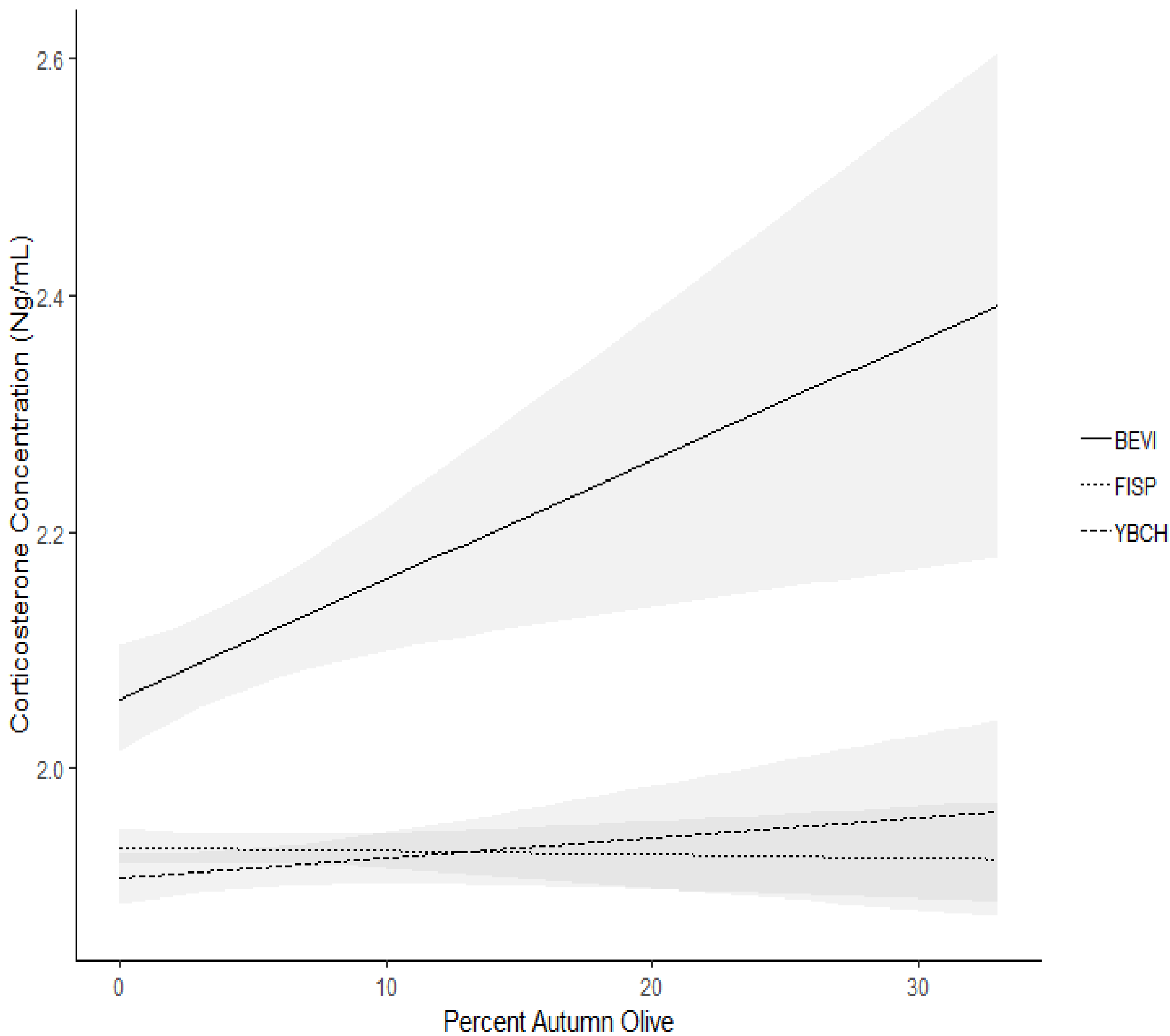

Figure 3.2. Predicted corticosterone concentrations (with 95% Confidence Intervals) and within-site percentage of autumn olive for each bird species. BEVI refers to Bell's Vireo, FISP to Field Sparrow, and YBCH to Yellow-breasted Chat.

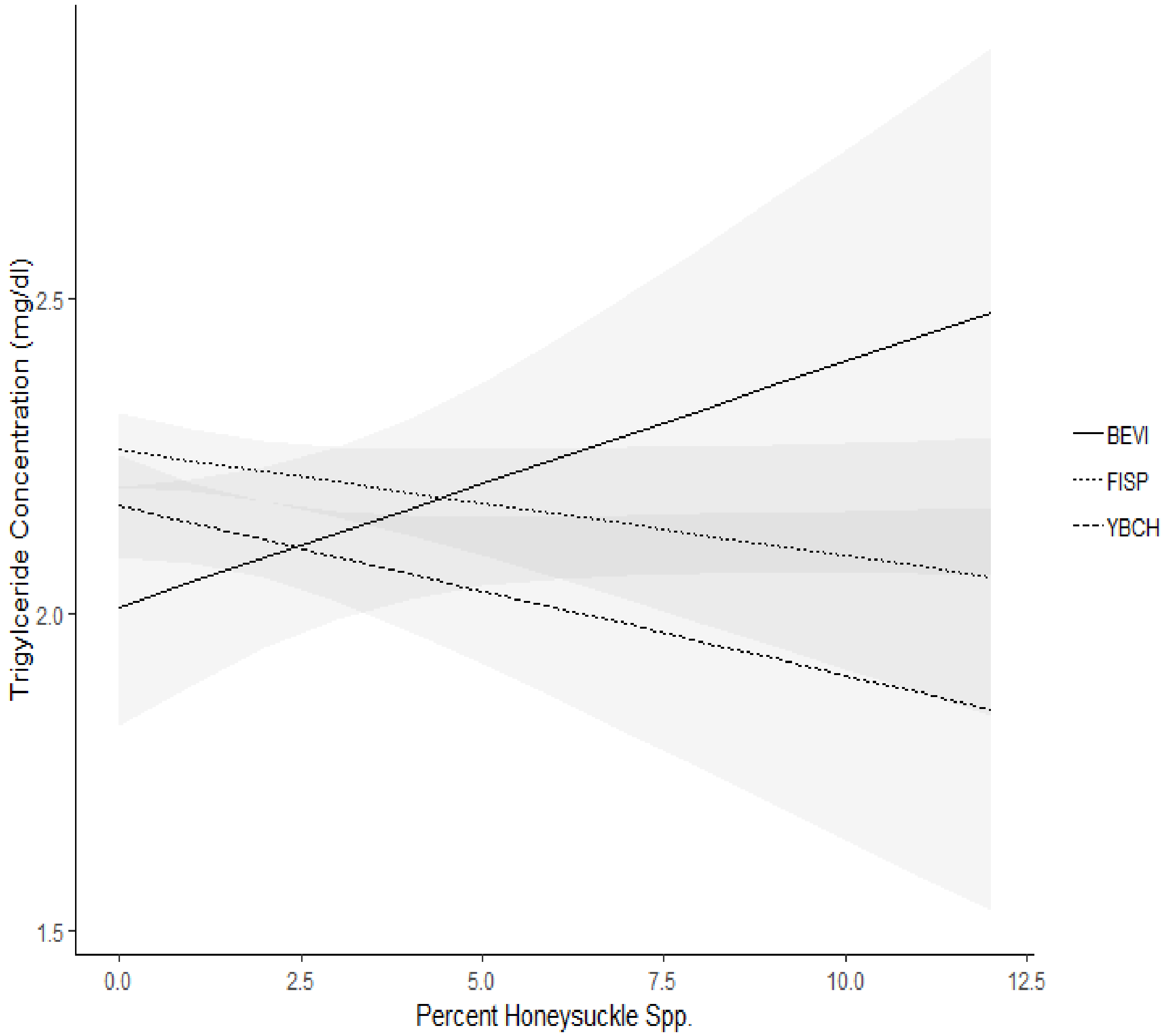

Figure 3.3. Predicted triglyceride concentrations (with 95% Confidence Intervals) and within-site percentage of honeysuckle for each bird species, sampled in shrublands throughout Illinois, 2017–2018. BEVI refers to Bell's Vireo, FISP to Field Sparrow, and YBCH to Yellow-breasted Chat.

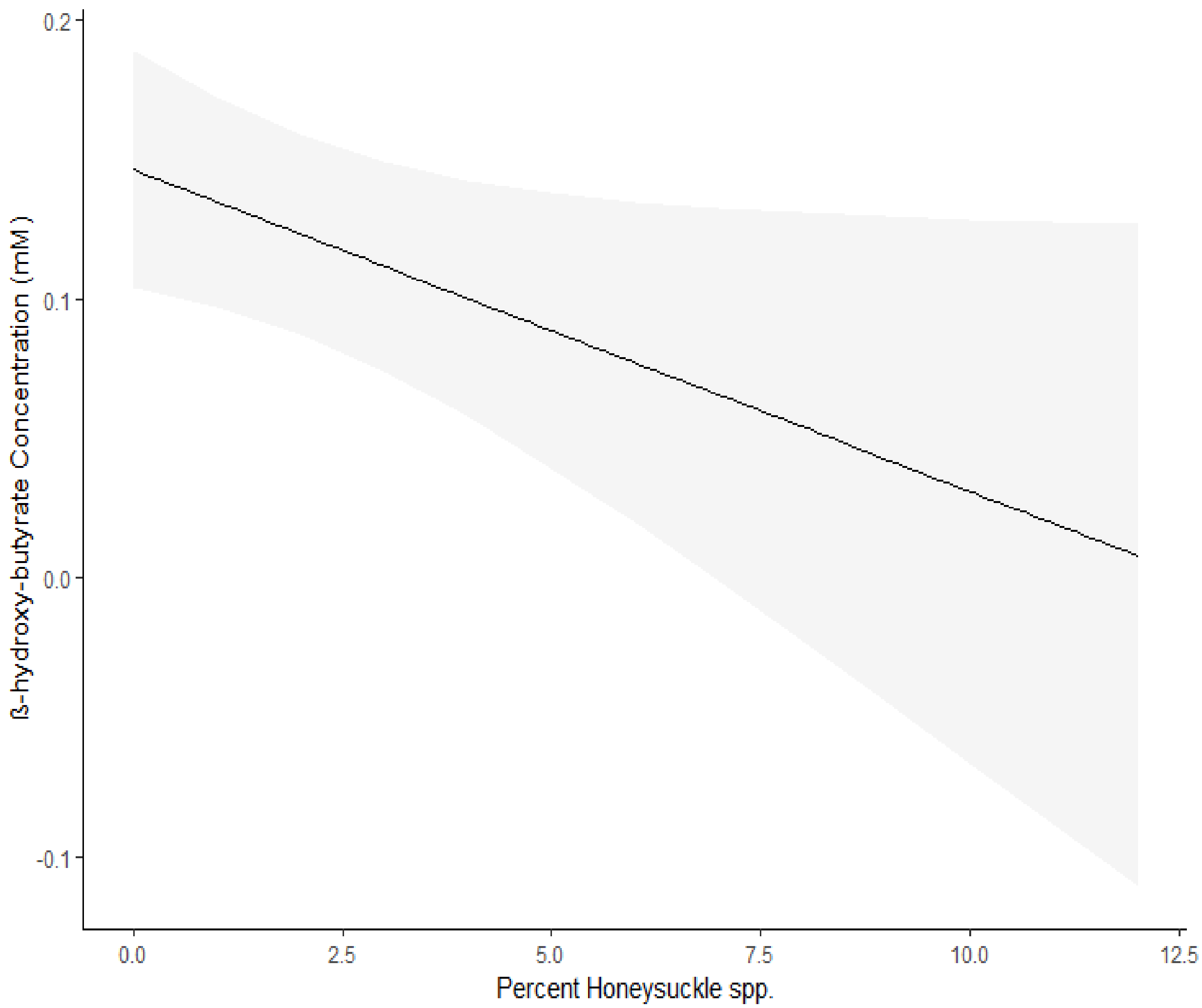

Figure 3.4. Predicted β-hydroxybutyrate concentrations (with 95% Confidence Intervals) and within-site percentage of honeysuckle for all three bird species (Bell's Vireo, Field Sparrow, and Yellow-breasted Chat).

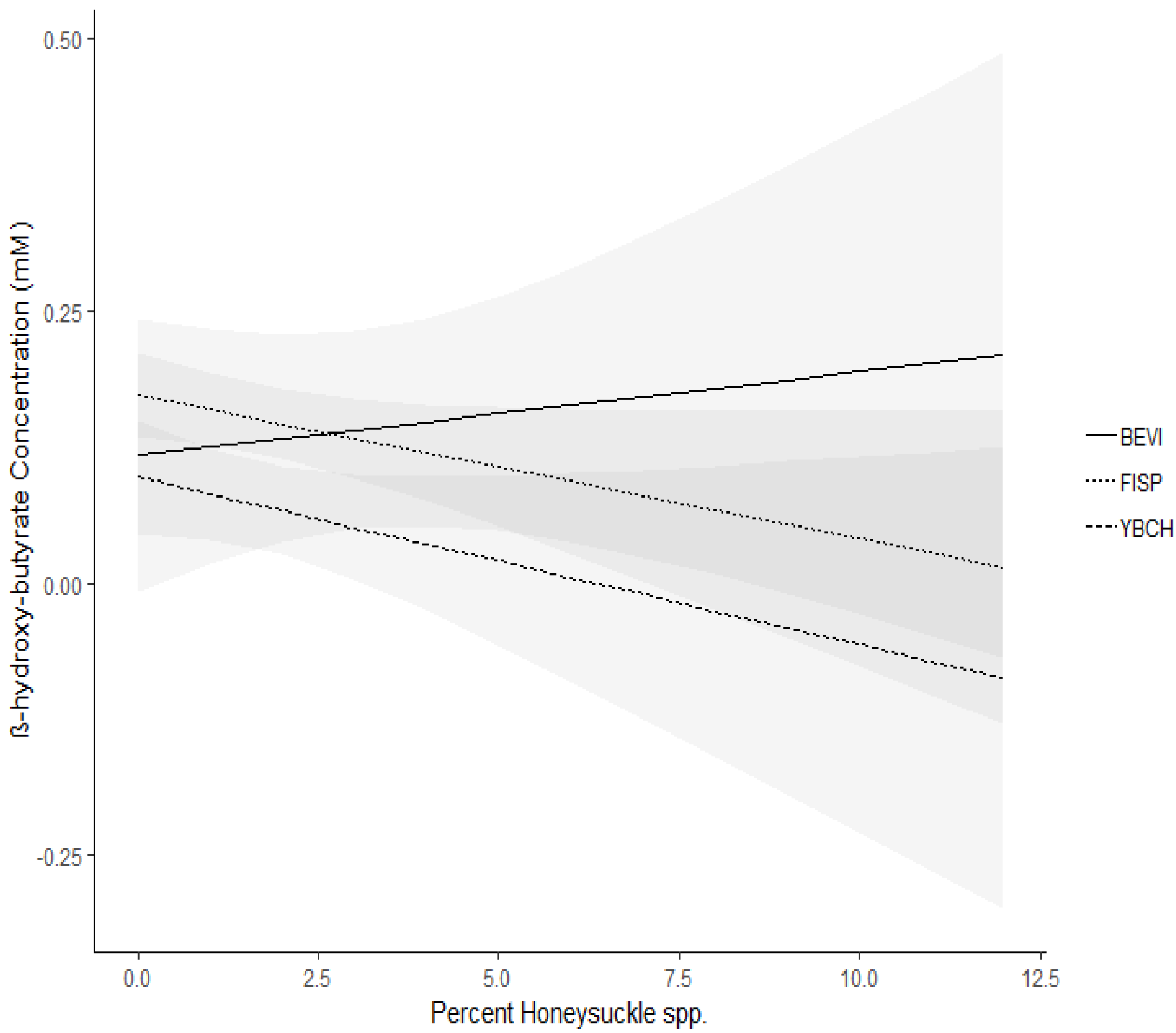

Figure 3.5. Predicted β-hydroxybutyrate concentrations (with 95% Confidence Intervals) and within-site percentage of honeysuckle, for each bird species, sampled in shrublands throughout Illinois, 2017–2018. BEVI refers to Bell's Vireo, FISP to Field Sparrow, and YBCH to Yellow-breasted Chat.

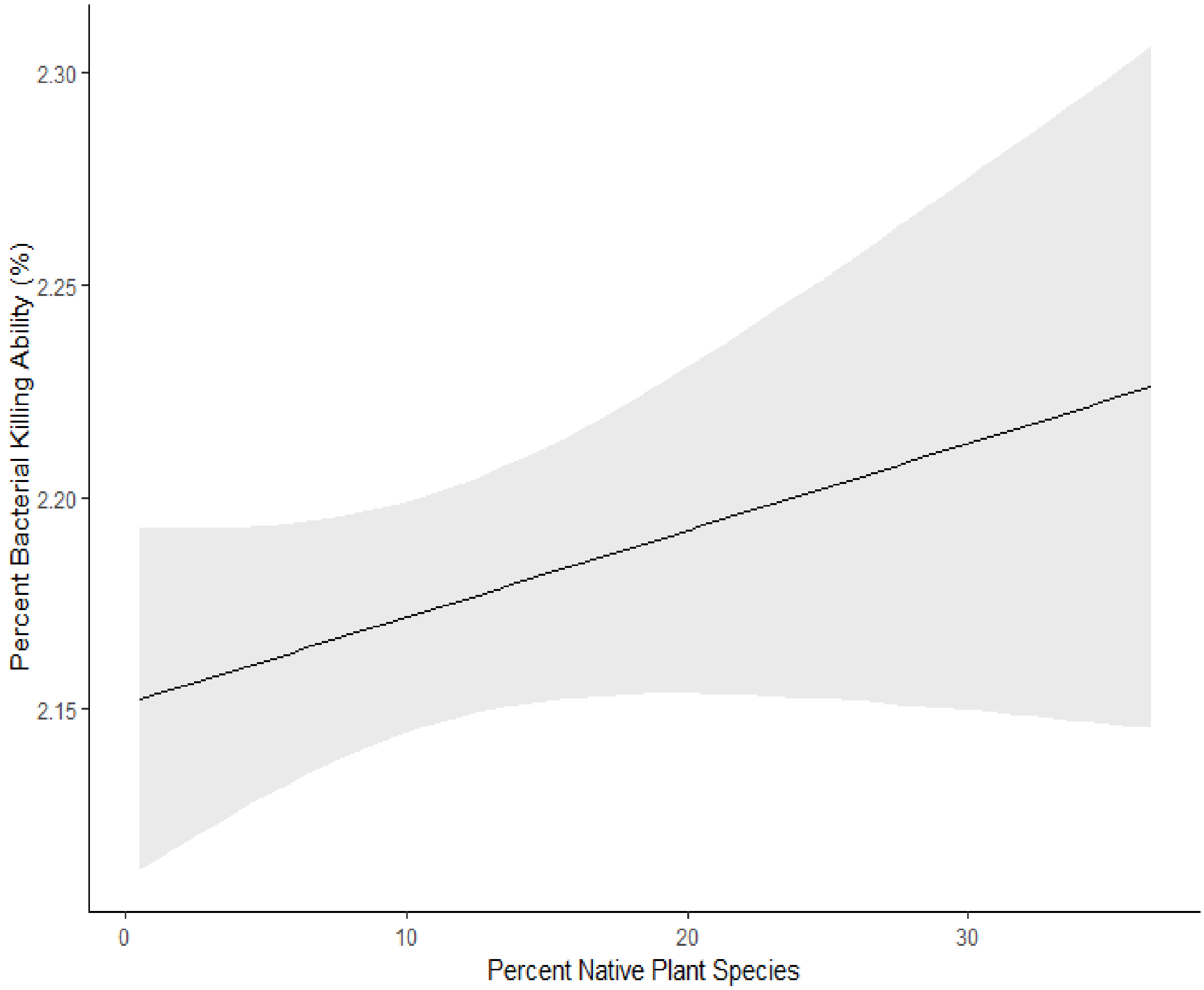

Figure 3.6. Predicted BKA (with 95% Confidence Intervals) and within-site percentage of native plant species, for all three bird species, sampled in shrublands throughout Illinois, 2017–2018 confidence intervals.

3.8 REFERENCES

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control 19:716-723.

Albano, N., J. Masero, A. Villegas, J. M. Abad-Gómez, and J. M. Sánchez-Guzmán. 2011. Plasma metabolite levels predict bird growth rates: A field test of model predictive ability. Comparative Biochemistry and Physiology. Part A 160:9–15.

Askins, R. A. 1993. Population trends in grassland, shrubland, and forest birds in eastern North America. In: Power D.M. (eds) Current Ornithology. Current Ornithology, vol 11. Springer, Boston, MA.

Askins, R. A. 2000. Restoring North America's birds: Lessons from landscape ecology. Yale University Press, New Haven, CT.

Barlow, J. C. 1962. Natural history of the Bell's Vireo, Vireo belli Audubon. University of Kansas Publications, Museum of Natural History, Lawrence Kansas 12:241-296.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67:1-48. doi:10.18637/jss.v067.i01.

Borgmann, K. L., and A. D. Rodewald. 2004. Nest predation in an urbanizing landscape: The role of exotic shrubs. Ecological Applications 14:1757-1765.

Brawn, J. D., S. K. Robinson, and F. R. Thompson III. 2001. The role of disturbances in the ecology and conservation of birds. Annual Review Ecological Systems 32:251-76.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of Invasive Alien Plants on Fire Regimes. Bioscience 54:677–688.

Budnik, J. M., M. R. Ryan, and F. R. Thompson III. 2016. Demography of Bell's Vireos in Missouri grassland-shrub habitats. The Auk 117:925-935.

Burghardt, K. T., D. W. Tallamy, and W. G. Shriver. 2009. Impact of native plants on bird and butterfly biodiversity in suburban landscapes. Conservation Biology 23:219–224.

Burnham KP, Anderson DR (2002) Model selection and multimodel inference: a practical information-theoretic approach, 2nd edn. Springer, New York.

Busch, D. S., and L. S. Hayward. 2009. Stress in a conservation context: A discussion of glucocorticoid actions and how levels change with conservation-relevant variables. Biological Conservation 142:2844–2853.

Carey, M., D. E. Burhans and D. A. Nelson. 2008. Field Sparrow (Spizella pusilla), The Birds of North America (P. G. Rodewald, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America: https://birdsna.org/Species-Account/bna/species/fiespa

Carter, E. T., B. C. Eads, M. J. Ravesi, and B. A. Kingsbury. 2015. Exotic non-native plants alter thermal regimes: implications for management using a case study of a native ectotherm. Functional Ecology 29:683–693.

DeGraaf, R. M., and M. Yamasaki. 2003. Options for managing early-successional forest and shrubland bird habitats in the northeastern United States. Forest Ecology and Management 185:179–191.

Dietz, M., S. Jenni-Eiermann, and T. Piersma. 2009. The use of plasma metabolites to predict weekly body-mass change in Red Knots. The Condor 111:88–99.

Ellis V. A., L. Merrill, J. C. Wingfield, A. L. O'Loghlen, and S. I. Rothstein. 2012. Changes in immunocompetence and other physiological measures during molt in brown-headed cowbirds (Molothrus ater). Auk 129:231–238.

Gardner, A. 2016. Direct and indirect effects of native and non-native plants on mosquito ecology (Doctoral dissertation). Retrieved from http://hdl.handle.net/2142/90761.

IWAP. 2005. The Illinois Comprehensive Wildlife Conservation Plan and Strategy. Retrieved from: https://www.dnr.illinois.gov/conservation/IWAP/Documents/IllinoisCWCP.pdf

Janeway C.A. Jr., Travers P., Walport M., et al. Immunobiology: The Immune System in Health and Disease. 5th edition. New York: Garland Science; 2001. The complement system and innate immunity. Available from: https://www.ncbi.nlm.nih.gov/books/NBK27100/

Jenni-Eiermann, S., and L. Jenni. 1994. Plasma metabolite levels predict individual body-mass changes in a small long-distance migrant, The Garden Warbler. The Auk 111:888-899.

Jenni-Eiermann, S., and L. Jenni 1997. Diurnal variation of metabolic responses to short-term fasting in passerine birds during the postbreeding, molting and migratory period. The Condor 99:113–122.

Keane, R. M., and M. J. Crawley. 2002. Exotic plant invasions and the enemy release hypothesis. Trends in Ecology and Evolution 17:164–170.

Kus, B., S. L. Hopp, R. R. Johnson and B. T. Brown. 2010. Bell's Vireo (Vireo bellii), The Birds of North America (P. G. Rodewald, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America: https://birdsna.org/Species-Account/bna/species/belvirDOI: 10.2173/bna.35

Landys, M. A., W. Goymann, I. Schwabl, M. Trapschuh, and T. Slagsvold. 2010. Impact of season and social challenge on testosterone and corticosterone levels in a year-round territorial bird. Hormones and Behavior 58:317-325.

Litt, A. R., E. E. Cord, T. E. Fulbright, and G. L. Schuster. 2014. Effects of non-native plants on arthropods. Conservation Biology 28:1532–1549.

Lobato, E., J. Moreno, S. Merino, J. Morales, G. Tomas, J. Martinez, R. A. Vasquez, A. Kuchar, E. Mostl, and J. L. Osorno. 2010. Arrival date and territorial behavior are associated with corticosterone metabolite levels in a migratory bird. Journal of Ornithology 151:587-597.

Love, J. P. 2006. Effects of Morrow's Honeysuckle Control and the Impact of the Shrub on Invertebrates at Fort Necessity National Battlefield, Pennsylvania.(Master's Thesis) Retrieved from: http://www.wvuforestry.com/jAnderson/Love_thesis.pdf.

Mark, M. M., and D. R. Rubenstein. 2013. Physiological costs and carry-over effects of avian interspecific brood parasitism influence reproductive tradeoffs. Hormones and Behavior 63:717–722.

Matson, K. D., B. I. Tieleman, and K. C. Klasing. 2006. Capture stress and the bactericidal competence of blood and plasma in five species of tropical birds. Physiological and Biochemical Zoology 79:556-564.

McEwen, B. S., and J. C. Wingfield. 2003. The concept of allostasis in biology and biomedicine. Hormones and Behavior 43:2–15.

Merrill L., F. Angelier, A. L. O'Loghlen, S. I. Rothstein, and J. C. Wingfield. 2012. Sex-specific variation in brown-headed cowbird immunity following acute stress: a mechanistic approach. Oecologia 170:25–38.

Merrill L., A. L. O'Loghlen, J. C. Wingfield, and S. I. Rothstein. 2013a. Linking a static signal to current condition: song-repertoire size, corticosterone, and immunity in the brown-headed cowbird. Condor 115:434–441.

Merrill L., A. L. O'Loghlen, J. C. Wingfield, and S. I. Rothstein. 2013b. Immune function in an avian brood parasite and its nonparasitic relative. Physiol Biochem Zool 86:61–72.

Merrill, L., T. E. Stewart Merrill, A. Barger, T. J. Benson. 2019. Avian health across the landscape: nestling immunity covaries with changing landcover. Integr Comp Biol. DOI:10.1093/icb/icz037

Millet S., J. Bennett, K. A. Lee, M. Hau, and K. C. Klasing. 2007. Quantifying and comparing constitutive immunity across avian species. Develop Comp Immunol 31:188–201.

Morrison E. S., D. R. Ardia, and E. D. Clotfelter. 2009. Cross-fostering reveals sources of variation in innate immunity and hematocrit in nestling tree swallows Tachycineta bicolor. J Avian Biol 40:573–578.

Mumford, R. E. 1952. Bell's Vireo in Indiana. The Wilson Bulletin. 64:224–233

Munro, C., and G. Stabenfeldt. 1984. Development of a microtitre plate enzyme immunoassay for the determination of progesterone. Journal of Endocrinology 101:41-49.

Narango, D. L., D. W. Tallamy, and P. P. Marra. 2017. Native plants improve breeding and foraging habitat for an insectivorous bird. Biological Conservation 213:42-50.

Narayan, E., F. Molinia, K. Christi, C. Morley, and J. Cockrem. 2010. Urinary corticosterone metabolite responses to capture, and annual patterns of urinary corticosterone in wild and captive endangered Fijian ground frogs (Platymantis vitiana). Aust. J. Zool. 58:189-197.

Nelson, S. B., J. J. Coon, C. J. Duchardt, J. D. Fischer, S. J. Halsey, A. J. Kranz, C. M. Parker, S. C. Schneider, T. M. Swartz, and J. R. Miller. 2017. Patterns and mechanisms of invasive plant impacts on North American birds: a systematic review. Biological Invasions 19:1547-1563.

Owen, J. P., A. C. Nelson, and D. H. Clayton. 2010. Ecological immunology of bird-ectoparasite systems. Trends in Parasitology 26:530-539.

Peiman K. S., and B. W. Robinson. 2010. Ecology and evolution of resource-related heterospecific aggression. The Quarterly Review of Biology 85:133-158.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Reiley, B. M. 2017. Habitat use, population size, and nesting ecology of conservation priority bird species using restored fields in agricultural landscapes (Doctoral Dissertation) Retrieved from: https://www.ideals.illinois.edu/bitstream/handle/2142/99344/REILEY-DISSERTATION-2017.pdf?sequence=1

Rodewald, A. D. 2009. Urban-associated habitat alteration promotes brood parasitism of Acadian Flycatchers. Journal of Field Ornithology 80:234-241.

Rodewald, A. D., D. P. Shustack, and L. E. Hitchcock. 2010. Exotic shrubs as ephemeral ecological traps for nesting birds. Biological Invasions 12:33-39.

Romero, L. M., and J. M. Reed. 2005. Collecting baseline corticosterone samples in the field: Is under 3 min good enough? Comparative Biochemistry and Physiology, Part A 140:73–79.

Rosenberg, K. V., J. A. Kennedy, R. Dettmers, R. P. Ford, D. Reynolds, J.D. Alexander, C. J. Beardmore, P. J. Blancher, R. E. Bogart, G. S. Butcher, A. F. Camfield, A. Couturier, D. W. Demarest, W. E. Easton, J.J. Giocomo, R.H. Keller, A. E. Mini, A. O. Panjabi, D. N. Pashley, T. D. Rich, J. M. Ruth, H. Stabins, J. Stanton, T. Will. 2016. Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee. 119 pp.

Santymire R. M., and D. A. Armstrong. 2009. Development of a field-friendly technique for fecal steroid extraction and storage using the African wild dog (Lycaon pictus). Zoo Biol 28:1–14.

Sauer, J. R., D. K. Niven, J. E. Hines, D. J. Ziolkowski, Jr, K. L. Pardieck, J. E. Fallon, and W. A. Link. 2017. The North American Breeding Bird Survey, results and analysis 1966-2015. Version 2.07.2017 USGS Patuxtent Wildlife Research Center, Laurel, MD.

Schowalter, T. D., J. W. Webb, and D. A. Crossley, Jr. 1981. Community structure and nutrient content of canopy arthropods in clearcut and uncut forest ecosystems. Ecology 62:1010-1019.

Sharp, B. L., and B. E. Kus. 2004. Sunrise nest attendance and aggression by Least Bell’s Vireos fail to deter cowbird parasitism. The Wilson Journal of Ornithology 116:17–22.

Smith, S. B., S. A. DeSando, and T. Pagano. 2013. The value of native and non-native fruit-bearing shrubs for migrating songbirds. Northeastern Naturalist 20:171–184.

Stoleson S. H., and D. M. Finch. 2001. Breeding bird use of and nesting success in exotic Russian olive in New Mexico. Wilson Bulletin 113: 452–455

Thompson, C. F., and V. Nolan Jr. 1973. Population biology of the Yellow-Breasted Chat (Icteria Virens L .) in Southern Indiana. Ecological Monographs 43:145–171.

Tieleman, B. I., J. G. Williams, R. E. Ricklefs, and K. C. Klasing. 2005. Constitutive innate immunity is a component of the pace-of-life syndrome in tropical birds. Proceedings of the Royal Society B. 272:1715-1720.

Tremblay, I., D. Thomas, J. Blondel, P. Perret, and M. M. Lambrechts. 2005. The effect of habitat quality on foraging patterns, provisioning rate and nestling growth in Corsican Blue Tits: Parus caeruleus. Ibis 147:17-24.

Wilcoxen T. E., R. K. Boughton, and S. J. Schoech. 2010. Selection on innate immunity and body condition in Florida scrub-jays throughout an epidemic. Biol Lett 6:552–554.

Wikelski, M., and S. J. Cooke. 2006. Conservation physiology. Trends in Ecology and Evolution 21:38–46.

CHAPTER 4: GENERAL CONCLUSION

Shrubland birds have been one of the fastest declining groups of birds over the past 50 years, while receiving less conservation attention than other groups. While habitat loss and degradation may be the main drivers of population declines (Rosenberg *et al.* 2016), I found that non-native plant species appear to be contributing to these declines as well. Non-native plant species not only impacted site selection and site fidelity but the physiological health and condition of three shrubland species considered in Greatest Need of Conservation (Illinois Department of Natural Resources2005, Bell's Vireo (*Vireo bellii bellii*), Yellow-breasted Chat (*Icteria virens*), and Field Sparrow (*Spizella pusilla*)).

In chapter 2, I investigated the influence that landscape context, habitat structure, and species identity had on the occupancy dynamics of Bell's Vireo, Yellow-breasted Chat, and Field Sparrow. I found that multiflora rose (*Rosa multiflora*) had negative influences on the site selection for Bell's Vireo and the site fidelity or Bell's Vireo and Yellow-breasted Chat. This suggests that for more specialized species, habitat quality is more important than landscape context. Additionally, I found no effect of habitat structure or landscape context. This suggests that some species with widespread and abundant populations, like the Field Sparrow, are less sensitive to the condition of shrublands and are taking advantage of these ephemeral habitats regardless of their location or size on the landscape. Therefore, increasing the number of shrublands on the landscape would greatly benefit these species.

In chapter 3, I investigated the effects that non-native plant species had on the physiological health and condition of shrubland birds of conservation concern. Specifically, I investigated four physiological biomarkers, glucocorticoid hormone (corticosterone), dietary metabolites (triglyceride and β-hydroxybutyrate) and bacteria-killing ability (BKA), in relation to prevalence of the three most widespread and abundant non-native woody plant species found in shrublands throughout Illinois. I found that autumn olive (*Elaeagnus umbellata*) was associated with increased concentrations of corticosterone for Bell’s Vireo. I also found that Yellow-breasted Chat and Field Sparrow had lower triglyceride concentrations in relation to increasing prevalence of honeysuckle (*Lonicera* spp.), and all three species had decreasing concentrations of β-hydroxybutyrate in relation to honeysuckle as well. This suggests that honeysuckle is not decreasing the quantity, but rather the quality, of food available. Finally, I found that increasing percentages of native plant species had a positive influence on the bacteria killing-ability of all three species.

In summary, non-native woody shrubs appear to be negatively influencing shrubland obligate species of conservation concern. Looking at both occupancy dynamics as well as physiological health and condition in association to various habitat characteristics can provide important conservation implications. I found that all three non-native plant species are influencing shrubland obligate species by decreasing the quality of the habitats. While species that are more tolerant of varying conditions in a site would benefit from increasing the number of shrublands on the landscape, it appears that the quality is even more important to all shrubland obligate species influencing both their occupancy dynamics and physiological health and condition. Linking these findings together can help streamline efforts to manage shrublands for these species of conservation concern. For instance, management in areas with higher prevalence of multiflora rose would benefit from efforts to remove or prevent further invasion of the non-native shrub to help increase occupancy before managing to increase physiological condition. Since these birds are not selecting for sites with high prevalence of multiflora rose, efforts to manage shrublands with higher prevalence of multiflora rose to increase the quality in relation to physiological condition would be unproductive. Furthermore, future studies should focus on investigating the effects of non-native plant species on other shrubland obligate bird species. Increasing the effort to investigate these mechanisms in future studies has the potential to benefit management strategies for conserving other declining populations. Including supplemental data on food availability, nest success, and disease prevalence would also strengthen the results of this study. In conclusion, conservation and management actions that reduce or eliminate non-native woody plant species while facilitating native woody plants would benefit these conservation priority birds.

4.1 REFERENCES

Illinois Department of Natural Resources. 2005. The Illinois Comprehensive Wildlife Conservation Plan and Strategy. Retrieved from: https://www.dnr.illinois.gov/conservation/IWAP/Documents/IllinoisCWCP.pdf

Rosenberg, K. V., J. A. Kennedy, R. Dettmers, R. P. Ford, D. Reynolds, J.D. Alexander, C. J. Beardmore, P. J. Blancher, R. E. Bogart, G. S. Butcher, A. F. Camfield, A. Couturier, D. W. Demarest, W. E. Easton, J.J. Giocomo, R.H. Keller, A. E. Mini, A. O. Panjabi, D. N. Pashley, T. D. Rich, J. M. Ruth, H. Stabins, J. Stanton, T. Will. 2016. Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee. 119 pp.