ASSESSING THE IMPACT OF INVASIVE WOODY PLANT SPECIES ON SHRUBLAND BIRDS IN GREATEST NEED OF CONSERVATION

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Final Report

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Project Summary

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 is unknown. We investigated the role that non-native woody plant species may be having on changing habitat quality and causing declines in shrubland birds. Specifically, we investigated the distribution and predictors of non-native woody plant species (Objective 1), the influence non-native woody plant species had on the avian community, and 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*) – Objective 2), and the effects of non-native woody plant species on the physiological health of the three focal Species in Greatest Need of Conservation (Objective 3).

To address the three objectives we put forth, we visited 112 shrubland sites across Illinois to gather information on the bird and vegetation community. We visited these sites over a three-year period during the breeding season (May-July) from 2016-2018. At each site, we described the vegetation community with a particular emphasis on non-native woody plant species. We conducted avian point counts at all shrubland locations, visiting each site at least once and most sites multiple times over multiple years, to gain information on the avian community. We conducted targeted avian counts that included the use of call playbacks for three species listed as Species in Greatest Need of Conservation: Bell's Vireo, Yellow-breasted Chat, and Field Sparrow. Finally, we captured the three focal Species in Greatest Need of Conservation and collected information on their physiological health.

Objective 1. – We found 21 non-native woody plant species on the 112 shrublands we visited, which represented approximately 20% of all species found. Non-native woody plant species were found on all shrubland sites we visited. However, these plants typically made up less than half of all woody plant species at a site. Of the non-native species present, autumn olive (*Elaeagnus umbellate)* was the most widespread non-native species, being found at 67 locations. Multiflora rose (*Rosa multiflora)* and Amur honeysuckle (*Lonicera maackii)* were the next most abundant non-native woody plant species, being found at 59 and 45 locations respectively. No other non-native woody plant species was observed at more than 15 locations, although all shrublands contained non-native woody plants.

Non-native woody plant species richness was greatest in the northeast part of the state, near Chicago. On average we found 2.7 non-native species per shrubland, although this increased near Chicago, primarily because of the prevalence of buckthorn, which was found nowhere else. The surrounding landscape, defined in terms of proportion of area devoted to agricultural crops, had a significantly negative influence on species richness and autumn olive. We believe that isolation from forested areas, which may be the source of many non-native woody plant species, may be behind this relationship. Human population density surrounding a shrubland also appeared to be important, especially for multiflora rose and to a lesser extent buckthorn. We failed to find any other drivers of non-native woody plant species presence, presumably because they are so widespread and diverse in shrublands throughout Illinois.

Objective 2. – Shrublands in Illinois appear to be providing valuable habitat for numerous species and numerous species of conservation concern. We estimated that nearly 30 species of birds can be found on a given shrubland in Illinois over a three year period. Many of these species may be transients from nearby forests or prairies, but nonetheless are utilizing the habitat. Additionally, 15 of the bird species we detected on shrublands were species listed as Species in Greatest Need of Conservation. We used an N-mixture abundance model (Kery et al. 2005) to determine the effects of non-native woody plants on avian species richness. Contrary to what we originally believed, we did not find any evidence that non-native woody plant species influenced avian species richness. Consequently, the effects of non-native woody plant species on birds may be more individualistic.

We investigated the individual effects on non-native woody plants on the three focal Species in Greatest Need of Conservation: Bell's Vireo, Yellow-breasted Chat, and Field Sparrow. We utilized multi-season occupancy models (MacKenzie et al. 2003) to determine the influence landscape factors, vegetation structure at a site, and non-native woody plant species had on the occupancy dynamics of the three focal species. We 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 we surveyed, and appeared to utilize shrublands regardless of their composition or context on the landscape.

Objective 3. – We investigated the physiological responses of the three focal bird species in relation to the three most ubiquitous non-native woody shrubs using four biomarkers. Specifically, we investigated corticosterone concentrations in the plasma, a common biomarker used to measure the impact that environmental factors have on the chronic stress levels of individuals (Wingfield *et al.* 1997). Additionally, we measured the association of these environmental factors on individuals through two dietary metabolite assays (triglycerides and β-hydroxybutyrate) to assess short-term diet quality of individuals. Triglycerides, a form of lipid stored in the plasma, are used as an energy reserve, and higher concentrations in the plasma indicate a higher diet quality. β-hydroxybutyrate is a form of ketone acid found in the plasma that is used to catabolize stored energy in order to fuel their activities, with higher concentrations indicating a lower diet quality. Finally, we investigated an aspect of the birds' immunocompetence using a bacteria-killing ability assay which reflects an individual's capacity to clear a bacterial infection. We 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.

Conclusions. – 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 considered to be species of conservation concern. Landscape changes such as decreased shrubland abundances as well as encroachment of non-native plant species have left the quality of the remaining shrublands in question.

We found that non-native woody plant species are ubiquitous throughout Illinois. Autumn olive, multiflora rose, and honeysuckle spp. were the most widespread and abundant non-native species. Isolation and distance from Chicago may influence the number of non-native species, although distribution of most species is highly individualistic. However, non-native woody plant species were not as dominant as we originally believed, representing less than half of the species present at most sites. There were only a handful of sites where non-native species made up the majority of woody plant species. Consequently, removing some of the more dominant species, such as autumn olive, honeysuckle, and multiflora rose, on select shrublands may help increase the diversity and quality. Additionally, some species that may not be dominant now may have the potential to become dominant and a nuisance in the future (Richardson et al. 2000), although our results indicate it would be difficult to predict where.

The effects of non-native woody plant species encroachment on birds is species dependent. We did not find much evidence that non-native woody plant species in general nor specific non-native species autumn olive, multiflora rose, and honeysuckle influenced the bird community, as many bird species were highly transient over the three years of our study. However, we did find specific effects of multiflora rose on Bell’s Vireo and Yellow-breasted Chat. Multiflora rose leafs out earlier than most native species and forms a dense layer of vegetation that may be unacceptable for nest placement by these two Species in Greatest Need of Conservation. Consequently, targeted removal of multiflora rose may help increase the distribution and abundance of these two species of conservation concern. Additionally, increasing the amount of shrubland habitat on the landscape would inevitably help these species and the Field Sparrrow, which we found to be present on nearly all shrublands, indicating that habitat creation would be the only means of increasing its population.

Literature cited

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.

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.

Kery, M., J.A. Royle, and H. Schmid. 2005. Modeling avian abundance from replicated counts using binomial mixture models. Ecological Applications 15:1450-1461.

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.

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.

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.

Introduction

With changing agricultural practices and the alteration of disturbance dynamics, the availability of shrubland habitats have been drastically diminished and many species have undergone precipitous population declines. Shrubland bird species are no exception. Breeding Bird Survey data indicates that in the last 50 years nearly twice as many shrubland bird species have declined compared to the number that have increased in the central United States (Sauer et al. 2008). In Illinois, the downward trend may be even more dramatic. Over the last 100 years, shrubland bird species have declined more precipitously than even grassland species (Walk et al. 2010), while not receiving the same amount of conservation attention. Although it is clear that shrublands bird species are in decline the cause of that decline is less certain.

Invasive plant species encroachment into natural habitat can have wide-ranging detrimental effects (Enserink 1999, Everett 2000). Invasive species may be particularly problematic in successional shrubland habitats (Hobbs and Huenneke 1992), which typically form on fallow lands or following major disturbance and are associated with high species turnover. The structural characteristics of invaded shrublands can vastly differ from shrublands dominated by native species. For birds in particular, invasive species can change the availability of safe nesting, foraging, and loafing areas. Consequently, highly invaded shrublands may not be of the same quality as shrublands dominated by native species, which may decrease shrubland bird abundance and diversity, or impact the physical health of birds utilizing shrublands.

Shrubland habitats are uncommon and understudied in Illinois. Many species associated with this habitat are classified as Species in Greatest Need of Conservation (SGNC). Consequently, the Illinois State Wildlife Action Plan lists the maintenance and enhancement of shrub habitats in multiple Campaigns, and in the descriptions of Conservation Opportunity Areas across the state. However, managing shrublands requires an understanding of what constitutes quality, especially for wildlife species of concern. Although shrublands all share similar structural characteristics, the composition of the shrub community may play a large role in determining quality. Specifically, shrublands dominated by invasive species may be actively avoided, while others may act as ecological traps where species of concern suffer reduced fitness in habitat that appears suitable. Unfortunately, it is not economically or logistically feasible to remove all invasive species from all shrublands in Illinois. Consequently, we need to understand how non-native species affect SGNC and how to best allocate limited resources to effectively control the negative impacts of invasive plant species on SGNC. With this knowledge, the Illinois Department of Natural Resources (IDNR) will be able to prioritize management on sites where invasive species control will be most beneficial and cost effective in the effort to protect SGNC.

In 2016, we began a large-scale research project aimed at providing the IDNR with information to help prioritize management of shrubland habitat across the state of Illinois, work that continues today. Our goals were to quantify the impacts of invasive plant species on the shrubland bird community and determine the relationship between invasive plant species and habitat quality for SGNC. Specifically, we wanted to address three Priority Conservation Actions identified in the Forest and Invasive Species Campaigns described in the State Wildlife Action Plan. 1) Fill information gaps by determining how invasive species encroachment influences the shrubland bird community with special emphasis on three SGNC - the Yellow-breasted Chat (*Icteria virens*), Bell's Vireo (*Vireo bellii*), and Field Sparrow (*Spizella pusilla*). 2) Determine the extent and condition of shrub/successional habitats by documenting invasive species encroachment and identifying site-level characteristics that may influence the footprint of invasive species. 3) Evaluating unacceptable levels of invasive species encroachment and identifying potential thresholds at which their abundance and distribution becomes detrimental to SGNC. We are addressing these Priority Conservation Actions by focusing on three specific objectives.

Project Objectives

Objective 1: Identifying site-level characteristics influencing the establishment and abundance of invasive woody plant species by examining invasive woody plant species composition at shrubland sites throughout the state of Illinois.

Objective 2: Determining the influence of invasive woody plant species abundance has on the shrubland bird community by investigating how invasive woody plant species impact the presence and abundance of shrubland birds at shrubland sites throughout the state of Illinois.

Objective 3: Assessing the impacts of invasive woody plant species abundance on the physiological condition of SGNC.

Literature cited

Enserink, M. 1999. Biological invaders sweep in. Science 285:1834-1836.

Everett, R. A. 2000. Patterns and pathways of biological invasions. Trends in Ecology and Evolution 15:177-178.

Hobbs, R.J., and L.F. Huenneke. 1992. Disturbance, Diversity, and Invasion: Implications for Conservation. Conservation Biology 6:324-337.

Sauer, J. R., J. E. Hines, and J. Fallon. 2008. The North American Breeding Bird Survey, results and analysis 1966-2007. Version 5.15.2008. USGS Patuxent Wildlife Research Center, Laurel, MD.

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.

Objective 1: Identify site-level characteristics influencing the establishment and spread of invasive woody plant species

Task 1.1: Identify shrubland sites in Illinois and characterize the woody vegetation.

Methods

We visited 112 publicly owned shrublands located throughout the state of Illinois between late May and early July 2016, 2017 and 2018 (Figure 1). 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. At each location we surveyed the vegetation, identifying all woody plant species along three strata we believed important to the structure and function of a shrubland. Vegetation surveys consisted of 100-m transects laid out in a random direction from the approximate center of a site. We defined sites as the extent of the entire shrubland patch. The sites we surveyed had to fit a 100 m transect within the shrubland patch, and there were not maximum requirements for size of the site. Five 10 × 10 m plots were located every 20 m along the 100-m transect. We 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. 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).

Results

Most shrublands in Illinois were composed of nine to 10 woody plant species (Figure 2). We identified 100 woody plant species on the 112 sites (Table 1) we visited with 21 of these species considered non-native (Table 1). However, non-native woody plants typically made up less than half of all woody plant species at a site, as calculated using the abundance of non-native woody species in relation to the total number of woody species found at a site (Figure 2). Of the non-native species present, autumn olive (*Elaeagnus umbellate)* was the most widespread non-native species, being found at 67 locations. Multiflora rose (*Rosa multiflora)* and Amur honeysuckle (*Lonicera maackii)* were the next most abundant non-native woody plant species, being found at 59 and 45 locations respectively. No other non-native woody plant species was observed at more than 15 locations, although all shrublands contained non-native woody plants.

Discussion

Non-native woody plants were ubiquitous throughout Illinois. We found at least one non-native woody plant species on all 112 shrubland sites we surveyed. However, while non-native woody plant species were everywhere, they were not as dominant as we originally believed they would be. Most of the sites we visited consisted of more native woody plant species than non-native plant species. There were three non-native woody plant species that were disproportionately present at more sites compared to other species: autumn olive, multiflora rose, and honeysuckle. However, even the most ubiquitous, autumn olive, was only found at approximately half of the sites we visited. Therefore, the influence that non-native woody plant species may be having on the quality of existing shrublands may be more dependent on the specific non-native species and its particular characteristics than on the overall abundance of non-native species without regard to species identity.

Table 1. Woody plant species observed on 112 shrublands throughout Illinois. Non-native species are indicated (**)

Acer ginnala **	*Crataegus punctata*	*Morus alba* **	*Quercus marilandica*	*Rubus strigosus*
Acer negundo	*Diospyros virginiana*	*Morus rubra*	*Quercus michauxii*	*Salix amygdaloides*
Acer rubrum	*Elaeagnus umbellata* **	*Opuntia humifusa*	*Quercus palustris*	*Salix bebbiana*
Acer saccharinum	*Fraxinus americana*	*Ostrya virginiana*	*Quercus rubra*	*Salix discolor*
Acer saccharum	*Fraxinus pennsylvanica var. subintegerrima*	*Pinus strobus* **	*Quercus velutina*	*Salix fragilis* **
Betula nigra	*Gleditsia triacanthos*	*Pinus sylvestris* **	*Rhamnus cathartica* **	*Salix humilis*
Betula populifolia **	*Juglans cinerea*	*Pinus virginiana* **	*Rhamnus frangula* **	*Salix nigra*
Carya cordiformis	*Juglans nigra*	*Platanus occidentalis*	*Rhus aromatica*	*Salix pedicellaris*
Carya glabra	*Juniperus virginiana*	*Populus deltoides*	*Rhus copalina*	*Sambucus sp.*
Carya ovata	*Ligustrum vulgare* **	*Populus heterophylla*	*Rhus glabra*	*Sassafras albidum*
Carya tomentosa	*Liquidambar styraciflua*	*Prunus americana*	*Rhus typhina*	*Spirea alba*
Catalpa speciosa **	*Liriodendron tulipifera*	*Prunus serotina*	*Ribes hirtellum*	*Symphoricarpos orbiculatus*
Celtis occidentalis	*Lonicera japonica* **	*Prunus virginiana*	*Robinia pseudoacacia*	*Tilia americana*
Cephalanthus occidentalis	*Lonicera maackii* **	*Ptelea trifoliata*	*Rosa carolina*	*Ulmus alata*
Cercis canadensis	*Lonicera morrowii* **	*Pyrus calleryana* **	*Rosa multiflora* **	*Ulmus americana*
Cornus drummondii	*Lonicera x bella* **	*Quercus alba*	*Rosa setigera*	*Ulmus rubra*
Cornus racemosa	*Maclura pomifera* **	*Quercus alba*	*Rubus allegheniensis*	*Viburnum lentago*
Cornus sericea	*Malus coronaria*	*Quercus bicolor*	*Rubus flagellaris*	*Viburnum opulus* **
Corylus americana	*Malus ioensis*	*Quercus imbricaria*	*Rubus hispidus*	*Viburnum prunifolium*
Crataegus	*Malus sieboldii* **	*Quercus macrocarpa*	*Rubus occidentalis*	*Zanthoxylum americanum*

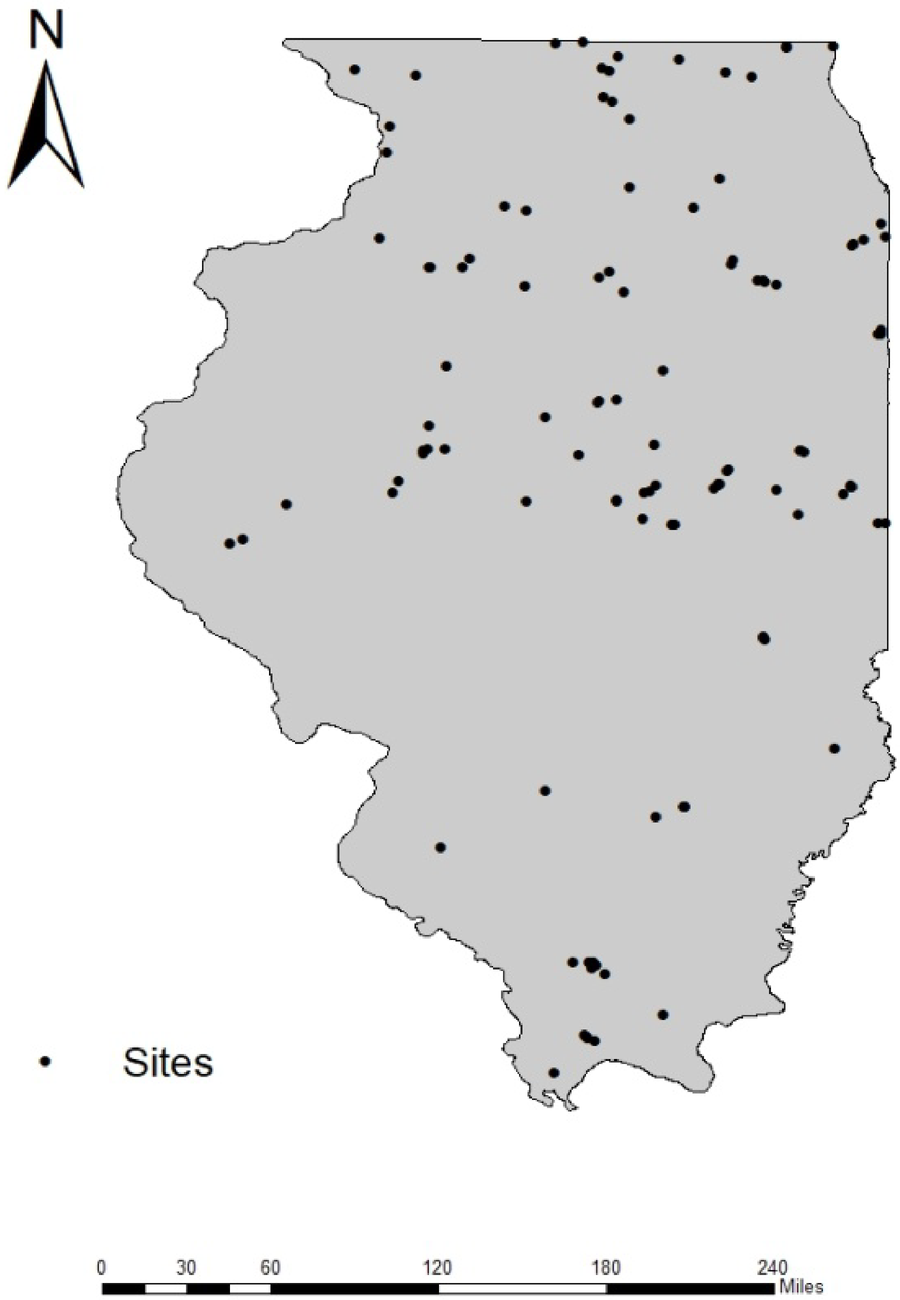

Figure 1. Location of 112 publically owned shrublands surveyed from 2016-2018.

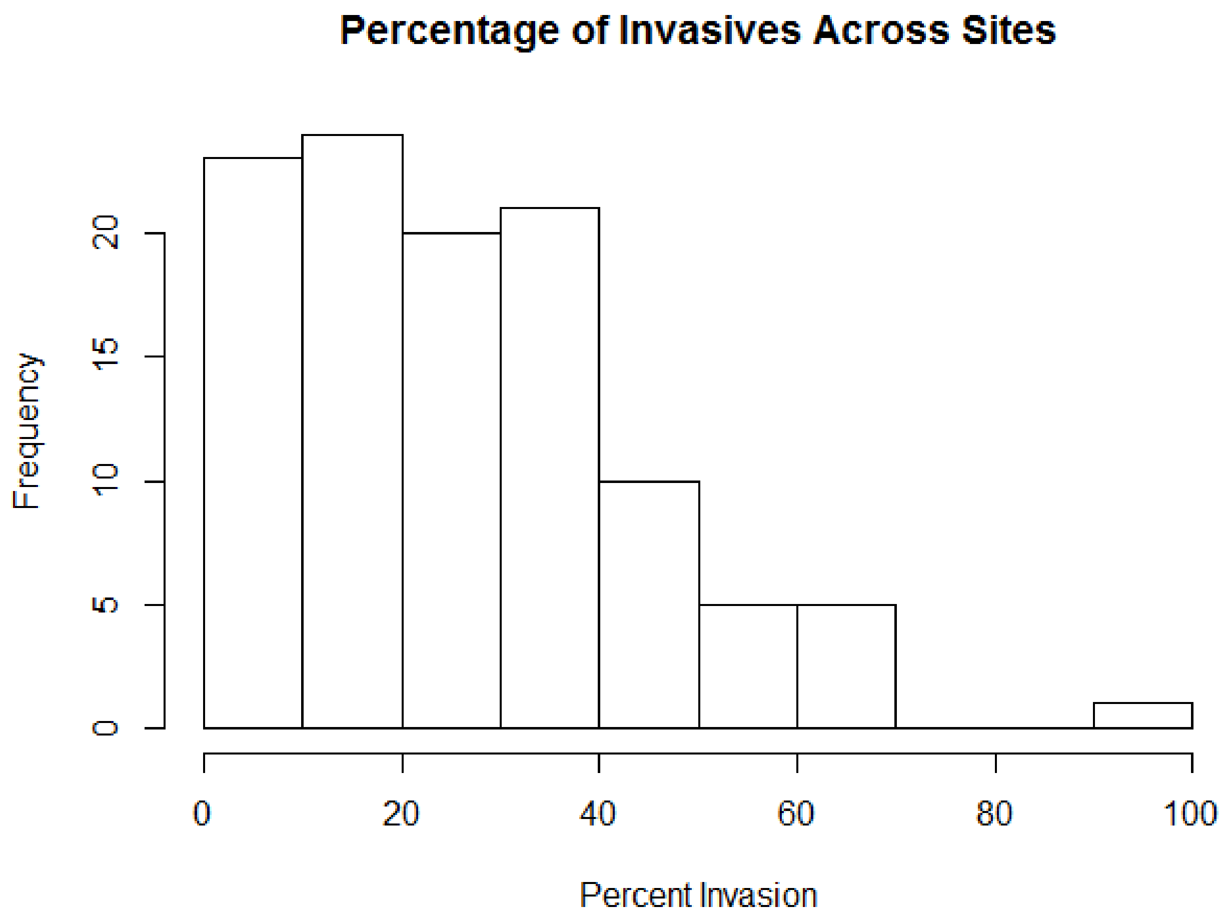

Figure 2. Frequency of the number of shrublands sites surveyed with varying degrees of invasive species presence

Task 1.2: Predict woody-species invasion into shrubland habitats.

Methods

We identified site- and landscape-level predictors that may be influencing the presence of four of the most abundant non-native woody plant species: autumn olive, multiflora rose, honeysuckle, and buckthorn, and non-native species richness. Specifically, we investigated the effects of geographic location within the state, the influence of surrounding agricultural land within 1km, population density within 25 km, and the estimated size of the shrubland. We georeferenced all shrublands we visited, recording Latitude and Longitude. We overlaid site locations onto the National Agricultural Statistics Service's Cropland Data Layer (CDL 2015) raster file (USDA NASS 2015) in ArcGIS 10.5.1, and used the Geospatial Modeling Environment (Beyer 2012) to determine the proportion of the surrounding landscape devoted to row-crop agriculture. We focused on surrounding agriculture because it is the dominant landscape feature in Illinois and correlated with other land-cover types. We calculated population density within a 25km buffer of each site, by calculating estimated population of 100 x 100m grids and average, while excluding cells with no data (surrounding states or large bodies of water). Finally, the extent of each shrubland was determined using ArcGIS 10.5.1 and visual inspection of aerial photographs.

Statistical analyses. – We used the data collected from each of the five 10m x 10m replicate vegetation surveys to determine how site- and landscape-level factors influenced the presence of the four most abundant non-native woody plants and non-native woody plant species richness. For the four individual non-native woody plant species we investigated the probability a site was occupied while incorporating imperfect detection using occupancy models (MacKenzie et al. 2002). Specifically, occupancy was modelled as a function of Latitude (LAT), Longitude (LON), surrounding crops (CROP), population density (POP), and patch size

(PATCH) on the logit scale with detection as a binomial process. Each individual 10m x 10m survey location was treated as a replicate of the entire shrubland, which allowed us to control for imperfect detection due to random placement of a survey location within a shrubland. We also modelled the abundance of non-native woody plant species using the N-mixture abundance model of Kery et al. (2005). We calculated total number of non-native woody plant species found at each of the five 10m x 10m replicate vegetation surveys and used these data to calculate estimated species richness. Specifically, non-native woody plant species richness was assumed to be distributed according to the Poisson distribution, and non-native woody plant species richness was modelled as a function of Latitude (LAT), Longitude (LON), surrounding crops (CROP), population density (POP), and patch size (PATCH) on the log scale with detection as a binomial process. Inferences were made under a Bayesian framework. We used vague priors for the effects of LAT, LON, CROP, POP, and PATCH for occupancy models (Normal distribution: mean=0, precision=0.2), and N-mixture abundance model (Normal distribution: mean=0, precision=0.001). Vague priors for the detection portion of each model were considered to be uniformly distributed (range 0-1). We ran 3 chains of 80,000 iterations with a 25,000 iteration burn-in period. We made inferences about the effects of our predictor variables using 95% confidence intervals (Gerard et al. 1998). The model was performed using JAGS 3.4 (Plummer 2003) and run via the package R2jags in R (R Core Team 2018).

Results

Autumn olive– We estimated that autumn olive was present on 60% of the 112 shrublands we surveyed. It was most prevalent in the middle of the state (Figure 1), but was found in all regions. The presence of autumn olive was heavily influenced by the amount of surrounding cropland. As the percent of cropland increased within the 1 km buffer surrounding a shrubland, autumn olive was nearly 13 times less likely to be present (Table 1). None of the other predictor variables appeared to influence the presence of autumn olive (Table 1).

Multiflora rose– We estimated that multiflora rose was present at 57% of the 112 shrubland sites we visited, which was slightly more than our naïve estimate of 59 sites being occupied. Multiflora rose presence was strongly influenced by surrounding population size, where on average the probability a site was occupied by multiflora rose increased 2.6 times for an increase in every 100 people (Table 1). None of the other predictor variables appeared to influence the presence of multiflora rose (Table 1). Mutliflora rose was most common on the eastern side of the state, but it was found throughout (Figure 2).

Honeysuckle– We estimated that honeysuckle was present at 43% of the 112 shrubland sites we visited. Patch size and surrounding population density may have influenced the probability of occupancy for honeysuckle, where the probability of its presence decreased with increasing site size and surrounding population density (Table 1). However, the estimates were not precise (Table 1). None of the other predictor variables appeared to influence the presence of honeysuckle (Table 1). Honeysuckle was present throughout the state, with localized areas where it occupied slightly more shrublands (Figure 3).

Buckthorn– We estimated that buckthorn was present at 13% of the 112 shrubland sites we visited and most of those were in the greater Chicago area (Figure 4). Population density may have been influencing its presence (Table 1), however, there was much uncertainty (Table 1). None of the other predictor variables appeared to influence the presence of buckthorn (Table 1).

Non-native species richness– We estimated that on average shrubland sites in Illinois contained 2.8 non-native woody plant species. The amount of surrounding land devoted to agriculture (CROP) negatively influenced the number of non-native woody plant species found on a shrubland. Larger shrublands may have contained slightly fewer non-native species (Table 2), although there was much uncertainty around the estimate (Table 2). None of the other predictors of non-native woody plant species exhibited much of a relationship (Table 2). Finally, there were more non-native woody plant species in the greater Chicago area in comparison to the rest of the state (Figure 5).

Discussion

The greater Chicago area appears to be a hotspot for non-native woody plant species. Total species richness was much greater in the northeast part of the state compared to other areas, which was similar to what Matthews et al. (2009) found in wetlands. European buckthorn is partially responsible for this geographic pattern in non-native woody plant species, with it being present at all shrublands we surveyed in the northeast part of the state. Non-native woody plant species were observed throughout the state however, and their presence may be influenced by the surrounding landscape. Non-native species richness declined dramatically with increasing proportion of agricultural crops surrounding a shrubland. Shrublands that are surrounded by crops may be functionally isolated from source pools of non-native woody plant species (Brockerhoff et al. 2014).

Non-native woody plant species were ubiquitous on shrublands throughout the state of Illinois. Shrublands are ephemeral early successional areas that may be prone to invasion by non-native species. Non-native species, especially when invasive, may be particularly adept at utilizing these early successional areas (e,g,, Seabloom et al. 2003). Therefore, we had difficulty predicting characteristics associated with non-native woody plant species presence, because these species seemed to be replaceable. Non-native woody plant species were also not as dominant as we originally believed and typically constituted less than half the total number of woody plant species. Furthermore, only a few species were abundant, with autumn olive being the most wide-spread. Consequently, non-native woody plant species may not be having as great of an impact on the quality of shrubland sites in Illinois as we originally suspected. However, removing some of the more dominant species, such as autumn olive, honeysuckle, and multiflora rose may help create space for native species. Additionally, some species that may not be dominant now may have the potential to become dominant and a nuisance in the future (Richardson et al. 2000), although our results indicate it would be difficult to predict where.

Literature cited

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

Brockerhoff, E.G., M. Kimberley, A.M. Liebhold, R.A. Haack, and J.F. Cavey. 2014. Predicting how altering propagule pressure changes establishment rates of biological invaders across species pools. Ecology 95:594-601.

Gerard, P.D., D.R. Smith, and G. Weerakkody. 1998. Limits of retrospective power analysis. Journal of Wildlife Management. 62:801-807.

Kery, M., J.A. Royle, and H. Schmid. 2005. Modeling avian abundance from replicated counts using binomial mixture models. Ecological Applications 15:1450-1461.

MacKenzie, D.I., J.D.Nichols, G.B. Lachman, S. Droege, J.A. Royle, and C.A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83: 2248-2255.

Martyn Plummer. 2003. JAGS: A Program for Analysis of Bayesian Graphical Models Using Gibbs Sampling, Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003), March 20–22, Vienna, Austria.

Matthews, J.W, A.L. Peralta, A. Soni, P. Baldwin, A.D. Kent, and A.G. Endress. 2009. Local and landscape correlates of non-native species invasion in restored wetlands. Ecography:1031-1039.

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/.

Richnardson, D.M., P. Pysek, M. Rejmanek, M.G. Barbour, F.D. Panetta, and C.J. West. 2000. Naturalization and invasion of alien plants: concepts and definitions. Diversity and Distributions 6:93-107.

Seabloom, E.W., W.S. Harpole, O.J. Reichman, and D. Tilman. 2003. Invasion, competitive dominance, and resource use by exotic and native California grassland species. Proceedings of the National Academy of Sciences. 100:13384-13389.

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.

Table 1. Model coefficient estimates and 2.5% and 97.5% Bayesian Credible Intervals for occupancy models relating autumn olive, multiflora rose, honeysuckle, and buckthorn to Latitude (Lat), Longitude (Lon), agriculture land with 1 km (Crop), population density withn 25 km (Pop), and size of shrubland (Patch) utilizing a logit link. Detection was a binomial process. Data came from 112 shrubland sites throughout Illinois.

		Credible Interval	
Autumn olive	Average	2.5%	97.5
Occupancy intercept	0.170	-4.186	4.529
Lat	-0.038	-0.198	0.116
Lon	-0.074	-0.412	0.252
Crop	-2.558	-4.631	-0.569
Pop	-0.135	-0.626	0.388
Patch	-0.383	-1.292	0.379
Detection	0.617	0.563	0.670
Multiflora rose			
Occupancy intercept	0.470	-3.905	4.822
Lat	-0.111	-0.296	0.059
Lon	-0.260	-0.659	0.105
Crop	-0.753	-2.916	1.417
Pop	1.021	0.005	2.352
Patch	-0.548	-1.571	0.348
Detection	0.431	0.368	0.495
Honeysuckle			
Occupancy intercept	-0.068	-4.394	4.267
Lat	0.084	-0.072	0.245
Lon	0.184	-0.147	0.524
Crop	-0.874	-2.949	1.169
Pop	-0.469	-1.121	0.090
Patch	-1.163	-2.933	0.067
Detection	0.439	0.366	0.511
Buckthorn			
Occupancy intercept	-0.035	-4.404	4.328
Lat	1.319	0.512	2.302
Lon	2.748	1.021	4.835
Crop	-0.092	-3.735	3.521
Pop	0.982	-0.317	3.183
Patch	-1.400	-3.748	0.830
Detection	0.406	0.268	0.560

Table 2. Model coefficient estimates and 2.5% and 97.5% Bayesian Credible Intervals for N-mixture Poisson abundance model relating species richness to Latitude (Lat), Longitude (Lon), agriculture land with 1 km (Crop), population density withn 25 km (Pop), and size of shrubland (Patch) utilizing a log link. Detection was a binomial process. Data came from 112 shrubland sites throughout Illinois.

	Mean	2.50%	97.50%
Abundance intercept	8.164	-6.881	23.416
Lat	0.123	-0.046	0.295
Lon	0.092	-0.006	0.192
Crop	-1.005	-1.762	-0.283
Pop	0.031	-0.095	0.15
Patch	-0.143	-0.387	0.058
Detection	0.451	0.393	0.505

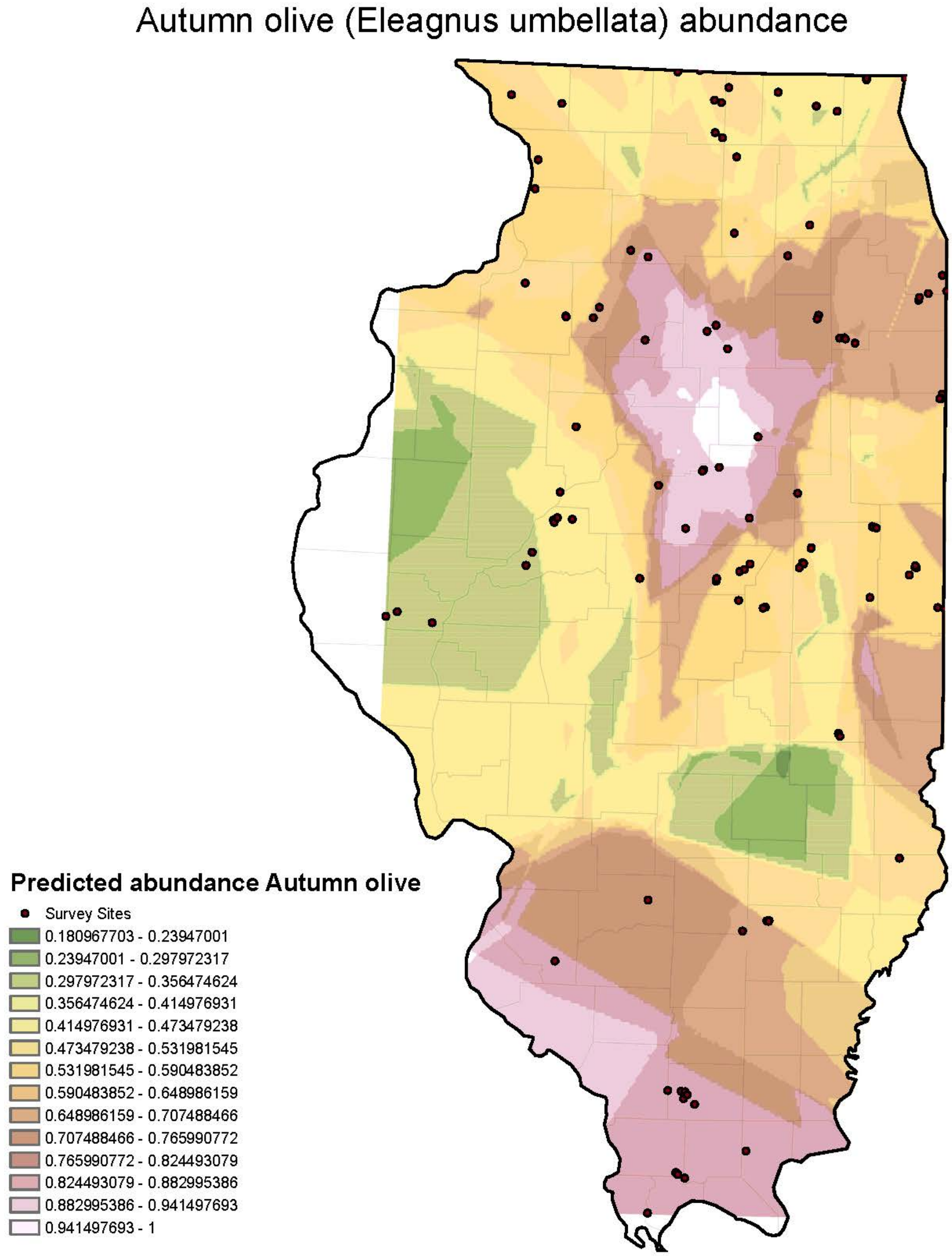

Figure 1. Estimated distribution of autumn olive throughout the state of Illinois. The map was generated using occupancy estimation data from 112 shrubland sites throughout Illinois with interpolated presence/absence between shrublands.

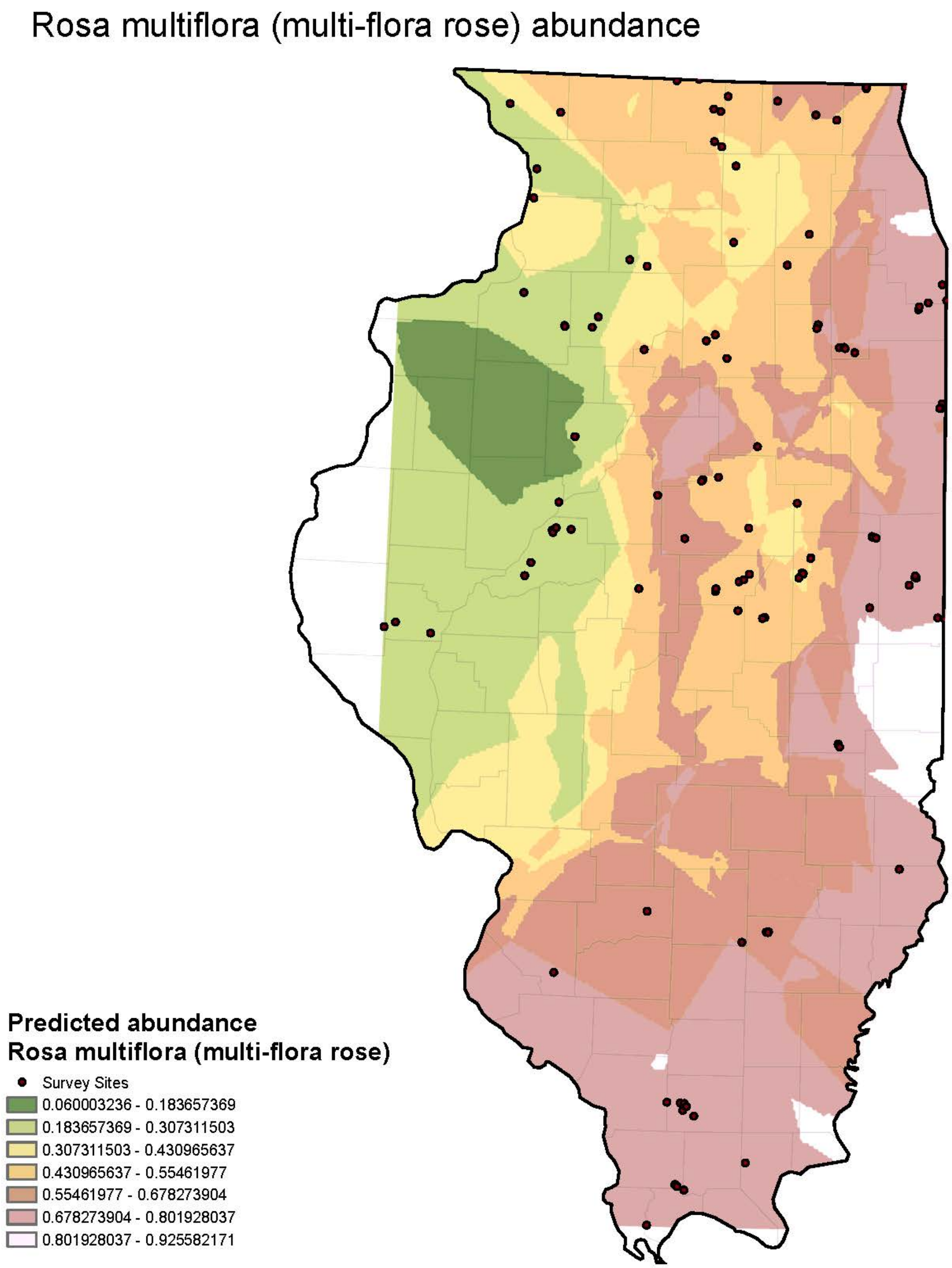

Figure 2. Estimated distribution of multiflora rose throughout the state of Illinois. The map was generated using occupancy estimation data from 112 shrubland sites throughout Illinois with interpolated presence/absence between shrublands.

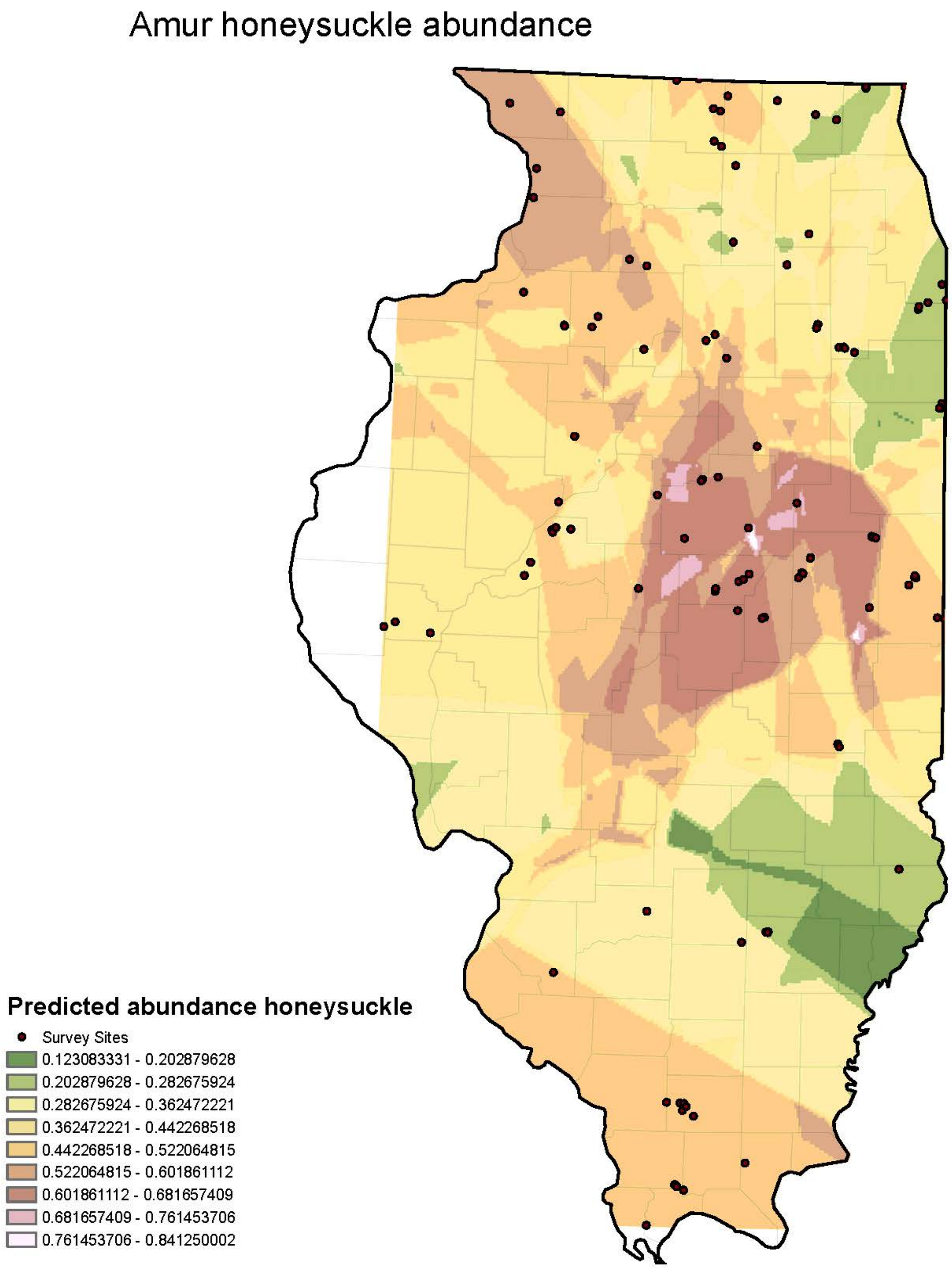

Figure 3. Estimated distribution of honeysuckle throughout the state of Illinois. The map was generated using occupancy estimation data from 112 shrubland sites throughout Illinois with interpolated presence/absence between shrublands.

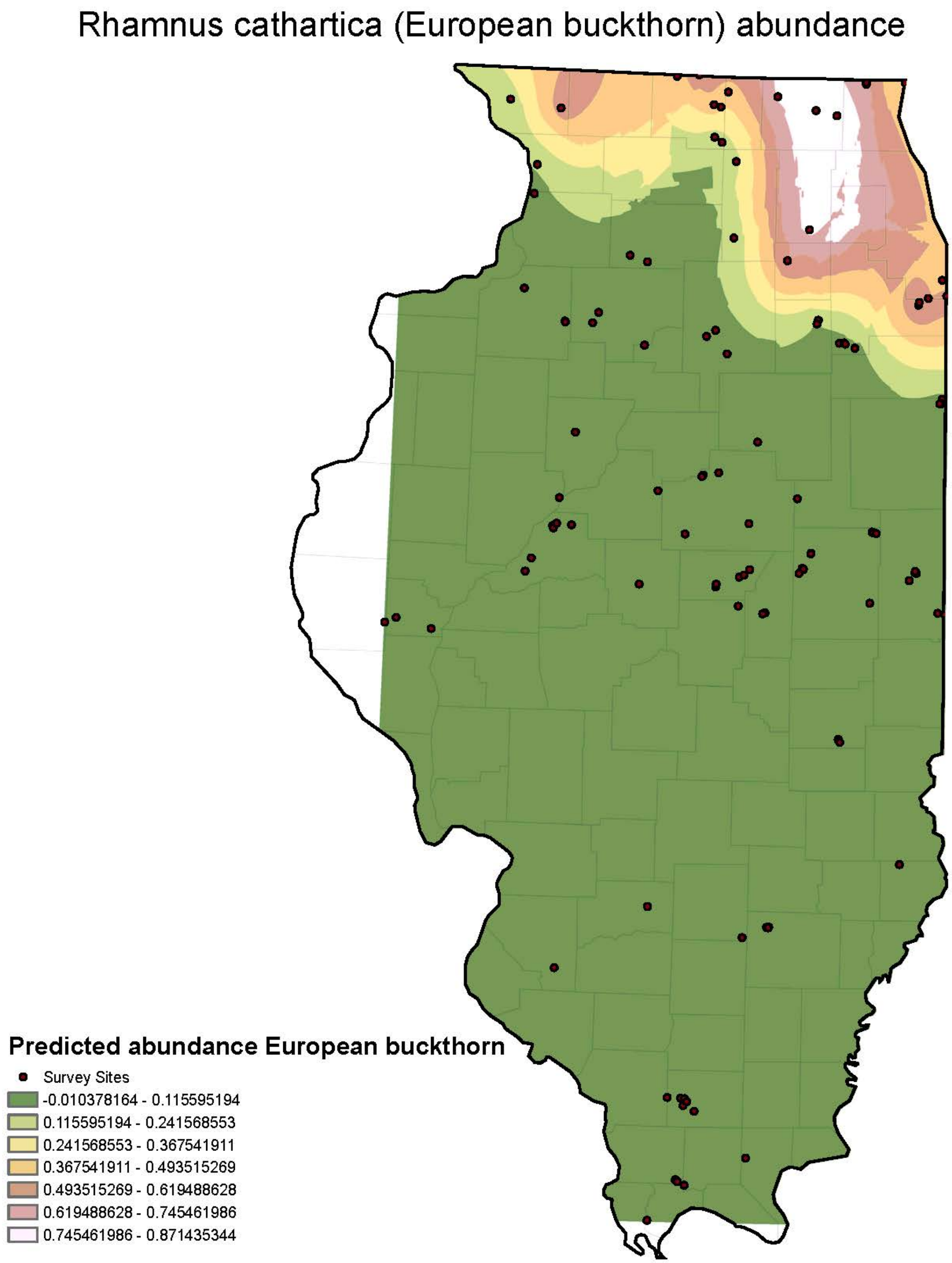

Figure 4. Estimated distribution of European buckthorn throughout the state of Illinois. The map was generated using occupancy estimation data from 112 shrubland sites throughout Illinois with interpolated presence/absence between shrublands.

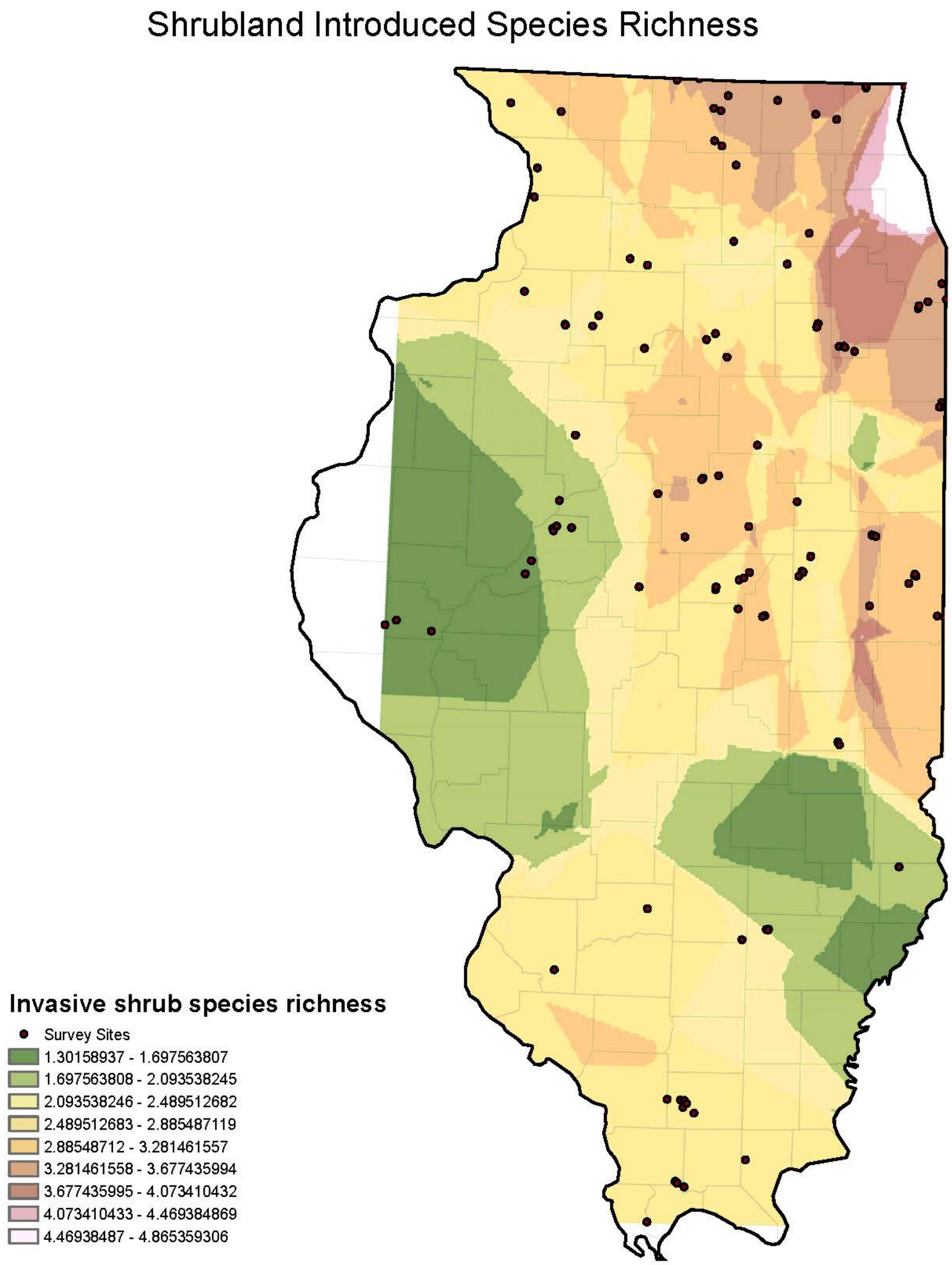

Figure 5. Estimated species richness of non-native woody plant species throughout the state of Illinois. The map was generated using an N-mixture abundance model where richness was assumed to be Poisson distributed. Data was gathered from 112 shrubland sites throughout Illinois with interpolated species richness between shrublands.

Objective 2: **Determine the influence invasive woody plant species encroachment has on the shrubland bird community**

Task 2.1: Identify how the avian community changes in relation to invasive species encroachment

Methods

We conducted point count and targeted callback surveys at all 112 shrubland sites we visited from 2016-2019. We visited 109 sites in 2016, 86 sites in 2017, and 109 in 2018. Most sites were visited in multiple years and we attempted to revisit sites within a year as well. At each site we conducted two 10-min point count surveys. Point counts were located 50 m away from the approximate center of each shrubland and 100 m away from each other. Each point count was treated as a replicate survey of the center of a shrubland. A minimum of 5 minutes elapsed between each point count. We recorded all species seen or heard within a 100-m radius.

Statistical analysis. – We investigated the influence of non-native woody plant species on bird species richness using a hierarchical n-mixture abundance model (Kery et al. 2005), which allowed us to account for imperfect detection. We calculated observed species richness for each visit at each site and used these data to estimate species richness and the potential effects of non-native woody plant species. Specifically, we developed a hierarchical Bayes' model where assumed species richness among sites followed a Poisson distribution and richness at a site was related to the abundance of autumn olive, multiflora rose, and honeysuckle, while controlling patch size and the surrounding landscape (proportion of agricultural land within 1 km). Detection was a binomial process and we controlled for the effect of year. We ran 3 chains of 80,000 iterations with a 25,000 iteration burn-in period. We used vague priors for the effects of autumn olive, multiflora rose, honeysuckle, patch size, surrounding crops (Normal distribution: mean=0, precision=0.001), and detection (Uniform distribution: range 0-1). We made inferences about the effects of our predictor variables using 95% confidence intervals (Gerard et al. 1998). The model was performed using JAGS 3.4 (Plummer 2003) and run via the package R2jags in R (R Core Team 2018).

Results

We detected 115 different species at shrublands throughout the state of Illinois, with 93 species being directly observed within 100 m of the center of a shrubland (Table 1). Twenty-four of the species we observed are considered Species in Greatest Need of Conservation in Illinois (Table 1). While a few of these species [Great Egret (*Ardea alba*), Bald Eagle (*Haliateetus leucocephelus*), Red-shouldered Hawk (*Buteo lineatus*), Broad-winged Hawk (*Buteo platypterus*), Peregrine Falcon (*Falco peregrinus*), and Chimney Swift (C*haetura pelagica*)] were flying over the sites and a handful more were using the surrounding habitat [Acadian Flycatcher (*Empidonax virescens*), Wood Thrush (*Hylocichla mustelina*), and Ovenbird (*Seiurus aurocapillus*)], 15 Species in Greatest Need of Conservation were observed inside the boundaries of the shrubland.

Ninety-three species were directly observed within 100m of the approximate center of the shrubland sites we visited. The average number of species we observed within 100m of the center of a shrubland was 14.4, with a minimum number detected of 8 and a maximum of 24. Many species were only observed sporadically at our sites. Consequently, detection of species richness tended to be fairly low (~0.5), with greatest detection in 2018 (average 0.51) and lowest in 2017 (average 0.44). As a result, we estimated an average of 30 species would be present or utilizing a shrubland in Illinois over a three year period. There was very little evidence that autumn olive, multiflora rose, or honeysuckle influenced species richness (Table 2).

Surrounding agricultural land and shrubland patch size did not influence species richness (Table 2).

Discussion

Shrublands in Illinois provided critical habitat to numerous species of conservation concern. We observed 24 species listed as in Greatest Need of Conservation during our visits in the breeding season between 2016 and 2018. While some of these species were clearly flying over a site or were more likely to be present in a surrounding forest, we still directly observed 15 Species in Greatest Need of Conservation within the shrubland boundaries. We also derived relatively high estimates of species richness in shrublands throughout Illinois. Because shrublands are unique habitat that represents a transition between prairie and forest, many bird species representing two distinct habitat guilds can be found, which may have led to large species richness estimates. However, many of the species may only be utilizing shrublands during part of their day and may not be wholly reliant on shrublands for breeding habitat. Consequently, we believe our estimates of species richness are somewhat inflated because of the low detection probability associated with species moving in and out of a site. The transient nature of shrubland birds needs to be taken into account when estimating richness in the future.

Contrary to what we originally believed, it does not appear that non-native species were influencing avian species richness on shrublands in Illinois. We found little evidence that either of the three most abundant non-native woody plant species, nor the prevalence of native woody shrubs, influenced avian species richness. From an avian community perspective, non-native woody shrubs provided habitat that was clearly being used by many species. Consequently, it may be that non-native woody plant species had negative effects on some individual bird species, but that at the community level these effects were mitigated by other bird species that may be more tolerant or actually prefer the structure and characteristics of the non-native species. We do not believe management needs to be focused on non-native woody plant species in shrublands if the goal is to increase avian species richness. However, non-native woody plant species may be having an effect on individual species and species of conservation concern, which we investigate in *task 2.2*.

Literature cited

Gerard, P.D., D.R. Smith, and G. Weerakkody. 1998. Limits of retrospective power analysis. Journal of Wildlife Management. 62:801-807.

Kery, M., J.A. Royle, and H. Schmid. 2005. Modeling avian abundance from replicated counts using binomial mixture models. Ecological Applications 15:1450-1461.

Martyn Plummer. 2003. JAGS: A Program for Analysis of Bayesian Graphical Models Using Gibbs Sampling, Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003), March 20–22, Vienna, Austria.

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/.

Table 1. List of species observed within 100 m of the center of a shrubland at 112 locations throughout Illinois during the breeding seasons (May-July) 2016-2018. Common name, scientific name, Order, and Family are included, along with their status as a Species in Greatest Need of Conservation, inclusion on the Partner's in Flight Watch List, and IUCN Redlist Status (LC= Least Concern, NT= Near Threatened).

Common Name	Scientific Name	Order	Family	Illinois SGNC	PIF	IUCN
Northern Bobwhite §, NT	Colinus virginianus	Galliformes	Odontophoridae	Yes		Near Threatened
Wild Turkey	Meleagris gallopavo	Galliformes	Phasianidae			Least Concern
Cooper's Hawk	Accipiter cooperii	Accipitriformes	Accipitridae			Least Concern
Red-tailed Hawk	Buteo jamaicensis	Accipitriformes	Accipitridae			Least Concern
Sandhill Crane §	Grus canadensis	Gruiformes	Gruidae	Yes		Least Concern
Killdeer	Charadrius vociferus	Charadriiformes	Charadriidae			Least Concern
Mourning Dove	Zenaida macroura	Columbiformes	Columbidae			Least Concern
Yellow-billed Cuckoo §	Coccyzus americanus	Cuculiformes	Cuculidae	Yes		Least Concern
Black-billed Cuckoo §, WL	Coccyzus erythropthalmus	Cuculiformes	Cuculidae	Yes	Yes	Least Concern
Barred Owl	Strix varia	Strigiformes	Strigidae			Least Concern
Common Nighthawk §	Chordeiles minor	Caprimulgiformes	Caprimulgidae	Yes		Least Concern
Chimney Swift §, NT	Chaetura pelagica	Apodiformes	Apodidae	Yes		Near Threatened

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Common Name	Scientific Name	Order	Family	Illinois SGNC	PIF	IUCN
Ruby-throated Hummingbird	Archilochus colubris	Apodiformes	Trochilidae			Least Concern
Belted Kingfisher	Megaceryle alcyon	Coraciiformes	Alcedinidae			Least Concern
Red-headed Woodpecker §, WL, NT	Melanerpes erythrocephalus	Piciformes	Picidae	Yes	Yes	Near Threatened
Red-bellied Woodpecker	Melanerpes carolinus	Piciformes	Picidae			Least Concern
Downy Woodpecker	Picoides pubescens	Piciformes	Picidae			Least Concern
Hairy Woodpecker	Picoides villosus	Piciformes	Picidae			Least Concern
Northern Flicker §	Colaptes auratus	Piciformes	Picidae	Yes		Least Concern
Pileated Woodpecker	Dryocopus pileatus	Piciformes	Picidae			Least Concern
American Kestrel	Falco sparverius	Falconiformes	Falconidae			Least Concern
Eastern Wood-Pewee	Contopus virens	Passeriformes	Tyrannidae			Least Concern
Acadian Flycatcher §	Empidonax virescens	Passeriformes	Tyrannidae	Yes		Least Concern
Alder Flycatcher	Empidonax alnorum	Passeriformes	Tyrannidae			Least Concern
Willow Flycatcher §	Empidonax traillii	Passeriformes	Tyrannidae	Yes		Least Concern

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Common Name	Scientific Name	Order	Family	Illinois SGNC	PIF	IUCN
Eastern Phoebe	Sayornis phoebe	Passeriformes	Tyrannidae			Least Concern
Great Crested Flycatcher	Myiarchus crinitus	Passeriformes	Tyrannidae			Least Concern
Eastern Kingbird	Tyrannus tyrannus	Passeriformes	Tyrannidae			Least Concern
White-eyed Vireo	Vireo griseus	Passeriformes	Vireonidae			Least Concern
Bell's Vireo §, NT	Vireo bellii	Passeriformes	Vireonidae	Yes		Near Threatened
Yellow-throated Vireo	Vireo flavifrons	Passeriformes	Vireonidae			Least Concern
Warbling Vireo	Vireo gilvus	Passeriformes	Vireonidae			Least Concern
Red-eyed Vireo	Vireo olivaceus	Passeriformes	Vireonidae			Least Concern
Blue Jay	Cyanocitta cristata	Passeriformes	Corvidae			Least Concern
American Crow	Corvus brachyrhynchos	Passeriformes	Corvidae			Least Concern
Purple Martin	Progne subis	Passeriformes	Hirundinidae			Least Concern
Tree Swallow	Tachycineta bicolor	Passeriformes	Hirundinidae			Least Concern

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Common Name	Scientific Name	Order	Family	Illinois SGNC	PIF	IUCN
Northern Rough-winged Swallow	Stelgidopteryx serripennis	Passeriformes	Hirundinidae			Least Concern
Bank Swallow	Riparia riparia	Passeriformes	Hirundinidae			Least Concern
Cliff Swallow	Petrochelidon pyrrhonota	Passeriformes	Hirundinidae			Least Concern
Barn Swallow	Hirundo rustica	Passeriformes	Hirundinidae			Least Concern
Carolina Chickadee	Poecile carolinensis	Passeriformes	Paridae			Least Concern
Black-capped Chickadee	Poecile atricapillus	Passeriformes	Paridae			Least Concern
Tufted Titmouse	Baeolophus bicolor	Passeriformes	Paridae			Least Concern
White-breasted Nuthatch	Sitta carolinensis	Passeriformes	Sittidae			Least Concern
House Wren	Troglodytes aedon	Passeriformes	Troglodytidae			Least Concern
Sedge Wren §	Cistothorus platensis	Passeriformes	Troglodytidae	Yes		Least Concern
Carolina Wren	Thryothorus ludovicianus	Passeriformes	Troglodytidae			Least Concern
Blue-gray Gnatcatcher	Polioptila caerulea	Passeriformes	Polioptilidae			Least Concern
Eastern Bluebird	Sialia sialis	Passeriformes	Turdidae			Least Concern

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Common Name	Scientific Name	Order	Family	Illinois SGNC	PIF	IUCN
Wood Thrush §, WL, NT	Hylocichla mustelina	Passeriformes	Turdidae	Yes	Yes	Near Threatened
American Robin	Turdus migratorius	Passeriformes	Turdidae			Least Concern
Gray Catbird	Dumetella carolinensis	Passeriformes	Mimidae			Least Concern
Brown Thrasher §	Toxostoma rufum	Passeriformes	Mimidae	Yes		Least Concern
Northern Mockingbird	Mimus polyglottos	Passeriformes	Mimidae			Least Concern
European Starling	Sturnus vulgaris	Passeriformes	Sturnidae			Least Concern
Cedar Waxwing	Bombycilla cedrorum	Passeriformes	Bombycillidae			Least Concern
Ovenbird §	Seiurus aurocapillus	Passeriformes	Parulidae	Yes		Least Concern
Worm-eating Warbler §	Helmitheros vermivorum	Passeriformes	Parulidae	Yes		Least Concern
Blue-winged Warbler §	Vermivora cyanoptera	Passeriformes	Parulidae	Yes		Least Concern
Common Yellowthroat	Geothlypis trichas	Passeriformes	Parulidae			Least Concern
American Redstart	Setophaga ruticilla	Passeriformes	Parulidae			Least Concern
Northern Parula	Parula americana	Passeriformes	Parulidae			Least Concern

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Common Name	Scientific Name	Order	Family	Illinois SGNC	PIF	IUCN
Yellow Warbler	Setophaga petechia	Passeriformes	Parulidae			Least Concern
Prairie Warbler §, WL	Setophaga discolor	Passeriformes	Parulidae	Yes	Yes	Least Concern
Wilson's Warbler	Cardellina pusilla	Passeriformes	Parulidae			Least Concern
Yellow-breasted Chat §	Icteria virens	Passeriformes	Parulidae	Yes		Least Concern
Eastern Towhee	Pipilo erythrophthalmus	Passeriformes	Emberizidae			Least Concern
Chipping Sparrow	Spizella passerina	Passeriformes	Emberizidae			Least Concern
Field Sparrow §	Spizella pusilla	Passeriformes	Emberizidae	Yes		Least Concern
Vesper Sparrow	Pooecetes gramineus	Passeriformes	Emberizidae			Least Concern
Lark Sparrow	Chondestes grammacus	Passeriformes	Emberizidae			Least Concern
Grasshopper Sparrow §	Ammodramus savannarum	Passeriformes	Emberizidae	Yes		Least Concern
Henslow's Sparrow §, WL, NT	Ammodramus henslowii	Passeriformes	Emberizidae	Yes	Yes	Near Threatened
Song Sparrow	Melospiza melodia	Passeriformes	Emberizidae			Least Concern
Swamp Sparrow	Melospiza georgiana	Passeriformes	Emberizidae			Least Concern

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Common Name	Scientific Name	Order	Family	Illinois SGNC	PIF	IUCN
Scarlet Tanager	Piranga olivacea	Passeriformes	Cardinalidae			Least Concern
Northern Cardinal	Cardinalis cardinalis	Passeriformes	Cardinalidae			Least Concern
Rose-breasted Grosbeak	Pheucticus ludovicianus	Passeriformes	Cardinalidae			Least Concern
Blue Grosbeak	Passerina caerulea	Passeriformes	Cardinalidae			Least Concern
Indigo Bunting	Passerina cyanea	Passeriformes	Cardinalidae			Least Concern
Dickcissel §	Spiza americana	Passeriformes	Cardinalidae	Yes		Least Concern
Bobolink §, WL	Dolichonyx oryzivorus	Passeriformes	Icteridae	Yes	Yes	Least Concern
Red-winged Blackbird	Agelaius phoeniceus	Passeriformes	Icteridae			Least Concern
Eastern Meadowlark	Sturnella magna	Passeriformes	Icteridae			Least Concern
Rusty Blackbird §, V	Euphagus carolinus	Passeriformes	Icteridae	Yes		Vulnerable
Common Grackle	Quiscalus quiscula	Passeriformes	Icteridae			Least Concern
Brown-headed Cowbird	Molothrus ater	Passeriformes	Icteridae			Least Concern
Orchard Oriole	Icterus spurius	Passeriformes	Icteridae			Least Concern

Table 1. List of species observed within 100 m of the center of a shrubland at 112 locations throughout Illinois during the breeding seasons (May-July) 2016-2018. Common name, scientific name, Order, and Family are included, along with their status as a Species in Greatest Need of Conservation, inclusion on the Partner's in Flight Watch List, and IUCN Redlist Status (LC= Least Concern, NT= Near Threatened).

Common Name	Scientific Name	Order	Family	Illinois SGNC	PIF	IUCN
Baltimore Oriole	Icterus galbula	Passeriformes	Icteridae			Least Concern
House Finch	Carpodacus mexicanus	Passeriformes	Fringillidae			Least Concern
American Goldfinch	Spinus tristis	Passeriformes	Fringillidae			Least Concern
House Sparrow	Passer domesticus	Passeriformes	Passeridae			Least Concern

Table 2. Average coefficients and 95% Credible Intervals for a hierarchical n-mix Bayesian model investigating the effects of autumn olive, honeysuckle, multiflora rose, percent native species (native), agricultural land within 1 km, and shrubland patch size on bird species richness on 112 shrubland sites throughout Illinois. The coefficients for detection, which included intercept, year 2016, year 2017, and year 2018, are also included.

Coefficient	Mean	2.5%	97.5%
Richness intercept	3.483	3.278	3.9
Autumn olive	0.008	-0.11	0.118
Agriculture	0.15	-0.034	0.332
Honeysuckle	0.01	-0.107	0.12
Native	-0.009	-0.119	0.109
Multiflora rose	0.008	-0.112	0.12
Patch size	-0.004	-0.065	0.054
Detection intercept	-0.178	-2.412	2.049
Year 2016	-0.104	-2.311	2.104
Year 2017	-0.174	-2.378	2.033
Year 2018	0.116	-2.091	2.326

Task 2.2: Identify how Yellow-Breasted Chat, Bell's Vireo, and Field Sparrow are influenced by the presence of invasive woody species

We brought on Kaity Ripple as a graduate student of Natural Resources and Environmental Sciences, University of Illinois, in 2016 to help us collect field data and address some of the objectives associated with the project. Her graduate research project focused on two of the objectives we had pertaining to this project. Kaity successfully defended her master's thesis in the spring of 2019 and her second chapter directly addresses Task 2.2. The manuscript has been included below. The target journal for this chapter is Condor.

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.

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 main 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 crops, and urban areas, and 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). In the Midwest, conversion to row crop agriculture is one of the main sources of habitat loss and fragmentation (Illinois Department of Natural Resources 2005). 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) 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 potential 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 reproduction (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 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.

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 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 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 not 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. 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).

RESULTS

Landscape – While there are a variety of landcover types in Illinois (e.g. forest, development, and wetlands), the shrublands that I sampled were predominantly surrounded by row-crop agriculture. On average the surrounding landscape was 26% row-crop agriculture (range: 0-81%) and 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. 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 1, Table 2, Figure 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, Figure 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) 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 detection probability was much greater when using callback surveys compared to passive point counts. Percentage of multiflora rose best predicted the occupancy dynamics for Yellow-breasted Chat (Table 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, Figure 5). Percent native woody plant species was the next best fitting model (Table 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).

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 greatest detection probability when using callback surveys.

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). Percent honeysuckle and percent non-native woody plant species were the next best predictors (Table 1), but there effects on initial occupancy, colonization, and extinction were unclear. (Table 2).

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 publically 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 shurbland 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

Table 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
	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. 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)

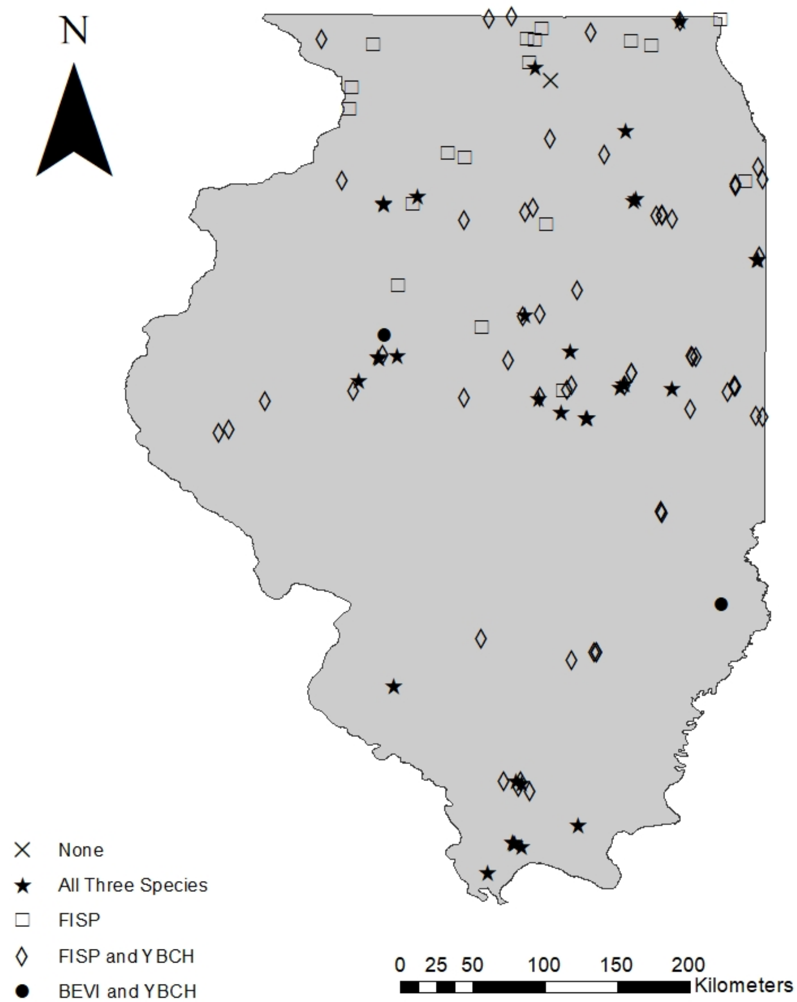

Figure 1. Publicly owned shrublands that were surveyed over the course of 2016-2018. 109 surveyed in 2016 with, 85 surveyed in 2017, and 109 surveyed in 2018. Symbols represent the species present at each of the sites of the three-year period.

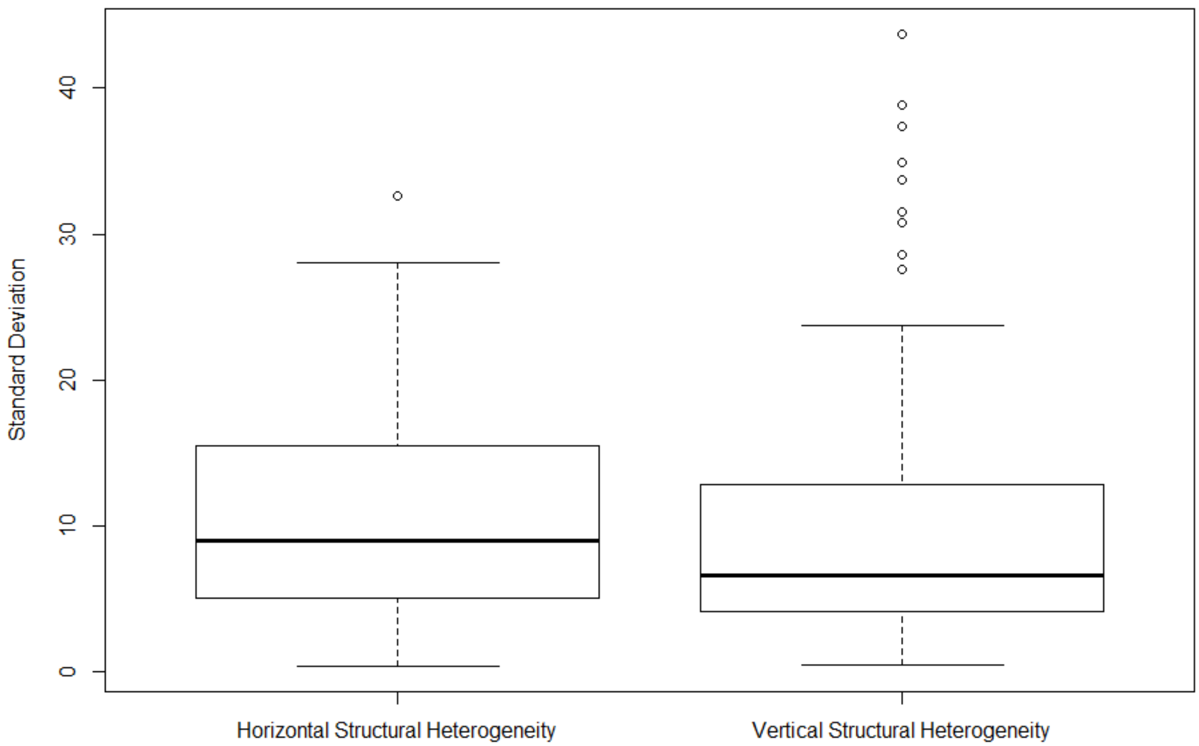

Figure 2. Distribution of the sites' horizontal and vertical structural heterogeneity.

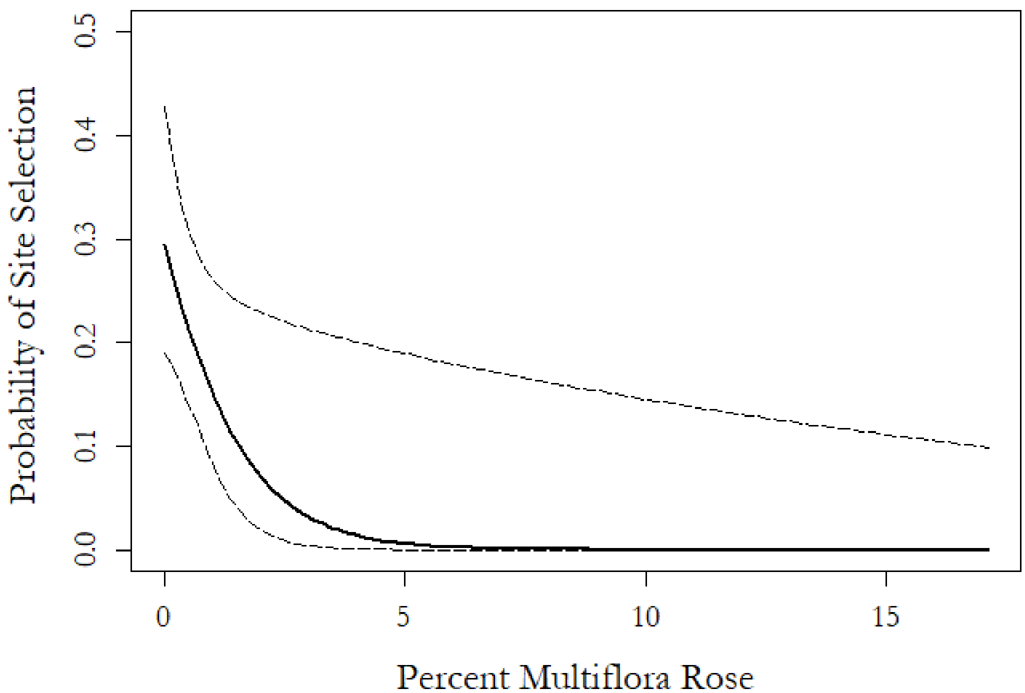

Figure 3. Predicted probability of initial site selection (with 95% confidence intervals) for Bell's Vireo with increasing percentages of multiflora rose in a site.

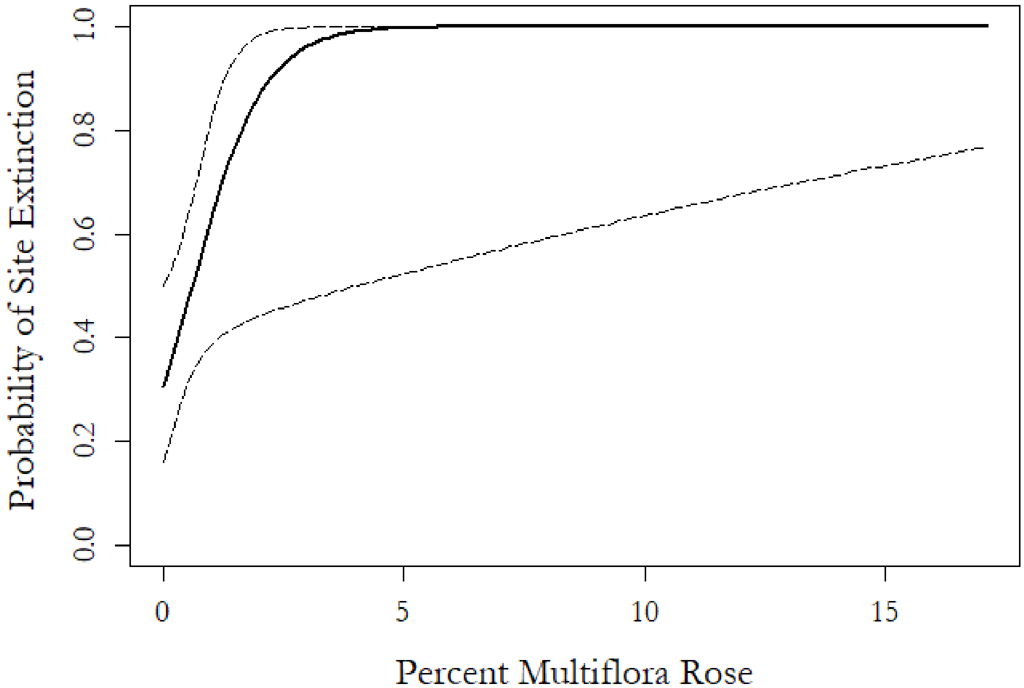

Figure 4. Predicted probability of a site becoming extinct the following year (with 95% confidence intervals) by Bell's Vireo with increasing percentages of multiflora rose.

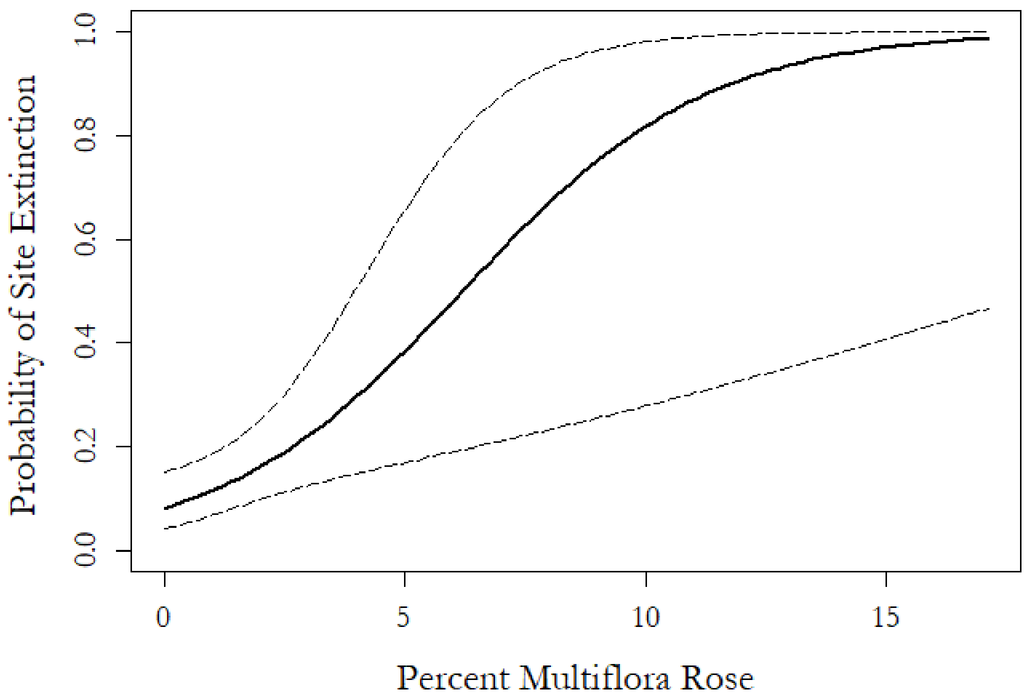

Figure 5. Predicted probability of a site becoming extinct the following year (with 95% confidence intervals) for Yellow-breasted Chat as the percentage of multiflora rose increases.

Literature Cited

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.

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 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.

Eckerle, K. P. and C. F. Thompson. 2001. Yellow-breasted Chat (Icteria virens), 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/yebcha

Fickenscher, J. L., J. A. Litvaitis, T. D. Lee, and P. C. Johnson. 2014. Insect responses to shrubs: Implications to managing thicket habitats in the northeastern United States. Forest Ecology and Management 322:127-135.

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/.

Gaertner, M., R. Biggs, M. T. Beest, C. Hui, J. Molofsky, and D. M. Richardson. 2014. Invasive plants as drivers of regime shifts: identifying high-priority invaders that alter feedback relationships. Diversity and Distributions 20:733–744.

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

Gleditsch, J. M. 2017. The role of invasive plant Species in urban avian conservation. In: Murgui E., Hedblom M. (eds) Ecology and Conservation of Birds in Environments. Springer, Cham. Pp 413-424.

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

Iverson, L. R. 1998. Land-use changes in Illinois, USA: The influence of landscape attributes on current and historic land use. Landscape Ecology 2:45-61.

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.

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

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.

McCarragher, S. 2015. Ecological and evolutionary invasion dynamics of Lonicera maackii (amur honeysuckle) in relation to white oak savanna sestoration management at Nachusa Grasslands, Illinois, USA (Doctoral Dissertation). Retrieved from https://search.proquest.com/docview/1722047692?accountid=14553

Ortega, Y. K., K. S., McKelvey, and D. L. Six. 2006. Invasion of an exotic forb impacts reproductive success and site fidelity of a migratory songbird. Oecolgia 149:340-351.

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/.

Ricketts, M. S., and G. Ritchison. 2000. Nesting success of Yellow-Breasted Chats: Effects of nest site and territory vegetation structure. The Wilson Bulletin 112:510-516.

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.

Smith, S. B. S. A. DeSando, and T. Pagano. 2013. The value of native and invasive fruit-bearing shrubs for migrating songbirds. Northeastern Naturalist 20(1): 171-184.

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.

Wolfe, B. E., and J. N. Klironomos. 2005. Breaking new ground: Soil communities and exotic plant invasion. Bioscience 55:477–487.

Objective 3: **Assess short and long-term impacts of invasive woody species encroachment on the physiological condition of Species in Greatest Need of Conservation**

Task 3.1 Identify the physiological health of the Yellow-breasted Chat, Bell's Vireo, and Field Sparrow

We brought on Kaity Ripple as a graduate student of Natural Resources and Environmental Sciences, University of Illinois, in 2016 to help us collect field data and address some of the objectives associated with the project. Her graduate research project focused on two of the objectives we had pertaining to this project. Kaity successfully defended her master's thesis in the spring of 2019 and her second chapter directly addresses Objective 3. The manuscript has been included below. The target journal for this chapter is *Physiological and Biochemical Zoology*.

ABSTRACT

Shrubland birds have experienced population declines across the U.S. for the past 50 years. Habitat loss and degradation are proposed as being responsible for these declines, yet, the mechanistic process 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 helath 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 four

different physiological biomarkers measuring stress levels (corticosterone), short-term diet quality (triglyceride and β-hydroxybutyrate), and immune function (bacteria-killing ability) to determine the physiological health in relation to four habitat characteristics; percentage of each of the three non-native plant species and the percentage of native plant species. I expected non-native plant species to have a negative effect on all three shrubland bird species, but did not find this to be the case. 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 prevalence honeysuckle Increasing percentages of native plant species had a positive influence on the bacteria killing-ability of all three species. Therefore, management should focus on removing or preventing further encroachment of non-native woody shrubs to benefit shrubland obligate species.

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 declines (Rosenberg *et al.* 2016), although the mechanisms linking these declines remains unclear. Over the past century, natural processes that created shrublands, like wildfires, have been suppressed (Askins 2000), and most of what existed has been turned into pasture, converted to row-crop agriculture, or lost to suburban sprawl. Furthermore, much of the remaining shrubland has become degraded by the colonization of non-native plant species (Askins 1993, Rosenberg *et al.* 2016). Consequently, fragmentation, loss of shrubland habitat, and deterioration of remaining shrublands are negatively impacting the bird community that depends on these areas for breeding (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 site-level characteristics such as habitat composition are influencing shrubland birds, so that conservation efforts can be tailored accordingly.

The increasing prevalence of non-native plant species is thought to be a major driver of bird population declines (Rosenberg *et al.* 2016), although the mechanisms linking non-native species encroachment to population declines is unclear. Most studies investigating the effects of non-native plant species on birds have focused on population measurements (eg. presence/absence, abundance, richness, or reproductive output) but have found varying results (Nelson *et al.* 2017). However, these studies do not investigate how non-native plant species may be influencing the physiological condition of bird populations.

Non-native plant species could influence bird populations in numerous ways. For instance, non-native plant species may be indirectly influencing birds by changing the availability of nesting substrates (Brawn *et al.* 2001), food resource availability (Brooks *et al.* 2004, Litt *et al.* 2014, Burghardt *et al.* 2009), resource competition (Narango *et al.* 2017), and lower nest success (Tremblay *et al.* 2005, Rodewald *et al.* 2010, Budnik *et al.* 2016), all of which may be linked to individuals' physiological condition. Consequently, understanding how non-native plant species encroachment into shrubland habitats can influence the physiological health of the birds may be an important step in understanding the overall effects of non-native plants on birds. Biomarkers of stress, diet quality, and immunocompetence may provide a link between habitat quality and bird condition, thereby providing insight into the mechanisms driving population declines in response to non-native plant invasions.

I used four biomarkers linked to health to examine the effects of non-native plant species encroachment on the health and condition of three shrubland bird species that have experienced dramatic population declines in Illinois. 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). Dietary metabolites, like triglyceride and β-hydroxybutyrate, are good measures of short-term diet quality of individuals and indicators of food availability (Jenni-Eiermann and Jenni 1994). Triglyceride, a form of stored lipid in the plasma, can be used as a measure of short-term diet quality with higher concentrations indicating that there are higher quality and more abundant food resources available (Dietz *et al.* 2009). β-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 the ability of an individual 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). 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 of 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). 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).

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.) bacteria-killing ability will decline, and 4.) ectoparasite burdens will increase. I aim to understand how the encroachment of non-native shrubs may be linked to the physiological condition of populations of conservation concern. These connections have the potential to provide important conservation implications which may then help better inform future management decisions.

METHODS

Focal 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 fragmentation, and loss of this early successional habitat, along with parasitism by the Brown-headed Cowbird (*Molothrus ater*), has contributed to their population decline (Barlow 1962, Kus *et al.* 2010). Yellow-breasted Chat another long-distance migrant, that 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, Field Sparrow are 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 at 29 sites (7 resampled) in 2017 and 36 sites (2 resampled) in 2018 in central Illinois (Figure 1). Sites were selected based on data I gathered in 2016 and 2017, where I systematically surveyed woody vegetation and the bird community at 112 sites throughout Illinois (Chapter 2). Specifically, I identified sites where the three focal bird species were present as well as sites with varying degrees of invasion of the three focal non-native shrubs.

Vegetation surveys – I measured vegetation at each site to quantify 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. A minimum of 12 μL of plasma was allocated into microcentrifuge tubes for corticosterone, 22 μL for dietary metabolite assays (triglyceride and β-hydroxybutyrate levels), and 5 μL for bacteria-killing assays.

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 50% concentration 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 in 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 bacteria-killing ability 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% concentration 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, therefore, 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 degrees Celsius, 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. Bacteria-killing ability 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. Individual samples with CVs greater than 20% were rerun. I did not rerun a subset of samples with CVs higher than 20% because the number of colonies on those plates was less than 92 colonies with a difference of 26 colonies or less making the absolute difference in colony numbers between the two plates indistinguishable. Mean intra-assay CV was 13% and inter-assay CV was 6%.

Ectoparasite burden – Birds were screened for ectoparasites by manually combing the head using a toothpick to look for mites, lice, and/or ticks and both wings and the tail feathers were spread, backlit, and photographed with a digital camera (Canon PowerShot SX610 HS). The digital images were later examined by four different observers. If unknown images were recorded, one observer (K. Ripple) checked on a computer screen to assess the number of feather lice and mites at a finer scale. Wing and tail ectoparasites were lumped into one group because the pictures were often not clear enough to distinguish between mites and lice.

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 physiological measures were log-transformed except for ectoparasite burden. I excluded five (2 YBCH and 3 FISP) samples from the dietary metabolite assays because the plasma was opaque or red, due to the nature of colorimetric assays. 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 to compare site characteristics to the physiological markers (corticosterone, triglyceride, β-hydroxybutyrate, bacteria-killing ability, and ectoparasite burden) I assessed. 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).

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 Vireo, 61 Field Sparrow, 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 1).

Corticosterone – Bell's Vireos had the greatest corticosterone concentrations, followed by Field Sparrows, and Yellow-breasted Chats (Table 2). Corticosterone levels were generally greater in 2018 compared to 2017 for all three focal species (Table 2). A species-specific effect of percent cover of autumn olive best described the variability in corticosterone concentrations (Table 3). Percent autumn olive had a positive influence on corticosterone concentrations in Bell's Vireos but appeared to have little effect on concentrations in both Yellow-breasted Chats and Field Sparrows (Table 4, Figure 2).

Triglyceride – Field Sparrows had the greatest triglyceride concentrations followed by Yellow-breasted Chats, and Bell's Vireos (Table 2). Triglyceride concentrations in the focal species were generally greater in 2017 than in 2018 (Table 2). Percent cover of honeysuckle. with a species-specific effect was the best-supported model describing triglyceride concentrations (Table 5). As the percentage of honeysuckle increased, the triglyceride levels of both Field Sparrows and Yellow-breasted Chats decreased (Table 6, Figure 3). The confidence intervals for the effect of honeysuckle on triglyceride concentrations of Bell's Vireos were large and therefore there the data did not support any relationship (Table 6, Figure 3).

β-hydroxybutyrate – Yellow-breasted Chats had the greatest concentration of β-hydroxybutyrate followed by Field Sparrows and Bell's Vireos (Table 2). β-hydroxybutyrate concentrations in the focal species generally did not differ between years (Table 2). Percent cover of honeysuckle without a species-specific effect was the best-supported models describing β-hydroxybutyrate levels (Table 7). As the percentage of honeysuckle increased, β-hydroxybutyrate concentrations decreased (Table 8, Figure 4).

Bacteria-killing Ability –Bell's Vireos and Yellow-breasted Chats had the greatest bacteria-killing ability followed by Field Sparrows (Table 2). The bacteria-killing ability of the focal species was generally greater in 2017 than in 2018 (Table 2). Percentage of native plant species was the best-supported model describing BKA (Table 9). Increasing percentage of native woody plant species was positively related to BKA (Table 10, Figure 6).

Ectoparasites- Field Sparrows had the greatest ectoparasite loads followed by Yellow-breasted Chats and Bell's Vireos (Table 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 2). None of the models out-competed the model that only included species, year, and date (Table 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 encompassed zero (Table 12).

DISCUSSION

I predicted that non-native plant species would negatively impact the physiological health of the three focal avian species of conservation concern. However, I did not find a consistent negative effect. 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 non-native honeysuckle did impact diet quality, as measured by triglyceride and β-hydroxybutyrate concentrations, but not necessarily in the predicted direction. Triglyceride concentrations for Field Sparrows and Yellow-breasted Chats were negatively related to honeysuckle, suggesting that birds in areas with more honeysuckle are not storing as many fat stores as birds in areas with less prevalence of honeysuckle. The inverse association between β-hydroxybutyrate concentrations and honeysuckle, was the opposite of what was expected, especially considering the relationship with triglyceride. 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. The immune response, as measured by BKA did suggest that native plant species had a positive effect. 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. While I expected a similar relationship between bacteria-killing ability 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 bacteria-killing ability 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 were linked to any habitat characteristic. This suggests other factors may be influencing the ectoparasite burdens on these birds, likely through density of the birds rather than habitat features.

Autumn olive may be negatively influencing corticosterone concentrations in Bell's Vireo's in a variety of ways. 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 from more 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 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). 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 the parental habits through increased protection and provisioning, which increase corticosterone concentrations in parents (Mark and Rubenstein 2013). 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. 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 found that honeysuckle had an influence on short-term diet quality. I expected β-hydroxybutyrate levels to be inversely related to triglyceride levels but did not find that to be the case. Yellow-breasted Chat and Field Sparrow triglyceride concentrations, as well as β-hydroxybutyrate concentrations for all species, were inversely related to percentages of honeysuckle. There are a few possible explanations for this result. For instance, the inverse relationship of β-hydroxybutyrate concentrations and honeysuckle may be due to the low-quality food resources that honeysuckle may be providing. Therefore, birds in areas with honeysuckle are able to access enough food resources, which is reflected in the negative relationship with β-hydroxybutyrate, but the quality of the nutrition available is lower than areas without honeysuckle, which would lead to a negative relationship in triglycerides. 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). While honeysuckle may not dramatically influence invertebrate communities as many non-native plants have been found to do (Brooks *et al.* 2004, Litt *et al.* 2014, Burghardt *et al.* 2009), they have an influence on the abundance of larval leaf chewers (Love 2006), which are an important resource for the development of chicks (and may be important to adults during the breeding season as well) because of their high nutritional value (Schowalter *et al.* 1981). Additionally, Yellow-breasted Chats and Bell's Vireos will supplement their diets with fruit (Thompson and Nolan 2016, Kus *et al.* 2010), and honeysuckle provide an abundance of berries during the latter portion of the breeding period. However, these berries may be low in nutritional content and may not provide adequate nutrition for birds (Smith *et al.* 2013). Therefore, individuals may not be having problems finding food in areas with more honeysuckle, but the food in those areas may be lower quality.

Finally, I found that native plant species had a positive influence on BKA. In past studies, native plants have been found to be associated with decreased disease prevalence (Gardner 2016) and increased diet quality (Schowalter *et al.* 1981, Love 2006). Birds in areas with a greater prevalence of non-native species, and consequently greater prevalence of disease vectors, would have greater chances of being infected with vector-borne diseases, such as avian malaria or avipoxvirus, which could challenge their immune function. Additionally, native plants provide better quality nutrition than non-native plant species (Schowalter *et al.* 1981, Love 2006), which I found to be true for the diet quality in relation to honeysuckle Fighting off infections and other threats to the immune system is energetically costly (Owen *et al.* 2010), and the increased food quality associated with native plant species can supplement the energy stores needed to support the immune system. 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 habitat characteristics that I investigated. It is possible that other factors that are not habitat dependent are dictating the ectoparasite burdens on these birds. For instance, I found that Field Sparrows had higher ectoparasite loads than the other two species. Field Sparrows have smaller territories that are often overlapping with each other. It is possible that they are interacting with each other more and are therefore transferring ectoparasites horizontally through contact (Brooke 2010). The ectoparasites that I focused on transfer from host to host via direct contact and will die in a short period of time if they are not on a host (Rothschild and Clay 1952). Therefore, because the Bell's Vireo and Yellow-breasted Chats are not as saturated in shrublands as the Field Sparrows, they are likely not interacting with their conspecifics as often and therefore not transferring ectoparasites to each other.

Conservation implications

Non-native plant species are recognized as a globally important problem. Furthermore, they have been found to have negative impacts on some bird species (Nelson *et al.* 2017, Rodewald *et al.*). 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 to individual 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 are influencing nestlings may be more informative as nestlings may be more sensitive to surrounding habitat features around the nests than adults (Merrill *et al.* in review). However, there is 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.

Table 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 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 (Ng/mL)	*Field Sparrow*	48	50.3	108.3	72.0	60	78.4	128.5	99.5
	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 (mg/dl)	*Field Sparrow*	41	92.1	920.7	212.5	59	58.7	444.1	182.1
	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 (mM)	*Field Sparrow*	41	0.1	3.0	1.2	58	0.7	2.7	1.7
	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 (#/individual)	*Field Sparrow*	49	0	66	10.2	55	1	155	23.4
	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. 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 the species 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 4. Parameter estimates with standard error in parenthesis 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-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 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 the species 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 6. Parameter estimates with standard error in parenthesis 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-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 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 the species 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 8. Parameter estimates with standard error in parenthesis 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-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 9. Model selection table examining the relationship between habitat characteristics and bacteria-killing ability 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 the species as an interaction effect. All models were run with "species", "year". and "date" as covariates.

Model	**AIC**	**K**	**ΔAIC**	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 10. Parameter estimates with standard error in parenthesis for top-ranked AIC models comparing habitat characteristics to log transformed bacteria-killing ability 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 bacteria-killing ability 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-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 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 the species 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 12. Parameter estimates with standard error in parenthesis 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-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)

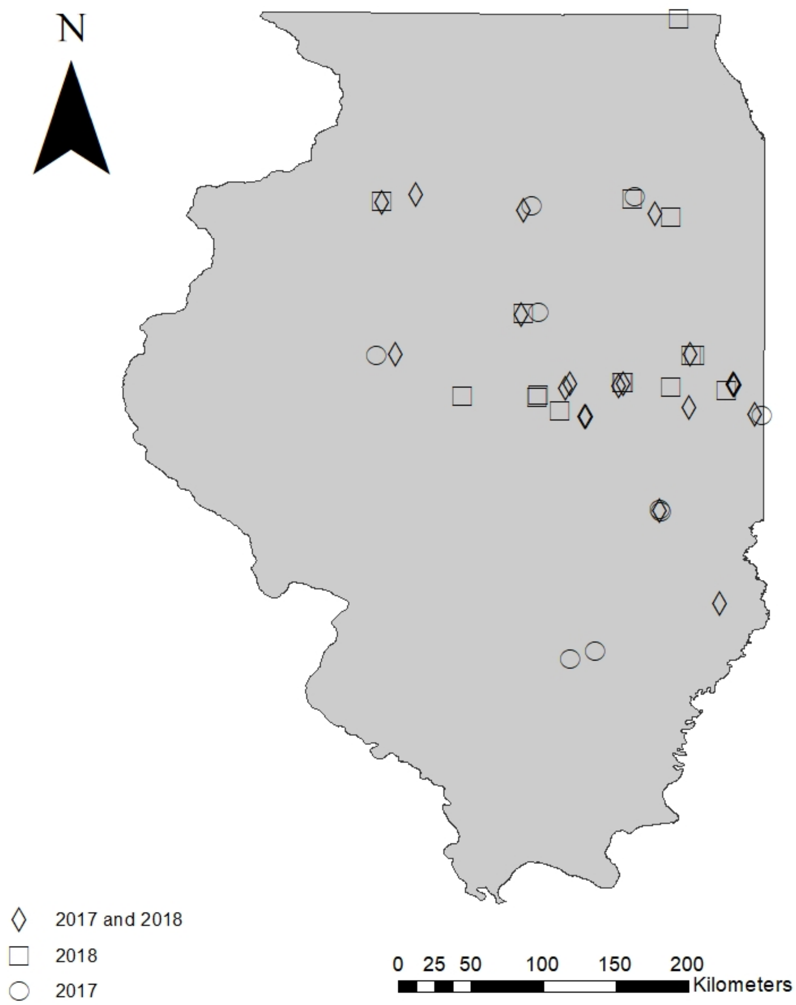

Figure 1. Map of sites visited during 2017 and 2018 from late May- mid-July Twenty-nine sites were visited in 2017 with 7 revisits, and 35 sites were visited in 2018 with 2 revisits. Symbols represent which sites were sampled during 2017 and 2018.

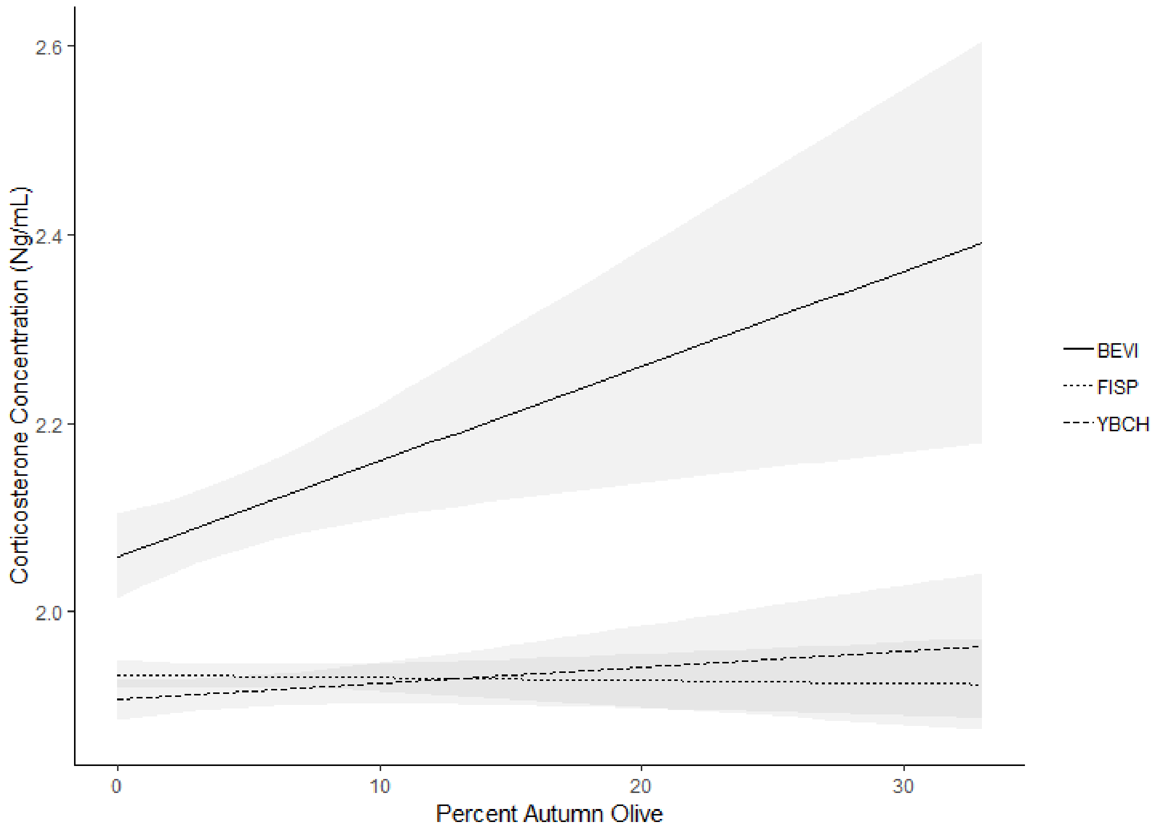

Figure 2. Corticosterone concentrations (with 95% Confidence Intervals) with increasing percentage of autumn olive within a site, for three focal bird species, sampled in shrublands throughout Illinois, 2017–2018 confidence intervals. BEVI refers to Bell's Vireo, FISP to Field Sparrow, and YBCH to Yellow-breasted Chat.

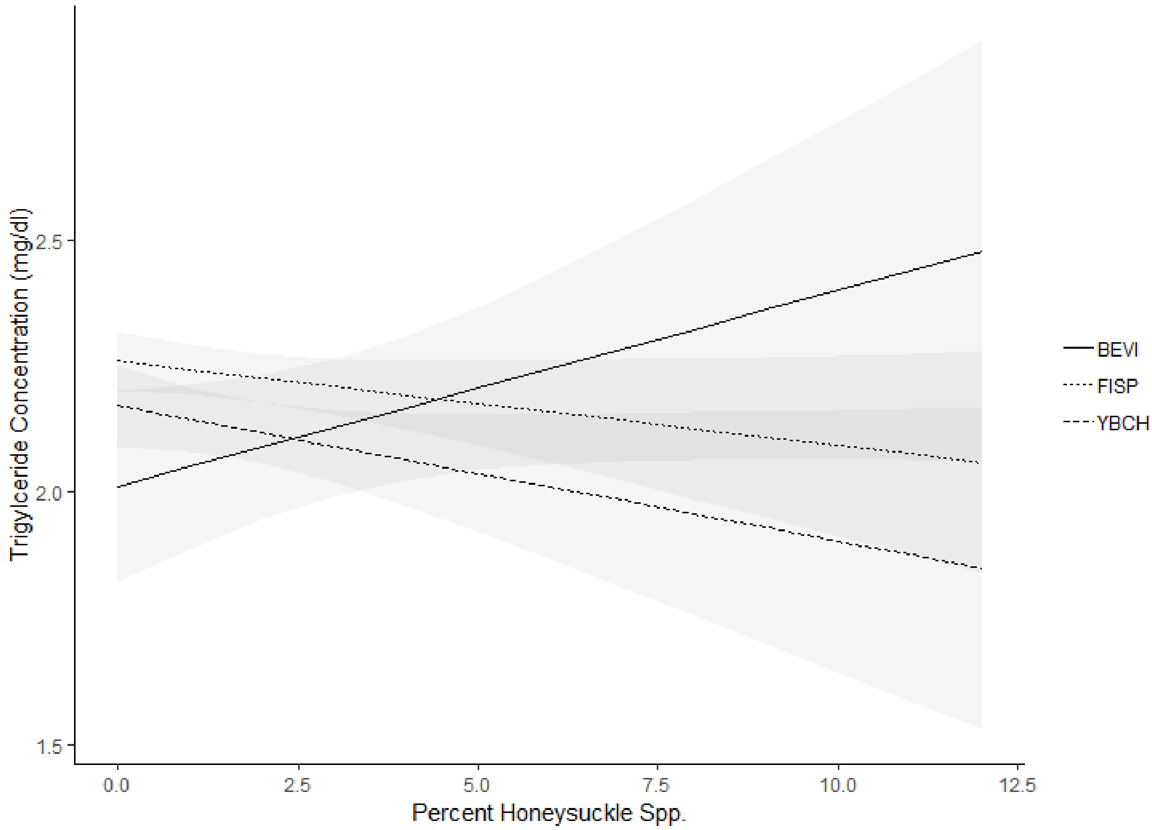

Figure 3. Triglyceride concentrations (with 95% Confidence Intervals) with increasing percentage of honeysuckle within a site, for three focal bird species, sampled in shrublands throughout Illinois, 2017–2018 confidence intervals. BEVI refers to Bell's Vireo, FISP to Field Sparrow, and YBCH to Yellow-breasted Chat.

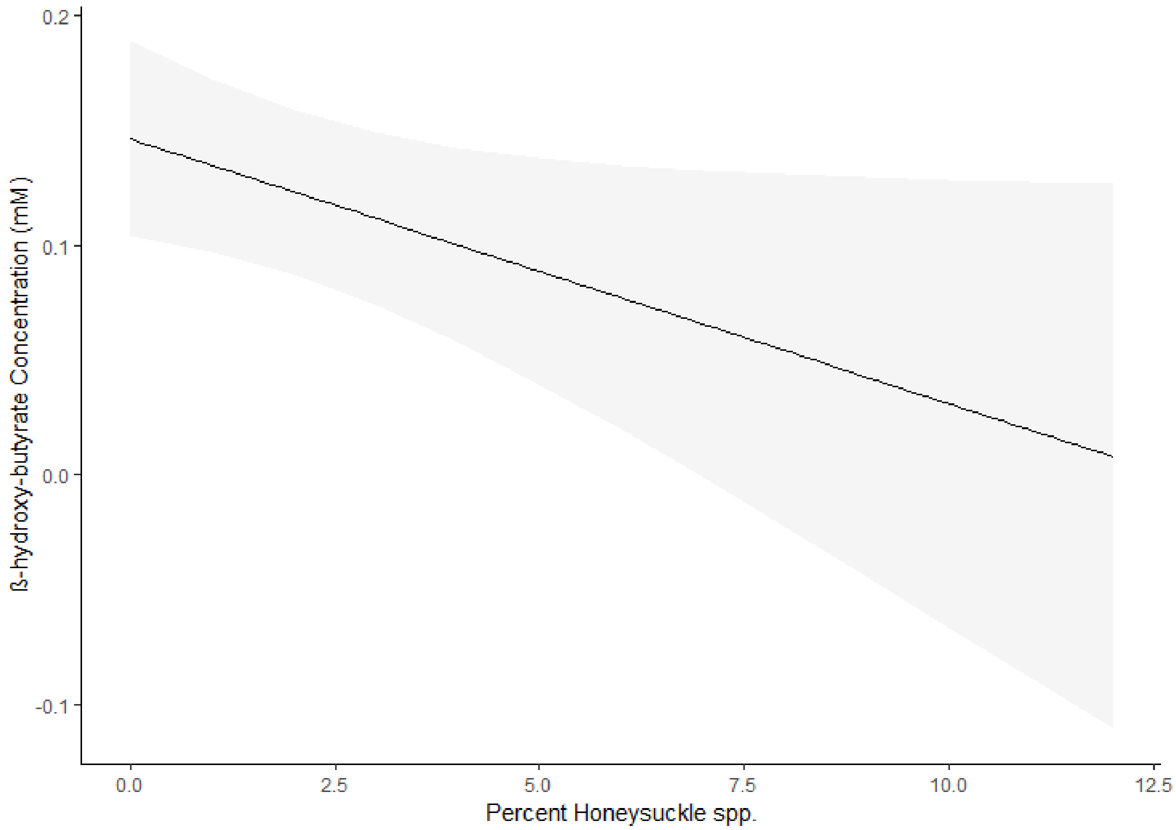

Figure 4. β-hydroxybutyrate concentrations (with 95% Confidence Intervals) with increasing percentage of honeysuckle within a site, for three focal bird species, sampled in shrublands throughout Illinois, 2017–2018 confidence intervals.

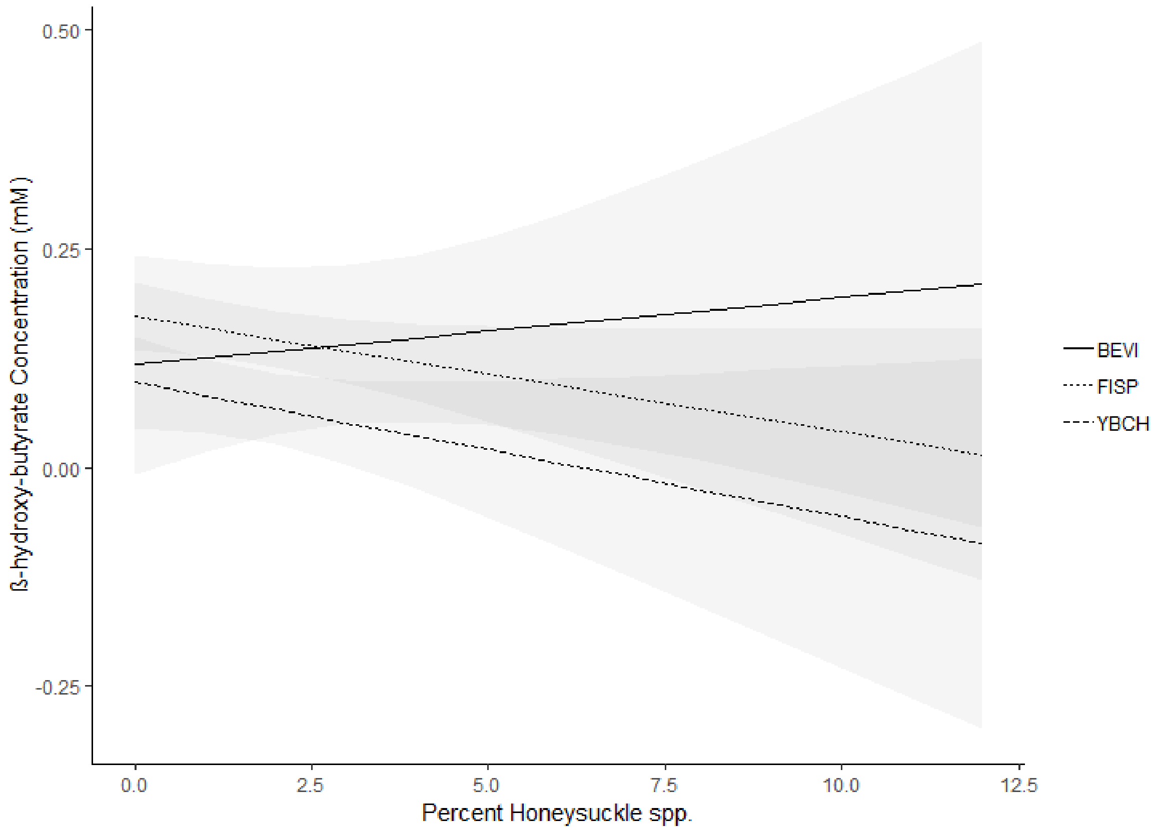

Figure 5. β-hydroxybutyrate concentrations (with 95% Confidence Intervals) with increasing percentage of honeysuckle within a site, for three focal bird species, sampled in shrublands throughout Illinois, 2017–2018 confidence intervals. BEVI refers to Bell's Vireo, FISP to Field Sparrow, and YBCH to Yellow-breasted Chat.

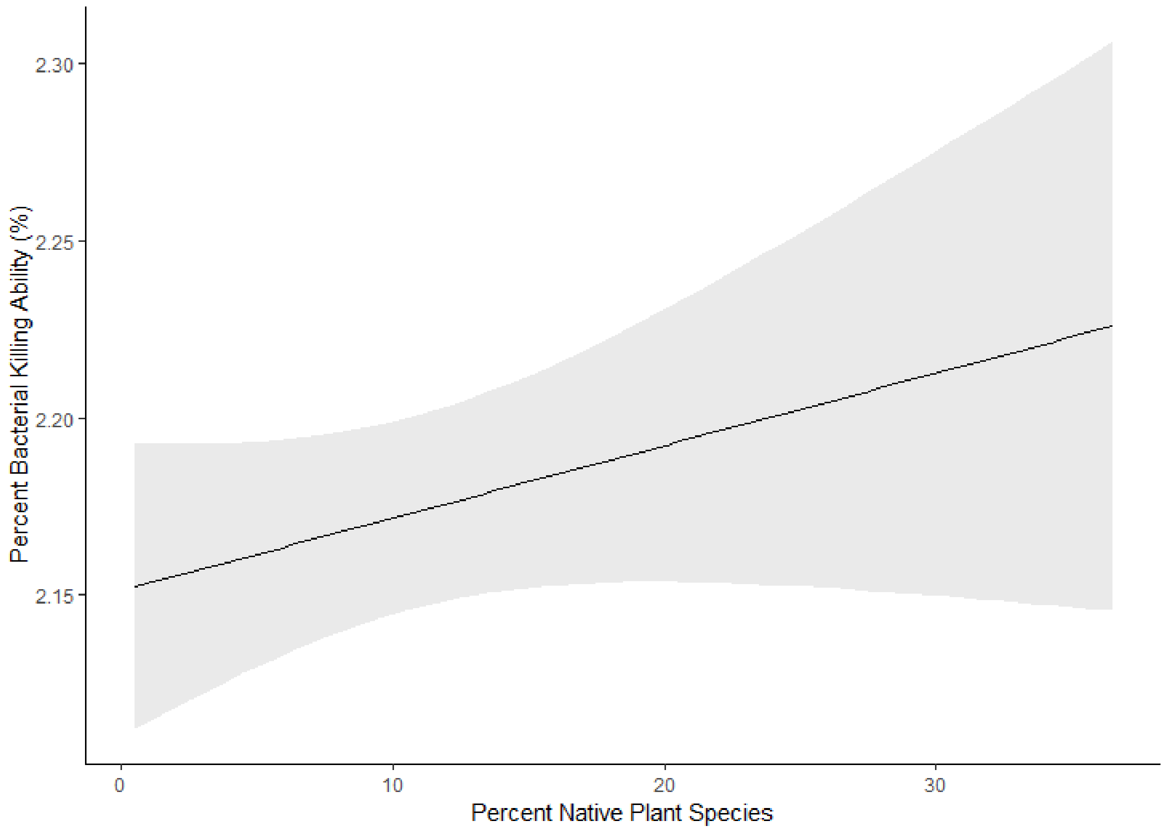

Figure 6. Bacteria-killing ability (with 95% Confidence Intervals) with increasing percentage of native plant species within a site, for three focal bird species, sampled in shrublands throughout Illinois, 2017–2018 confidence intervals.

Literature cited

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.

Ambuel, B., and S. A. Temple. 1983. Area-dependent changes in the bird communities and vegetation of southern Wisconsin forests. Ecology 64:1057–1068.

Arriero, E., J. Moreno, S. Merino, and J. Martinez. 2008. Habitat effects on physiological stress response in nestling blue tits are mediated through parasitism. Physiological and Biochemical Zoology 81:195-203.

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.

Askins, R. A., C. M. Folsom-O'Keefe, and M. C. Hardy. 2012. Effects of vegetation, corridor width and regional land use on early successional birds on powerline corridors. PLoS ONE 7:e31520.

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.

Bent, A. C. 1953b. Life histories of North American wood warblers. U.S. Natl. Mus. Bull. 203.

Brooke, M. de L. 2010. Vertical transmission of feather lice between adult blackbirds *Turdus merula* and their nestlings: A lousy perspective. Journal of Parasitology 96:1076-1080.

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.

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.

Burhans, D. E. and F. R. Thompson III. 1999. Habitat patch size and nesting success of Yellow-breasted Chats. Wilson Bulletin 111:210-215.

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.

Drake, S. J., J. F. Weltzin, and P. D. Parr. 2003. Assessment of non-native plant species on the United States Department of Energy Oak Ridge National Environmental Research Park. Castanea 68:15-30.

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.

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.

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 meriod. 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.

Kennedy, P. L., S. J. Debano, A. M. Bartuszevige, and A. S. Lueders. 2009. Effects of Native and Non-Native Grassland Plant Communities on Breeding Passerine Birds: Implications for Restoration of Northwest Bunchgrass Prairie. Restoration Ecology 17:515–525.

King, D. I., and B. E. Byers. 2002. An evaluation of powerline rights-of-way as habitat for early-successional shrubland birds. Wildlife Society Bulletin 30:868–874.

Knick, S. T., and J. T. Rotenberry. 2000. Ghosts of habitats past: Contribution of landscape change to current habitats used by shrubland birds. Ecology 81:220–227.

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.

Martin, T. E. and J. J. Roper. 1988. Nest predation and nest-site Selection of a western population of the Hermit Thrush. The Condor 90:51-57.

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.

McCusker, C. E., M. P. Ward, and J. D. Brawn. 2010. Seasonal responses of avian communities to non-native bush honeysuckles (Lonicera spp.). Biological Invasions 12:2459–2470.

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.

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.

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.

Norris, K. and M. R. Evans. 2000. Ecological immunology: life history trade-offs and immune defense in birds. Behavioral Ecolocy 11:19-26.

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.

Rothschild, M., and T. Clay. 1952. Fleas, flukes and cuckoos. Collins, London U.K. pp 304.

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.

Schmidt, K. A., and C. J. Whelan. 1999. Effects of exotic Lonicera and Rhamnus on songbird nest predation. Conservation Biology 13:1502–1506.

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.

Shake, C. S., C. E. Moorman, J. D. Riddle, and M. R. Burchell II. 2012. Influence of patch size and shape on occupancy by shrubland birds. The Condor 114:268–278.

Silverin, B. 1998. Behavioural and hormonal responses of the Pied Flycatcher to environmental stressors. Animal Behaviour 55:1411-1420.

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.

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.

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

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.

Wingfield, J. C, D. L. Maney, C. W. Breuner, J. D. Jacobs, S. Lynn, M. Ramenofsky, and R. D. Richardson. 1998. Ecological bases of hormone-behavior interactions: the "emergency life history stage". American Zoologist 38:191-206.

Zylberberg, M., K. A. Lee, K. C. Klasing, and M. Wikelsi. 2012. Increasing avian pox prevalence varies by species, and with immune function, in Galapagos finches. Biological Conservation 153:72-79.

Task 3.2 Assess food availability for Yellow-breasted Chat, Bell's Vireo, and Field Sparrow.

We attempted to assess food availability for Yellow-breasted Chat, Bell's Vireo, and Field Sparrow in the breeding season of 2017. At a subsample of shrublands, we visually inspected the leaves along a 1 meter section of the most common woody plant species for the presence of clinging arthropods. We classified arthropods according to functional guild (lepidopteran larvae, spiders, phloem feeders, etc.). Preliminary inspection of the data revealed high levels of variation and uncertainty. Consequently, we discontinued our assessment of food availability in 2018. However, we amended our original grant narrative to reflect our attempts at assessing food availability at the request of USFWS.

GENERAL CONCLUSION

Shrubland areas are rare and understudied in Illinois. The Illinois State Wildlife Action Plan lists the maintenance and enhancement of shrub habitats in multiple different Campaigns and in the descriptions of Conservation Opportunity Areas across the state. Non-native woody encroachment into shrubland areas has the potential to negatively influence the quality of remaining shrublands and removal of such species could represent a viable means of achieving the goals of enhancing shrub habitats. While we found that non-native woody plant species were ubiquitous throughout shrublands Illinois, they were not as prevalent as we originally believed. Most of the sites we visited were dominated by native shrubs, with non-native species making up a small proportion. Shrublands in the northeast part of the state, near Chicago, do appear to harbor a few more non-native woody plant species compared to the rest of the state. But even there, non-native woody plants are not that dominant. Consequently, focusing on removal of all non-native woody plants to improve shrubland habitat may not be effective. However, targeted removal of dominant species could have an effect.

The effect of non-native woody plants on shrubland birds appears to be species specific. 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), we found that non-native plant species may be contributing to these declines as well. While non-native plant species had little impact on avian species richness, it appear to have specific effects on a couple of species listed as in Greatest Need of Conservation. 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*)). Specifically, multiflora rose negative influenced site selection for Bell's Vireo and site fidelity or Bell's Vireo and Yellow-breasted Chat. Whereas we found that autumn olive (*Elaeagnus umbellata*) was associated with greater stress levels in Bell's Vireo and honeysuckle negatively influenced diet quality in Yellow-breasted Chat and Field Sparrow. Our results suggests that specific non-native woody plant species may be influencing the distribution and abundance of some species that are not widespread, e.g. Bell's Vireo and Yellow-breasted Chat. However, non-native woody plants species may even be having subtle effects on the physiological health of widespread and abundant species like the Field Sparrow. Targeted removal of certain abundant non-native woody plant species, in particular multiflora rose may help increase populations of species of concern that depend on shrubland habitat.

In summary, non-native woody shrubs are ubiquitous throughout Illinois, although not dominant within most shrublands. Non-native woody plant species have little influence on avian species richness in shrublands, but do appear to be negatively influencing specific shrubland obligate species of conservation concern. The three bird Species in Greatest Need of Conservation we focused on, Bell's Vireo, Yellow-breasted Chat, and Field Sparrow, varied greatly in their abundance and how they were impacted by non-native woody plant species. Bell's Vireo and Yellow-breasted Chat were less abundant than Field Sparrow, being observed at at approximately 20% and 60% of shrubland sites respectively, compared nearly 100% for Field Sparrow. Some of the difference in distribution may have been because of the effect that multiflora rose had, which decreased the probability of site occupancy for both species. Consequently, targeted removal of multiflora rose may be beneficial to Bell's Vireo and Yellow-breasted Chat. Field Sparrow, on the other hand, were found at nearly all shrubland sites.

Consequently, increasing the distribution of Field Sparrow would require the creation of new shrublands.

While bird species that are more tolerant of varying conditions in a site (e.g. Field Sparrow) would benefit from increasing the quantity of shrublands on the landscape, it appears that the quality of existing shrublands is also important to shrubland obligate bird species (e.g. Bell’s Vireo and Yellow-breasted Chat). 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 (eastern and southern portions of Illinois) would benefit from efforts to remove or prevent further invasion of the non-native shrub, which could help increase occupancy and improve physiological condition. However, creating shrublands in other parts of the state may benefit these species and wide spread ones, such as the Field Sparrow.

Literature cited

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.