THE IMPACT OF NON-NATIVE PLANTS

ON BIRD COMMUNITIES IN SUBURBAN FOREST FRAGMENTS

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Wildlife Ecology

Summer 2011

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ACKNOWLEDGMENTS

I would like to thank the USDA Forest Service and the University of Delaware for providing the funding for this research I would also like to thank the members of my committee, Dr. Greg Shriver and Dr. Douglas Tallamy. I would especially like to thank Dr. Tallamy for providing the inspiration for my project and working tirelessly to promote the benefits of native plants. I would also like to thank Dr. Shriver for always taking the time to provide me with support and advice throughout my time as a student. This project would not have been possible without my advisors Dr. Chris Williams and Dr. Vince D'Amico. I appreciate the chance you took on hiring me without a finalized project and I could never have succeeded in finishing this research without your endless personal and professional support and advice.

Special thanks to Jamie Zaccaria who was not only a wonderful and dependable research assistant, but a great friend as well. I truly enjoyed the two summers we spent together climbing through multiflora rose and swatting mosquitoes. Thank you to Ken Duren for his numerous edits and helpful advice and to Sadie Ulman for being such a great officemate over the last three years. Finally, thank you to all the other graduate students and staff in the Department of Entomology and Wildlife Ecology who have been close friends during my time in Delaware.

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ABSTRACT

Forest fragmentation has occurred across the Eastern United States, and an ecological effect linked to fragmentation is the invasion of non-native plants into forests. Few studies have examined the link between the density of native plants and avian habitat use in forest fragments. The objective of this project was to estimate the relationship between occupancy of eight songbird species and native plant density, forest structure, and invertebrate biomass. We collected data at ninety-eight 25 m radius forested plots in Delaware and Maryland. Avian point counts were conducted 3 times per season between 15 May – 7 August, 2009—2010. Vegetation was analyzed by measuring understory coverage, canopy coverage, basal area, and proportion of native plants. Invertebrate biomass was measured by vacuum sampling. We used program PRESENCE to build occupancy models with invertebrate biomass and vegetation characteristics as covariates to explain candidate bird species presence, and evaluated the models using Akaike Information Criterion. The proportion of native plants was the best variable in predicting Wood Thrush occupancy. Forest structure variables were the strongest predictors of presence for American Robin, Carolina Chickadee, and Gray Catbird. Both forest structure and native plant proportion were important variables in predicting the occupancy of Eastern Towhee, Northern Cardinal, and Ovenbird. For Carolina Wren, invertebrate abundance was the most important variable in predicting occupancy. My results suggest that native plant proportion and vegetation structure may both be important factors to consider in conservation planning and habitat restoration for these songbirds.

Chapter 1

THE IMPACT OF NON-NATIVE PLANTS ON OCCUPANCY OF SONGBIRDS IN SUBURBAN FOREST FRAGMENTS

Introduction

Forest cover in the Eastern United States has been fragmented into smaller patches by urban development and agriculture (Cavitt and Martin 2002, Riitters et al. 2002). Populations of many bird species that breed in Eastern forests have been experiencing steady population declines over the last 40 years (North American Bird Conservation Initiative, U.S. Committee 2009). The effects of fragmentation, such as increased nest predation and brood parasitism, are often cited as the driving forces in these declines (Villard et al. 1999, Cavitt and Martin 2002, Smith and Wachob 2006).

Population declines of forest birds have also been linked to an increase in non-native plants (Schmidt et al. 2005), which may be related to fragmentation (Yates and Levia 2004, Raupp et al. 2010). Almost 3500 non-native plants have been introduced into the United States since European settlement as ornamental landscaping plants and accidental releases (Qian and Ricklefs 2006). Non-native plants have been shown to be unpalatable to many invertebrate herbivores (Tallamy et al. 2010), as more than 90% of herbivore species are considered specialists and are only able to feed and reproduce on a limited number of plant genera with which they share an evolutionary history (Bernays and Graham 1988, Burghardt et al. 2009, Tallamy and Shropshire 2009). A common garden experiment by Burghardt et al. (2010) found only 25% of the insect species on non-native plants that were found on nearby native plants, as well as lower abundances of insects on non-native plants. Another common garden experiment found lower invertebrate biomass on non-native plants than on natives (Zuefle et al. 2008). In most bird species, the diet of nestlings consists primarily of invertebrates (Breitwisch et al. 1984), so a reduction in invertebrate biomass may lead to delayed nest initiation (Ortega et al. 2006), smaller nestlings, or a shorter breeding season (Zanette et al. 2000).

Despite the impacts of non-native plants on the food supply for songbirds, previous studies of the interactions between non-native plants and songbird nesting ecology have yielded mixed results. A number of studies have identified negative impacts of non-native plants, including higher nest predation rates (Schmidt and Whelan 1999), delayed initiation of nesting (Maddox and Wiedenmann 2005, Ortega et al. 2006), and decreased nestling mass (Borgmann and Rodewald 2004, Lloyd and Martin 2005). Other studies have found similar nest success for birds nesting in non-native species compared to those nesting in native substrates (Stoleson and Finch 2001, Maddox and Wiedenmann 2005, Schlossberg and King 2010). Lastly, a single study of Gray Catbirds (*Dumetella carolinensis*) found nests in non-native substrates had higher nest success rates than those in native substrates (Schlossberg and King 2010). However, a confounding factor in studies comparing nest success between native and non-native substrates is that nesting substrate is not always an accurate indicator of the vegetation composition of surrounding habitat.

Even as the fitness impacts of non-native plants on birds remain unresolved, it is crucial that researchers determine if birds select or avoid habitats with non-native plants. Second, if selection differs, does it differ by species? Few studies have explicitly examined the link between the density of non-native plants and bird occupancy in suburban habitats. Attempts to relate avian occupancy and diversity to non-native plants have yielded mixed results. Lloyd and Martin (2005) found no preference in Chestnut-collared Longspurs (*Calcarius ornatus*) for nesting in native versus non-native dominated grassland patches. In some cases, positive associations between bird abundance or nest placement and non-native plants have been found (Stoleson and Finch 2001, Heckscher 2004, Wilcox and Beck 2007). Elsewhere, abundance and diversity of birds increased in native-dominated areas (Wilson and Belcher 1989, Rottenborn 1999, Heckscher 2004, Flanders et al. 2006, Wilcox and Beck 2007, Burghardt et al. 2009). These contrasting results support the idea that the response of birds to non-native plants may be species-specific for both birds and plants. It is clear that all species of native plants are not equal in their ability to act as a host plant for invertebrate herbivores, and the same is true for non-native species (Tallamy and Shropshire 2009). However, most previous studies examined the response of a single bird species or categorized study areas based on the presence of a single non-native plant.

My objective was to build models of avian occupancy in suburban forest fragments to examine the effects of native plant density, forest structure, and invertebrate abundance on an assemblage of common Eastern birds. These models may be used to guide habitat management and restoration. A complete understanding of vegetation structure cues, as well as plant species composition preferences, is required to consider non-native plant removal in a whole-ecosystem context, and as a vital step in the design of an effective habitat restoration plan (Zavaleta et al. 2001).

Study Area

This research was conducted in Delaware and Maryland, United States, including mature forest patches located within White Clay Creek State Park, Fair Hill Natural Resources Management Area, St. Andrew's School, Mount Cuba Center, Red Clay Creek State Park, and Ashland Nature Center. Patches were highly linear and often interconnected, but varied in width from 52 m to 1388 m with an average width of 415.75 m (S.E. = 31.13). Currently, the 725 ha White Clay Creek watershed, containing the majority of the points, remains 23% forested, primarily in riparian and steeply sloping areas (Newbold et al., 1997).

The native land cover of the area is a mix of hardwood species including northern red oak (*Quercus rubra*), white oak (*Q. alba*), American beech (*Fagus grandifolia*), red maple (*Acer rubrum*), sycamore (*Platanus occidentalis*), and yellow poplar (*Liriodendron tulipifera*) (Heckscher, 2004). The land use in the surrounding landscape includes both agricultural and residential properties. Non-native plants present in the study areas include, but are not limited to: autumn olive (*Elaeagnus umbellate*), garlic mustard (*Alliaria petiolata*), Japanese barberry (*Berberis thunbergii*), Japanese honeysuckle (*Lonicera japonica*), Japanese stilt grass (*Microstegium vimineum*), Norway maple (*Acer platenoides*), oriental bittersweet (*Celastrus oriculatus*), multiflora rose (*Rosa multiflora*), and wineberry (*Rubus phoenicolasius*).

Methods

I sampled 98 plots within Delaware and Maryland for the presence of forest songbirds, vegetation structure, and invertebrate biomass (Figure 1). Sample plots were located in mature forest 25 m from a forest edge and were randomly selected from within forest patches using the Hawths Tools extension for ArcGIS 9.2 (Beyer 2004). I separated plots by 250 m to minimize the likelihood that individual birds would be double counted between sample plots (Bibby and Burgess 2000). At each of the 98 sampling plots, I conducted 25 m radius avian point counts to estimate occupancy (Bibby and Burgess 2000). I surveyed the plots 3 times per summer between 15 May–7 August in 2009 and 2010. Each point was visited on a randomly selected day between 15 May–15 June, 16 June–15 July, and 16 July–7 August. I was trained to identify eastern forest bird species by sight and sound and conducted all point counts across both seasons. Bird survey data was pooled across years and analyzed as a single season with 6 sampling occasions.

I conducted surveys between 15 min before sunrise and 5 h after sunrise, with > 96% of the surveys taking place between sunrise and 4 h after sunrise. Surveys were only conducted on precipitation-free days when the wind speed was < 6.5 km/hr. At each plot, I recorded the date, time, wind speed, percent cloud cover, and temperature. A 1-min acclimation period of minimal observer movement preceded each survey to minimize effects from observer disturbance (Buckland et al. 2001, Rosenstock et al. 2002). Following the acclimation period, I recorded all birds observed or heard within the survey area during a 5-min period of passive observation.

Within each 25 m radius plot, I measured a number of environmental variables for use as site covariates. I assumed vegetation structure and composition were constant across sampling years and sampled vegetation only in 2009. I sub-sampled vegetation via three subplots placed along a central transect at distances of 0 m, 25 m, and 50 m from the forest edge (Figure 2). From the center of the vegetation subplot I measured 1) understory coverage via a Nudds board (Nudds 1977) at two cardinal directions (parallel to the forest edge) from 10 m away, 2) basal area with a 10-factor prism, and 3) canopy coverage with a densiometer (Strickler 1959). I also measured vegetation composition along a 5 m transect running through the center of the subplot and parallel to the forest edge. I identified to species all vegetation ≤ 2 m in height intersecting each transect. Due to difficulty in identification, the terms "ferns" and "grasses" were used to indicate all species within these groups. I identified plants to species (plants from the genera *Rubus* and *Trifolum* were only identified to genus) and as native or non-native species. The proportion of native plants at each site was calculated by dividing the number of decimeter sections of the 5 m transect that contained at least one native plant by the number of sections that contained any vegetation, either native or non-native. The proportions calculated for the transects at the forest edge, 25 m from the forest edge, and 50 m from the forest edge at each point were averaged to obtain a value of native plant proportion for each sample plot. I also calculated the diversity of native plants at each sample point using the Shannon Diversity Index (Pielou 1966). A $\log_{10}$ transformation was applied to insect biomass data and a square-root transformation was applied to basal area and non-vegetated ground data to meet the assumptions of normality and homoscedasticity. All means and 95% confidence intervals are reported as back-transformed values (JMP version 8.0.1, SAS Institute, Inc. 2009).

In 2009 and 2010 I sampled for invertebrates within a 1 m radius area at the center of the same transects used for the vegetation surveys. I vacuum sampled vegetation for invertebrates using a reverse leaf blower (Craftsman 25cc Gas Blower/Vac Model #358794740) fitted with a nylon mesh paint strainer bag. A single technician performed all vacuum sampling to minimize the effects of sampling technique. Following sampling, I searched the vegetation for any remaining Lepidoptera larvae. Specimens were frozen at -10ºC in plastic zip-top bags before being sorted to retain invertebrate taxa known to be preferred breeding songbird foods (Martin et al. 1951). These taxa include the orders Orthoptera, Hemiptera, Coleoptera, Lepidoptera, Araneae, Opiliones, Hymenoptera, Diptera, and Isopoda, and the classes Gastropoda and Diplopoda. To determine biomass, I dried samples at 55ºC until constant mass (≥ 48 h) and weighed them using a microbalance (Mettler AE 100) to the nearest 0.0001 g.

To elucidate patterns among vegetation, invertebrates, and birds, I selected a subset of bird species that are ground foragers or foliage-gleaners and forage on invertebrates primarily within my surveyed vegetation zone of ≤ 2 m above the ground. I selected the ground foraging species: Wood Thrush (*Hylocichla mustelina*), Ovenbird (*Seiurus aurocapilla*), Eastern Towhee (*Pipilo erythrophthalmus*), Northern Cardinal (*Cardinalis cardinalis*), American Robin (*Turdus migratorius*), Gray Catbird, and Carolina Wren (*Thryothorus ludovicanus*). The foliage gleaner Carolina Chickadee (*Poecile carolinensis*) was also selected.

I used habitat occupancy modeling for the 8 candidate species to examine bird habitat selection. This type of modeling uses the presence or absence of a species at a certain site to determine the site habitat covariates related to the occupancy of that species while accounting for the probability of detection using survey covariates (MacKenzie et al. 2006). I used site covariates which were consistent over the duration of the study period, such as canopy coverage or native plant proportion, and survey covariates which changed between repeat visits, such as temperature or cloud cover (MacKenzie et al. 2006). Covariates used in my analysis were the environmental conditions for each avian survey, plant species composition, vegetation structure measurements, and invertebrate biomass (Table 1).

I used Program PRESENCE version 2.0 (Hines 2006) to model occupancy for candidate species. The models were evaluated using Akaike Information Criterion corrected for small sample size (AICc) to determine the most parsimonious model (MacKenzie et al. 2006). I first modeled detection of each individual species using the survey covariates (temperature, minutes since sunrise, wind, and cloud cover). For each species, every single-variable model was considered, as well as a null model where detection was constant, and a global model containing all variables. Additional detection covariates were individually added to high-ranked single-variable models. If an added covariate did not improve the log-likelihood estimate of the simpler model by > 2, I removed this model, as this indicates the model with the additional covariate is not supported over the single-variable model (Burnham and Anderson 2002). Models with ΔAICc values > 2 were rejected due to a lack of empirical support (Burnham and

Anderson 2002). If multiple models had ΔAICc values ≤ 2, each detection model was included in the habitat occupancy models for that species (Burnham and Anderson 2002).

To limit the number of analyzed occupancy models, I incorporated the best supported model(s) of detection for each species into an *a priori* set of occupancy models, including single-variable models of site covariates, a null model where occupancy was considered constant, and a global model with all site covariates (Table 2). Models with a ΔAICc > 2 were rejected due to a lack of empirical support (Burnham and Anderson 2002). For models with variance-covariance matrix or model convergence errors, I attempted to resolve the errors by providing different initial values or fixing the beta value for certain parameters. If the error could not be resolved, the model was removed from the set, as it was possibly overparameterized (Cooch 2006).

Results

I detected 59 species of birds during my point count surveys (Appendix A). Across both seasons, I detected Wood Thrush at 73 plots (74.5%), Ovenbird at 44 plots (44.9%), Eastern Towhee at 70 plots (71.4%), Northern Cardinal at 74 plots (52.0%), American Robin at 52 plots (53.1%), Carolina Chickadee at 58 plots (59.2%), Gray Catbird at 78 plots (79.6%), and Carolina Wren at 50 plots (51.0%).

I observed 94 species of plants during vegetation surveys, (Appendix B), 78.7% of which are considered native to the study region (U.S. Department of Agriculture 2011). The proportion of non-native plants at the selected sampling plots covered a normally distributed range of values from 0 to 1 (mean = 0.616 ± SE 0.023). The Shannon Diversity Index of native plants ranged from 0.074 to 0.584 (mean = 0.166 ± SE

0.008). The basal density at sampling plots ranged from 0.82 m/ha to 11.08 m/ha (mean = 5.25 m/ha, 95% CI [4.85 m/ha, 5.66 m/ha]). Canopy coverage ranged from 66.02% to 97.57% (mean = 87.54% ± SE 0.6%). Non-vegetated ground ranged from 0% to 62.66.% (mean = 16.70%, 95% CI [13.69%, 20.25%]. Values for understory coverage ranged from 4.17% to 75.69% (mean = 40.34% ± SE 1.61%).

I collected 588 vacuum samples for invertebrates within the 98 plots at 3 points per site each season, for a total of 6 samples per plot. The area sampled for invertebrates at each point was approximately 6.28 m^3. Samples yielded 12,303 invertebrates from eleven orders totaling 19.41 g. Samples were sorted to retain taxa considered as preferred breeding songbird foods, totaling 12,108 individuals and 18.69 g (Table 3). Total invertebrate biomass collected from each invertebrate sampling point in 2009 ranged from 0.018 g/m^3 to 0.12 g/m^3 (mean = 0.049, 95% CI [0.046, 0.052]). In 2010, total invertebrate biomass collected from each invertebrate sampling point ranged from 0.022 g/m^3 to 0.18 g/m^3 (mean = 0.053, 95% CI [0.050, 0.056]).

The number of detection models with ΔAICc values ≤ 2 for each species ranged from one to four. Time since sunrise was a significant covariate in the detection of six candidate species, and temperature was an additional significant covariate for the detection of four species (Table 4). The number of occupancy models I analyzed for each species ranged from 9 to 36, dependent on the number of well-supported detection models for the species.

The proportion of native plants was the most important variable in predicting Wood Thrush occupancy, and was positively related to Wood Thrush occupancy (Table

5). Native plant proportion was also a well-supported model and was positively related to occupancy for Ovenbird, in addition to the null model, basal density, canopy coverage, and non-vegetated ground. For the Eastern Towhee, native plant proportion was again included in the set of well-supported models, as well as native plant diversity, basal density, non-vegetated ground, canopy coverage, understory coverage, and the null model. In this species, occupancy was negatively related to native plant proportion, but positively related to native plant diversity. For Northern Cardinal, diversity of native plants is a top model of occupancy, along with basal density and the null model.

Canopy coverage was the strongest predictor of occupancy of American Robin and Carolina Chickadee, and was positively related to occupancy in both species. For Gray Catbird, non-vegetated ground was the strongest predictor of occupancy, and was negatively related to Catbird occupancy. Invertebrate biomass was the strongest predictor of occupancy for the Carolina Wren. In 2009, Carolina Wren occupancy was positively related to biomass, and in 2010 this relationship was negative.

Discussion

Native plant proportion was a strongly supported model of occupancy for three bird species, Wood Thrush, Ovenbird, and Eastern Towhee, and native plant diversity was a strongly supported model for two species, Eastern Towhee and Northern Cardinal. Although the direction of the relationships varied by species (Table 6), this result indicates this relationship should be considered in landscape planning.

A positive relationship with native plants was the only well-supported model of Wood Thrush occupancy. Although no prior studies have specifically examined Wood

Thrush occupancy and native plant proportion, associations have been found between Wood Thrush occupancy and a number of native shrubs present at my study sites, including Arrowwood (*Viburnum dentatum*), Blackhaw (*Viburnum prunifolium*), Spicebush (*Lindera benzoin*), and Blueberry (*Vaccinium spp.*) (Evans et al. 2011). Blueberry acts as a summer food source for Wood Thrush (Martin et al. 1951), and the remaining shrub species are common nesting substrates for Wood Thrush in my study area (Longcore and Jones 1969, Hoover and Brittingham 1998).

Ovenbird occupancy was also positively associated with native plant proportion. Models of basal density and canopy coverage also had significant support for ovenbird, indicating the birds are more likely to occupy patches with higher basal density and canopy coverage. This agrees with previous studies which identified canopy coverage and basal density as important parameters in nest-site selection, likely associated with the requirement of leaf litter for this ground-nesting species (Van Horn and Donovan 2011). However, inclusion of native plants in their habitat requirements is a new finding.

Eastern Towhee occupancy was negatively related to native plant proportion, but positively related to native plant diversity. A positive relationship with native plant diversity may indicate a preference for specific native plants, such as *Vaccinium* species, which have been found to be associated with more diverse plant communities (Fredericksen 1999), and have been identified as an important summer food resource for Towhees (Greenlaw 1996). A negative relationship with native plant proportion may be related to the significant component of fruits, seeds, and other plant matter in the diet of this species throughout the breeding season (Greenlaw 1996). Non-native plant species found in my study plots, such as Japanese Honeysuckle and Wineberry, may act as fruit sources, although the nutritional quality of this fruit compared to the fruit of native species may be inferior (Drummond 2005). In addition to the vegetation composition covariates, four other vegetation structure covariates, understory coverage, basal area, canopy coverage, and non-vegetated ground, were in the top models of occupancy for this species, indicating that many variables are playing a role in Eastern Towhee occupancy. Supporting the idea that Towhees select for complex habitats, Greenlaw (1996) found Towhees had varying responses to canopy coverage, patches of open ground, and understory coverage.

The null model was the best model of occupancy for Northern Cardinal, indicating that none of our measured occupancy variables were significantly influencing occupancy of this species. Basal area and native plant diversity were also included in the set of best-supported models, although the relationships between these variables and Cardinal occupancy are weak, as the 95% CI of the beta for these models contained zero. My results suggest a negative relationship between Cardinal occupancy and basal area, which agrees with previously identified habitat preferences of Cardinals for areas with shrubs or small trees (Halkin and Linville 1999).

For the remaining candidate bird species, American Robin, Carolina Chickadee, and Gray Catbird, native plant proportion or diversity was not a strongly supported occupancy variable. Instead, varying structural characteristics of the vegetation were the most important factors that I measured in determining the occupancy of these species. Increased canopy coverage was the most important factor in American Robin occupancy in this study, but little support for the importance of this single variable exists in previous studies, as most have shown Robin habitat choice to be extremely variable (Sallabanks and James 1999). Increased canopy coverage was also the most important factor in occupancy of the Carolina Chickadee, as this species requires large trees to provide nest cavities and has been found in previous research to prefer sites with high canopy coverage (Mostrom et al. 2002). Decreasing percentage of non-vegetated ground was the best model of occupancy for Gray Catbird in this study, which is supported by past studies linking increasing Catbird abundance to increasing vegetation density (Cimprich and Moore 1995).

Invertebrate biomass was a strongly supported variable in the occupancy of Carolina Wren. The direction of the relationship between Wren occupancy and invertebrate biomass varied by season. Invertebrate biomass was not a well-supported variable in the occupancy of the other candidate species. The varying relationship in Carolina Wren and lack of relationship in other species may be due to the mechanism by which birds assess the invertebrate food supply within a territory. Birds respond to vegetation structural cues that indicate an adequate invertebrate food supply, rather than directly assessing the invertebrates within a territory (Marshall and Cooper 2004). In order for the vegetation structure of a habitat to act as a cue to birds as to the food supply in the area, a predictable and long-term relationship between vegetation structure and invertebrate biomass must exist, although annual variations in food supply are expected (Smith and Shugart 1987, Marshall and Cooper 2004). The two years of invertebrate sampling in this study may not have adequately accessed the long-term average invertebrate food supply at my sites. Additionally, a breakdown in the trophic relationship between invertebrate herbivores and non-native plants may be providing false cues about the area's food supply, and leading birds to preferentially select habitats with low invertebrate prey abundances. Finally, although the vacuum sampling technique used in this study effectively collects invertebrates from low vegetation (Doxon et al. 2011), I did not sample the leaf litter for invertebrates. If birds were responding to unsampled invertebrates, vacuum-sampled invertebrate biomass values may not be an accurate measure of the entire avian food supply within sampling plots. In future studies, litter collection and sampling over more seasons may provide a more accurate assessment of the average invertebrate community at my sites.

Overall, native plant proportion or native plant diversity was supported as strong variables in habitat occupancy for half of the candidate species in this study. This result supports that non-native plant invasion is affecting habitat occupancy of some songbird species in suburban forest fragments. Further study to determine the effect of native plant proportion on timing of nest initiation and nestling size and survivorship is needed to confirm the habitat quality and fitness impacts of non-native plants. One such study by Lloyd and Martin (2005) found Chestnut-collared Longspurs nested equally in native prairie and non-native Crested Wheatgrass (*Agropyron cristatum*), but nestlings in Crested Wheatgrass nests grew slower and had a smaller final weight than those developing in native prairie. Another study of Chipping Sparrows (*Spizella passerine*), found nest initiation was delayed in Spotted Knapweed (*Centaurea maculosa*) invaded habitats compared to univaded habitats (Ortega et al. 2006).

The modeling results suggest that managing non-native plant densities in suburban forest fragments for multiple bird species is a complicated process with many factors to consider. For species with occupancy positively related to native plant proportion, like Wood Thrush and Ovenbird, restoration of native plants in areas overcome by non-native plants may increase occupancy of the area. As Wood Thrush is listed as a Tier 1 Species of Conservation Concern in Delaware, indicating the need for conservation action (Allen et al. 2006), management for increased native plant proportion should be a concern for the conservation of this species. For the other candidate species whose occupancy was unrelated to native plant proportion or diversity, native plant restoration may have little impact on occupancy rates, as long as care is taken to maintain the structural cues to which each is responding. Non-native plant removal programs must be coupled with native plant restoration efforts to retain the understory structure and ground cover currently provided by non-native plants.

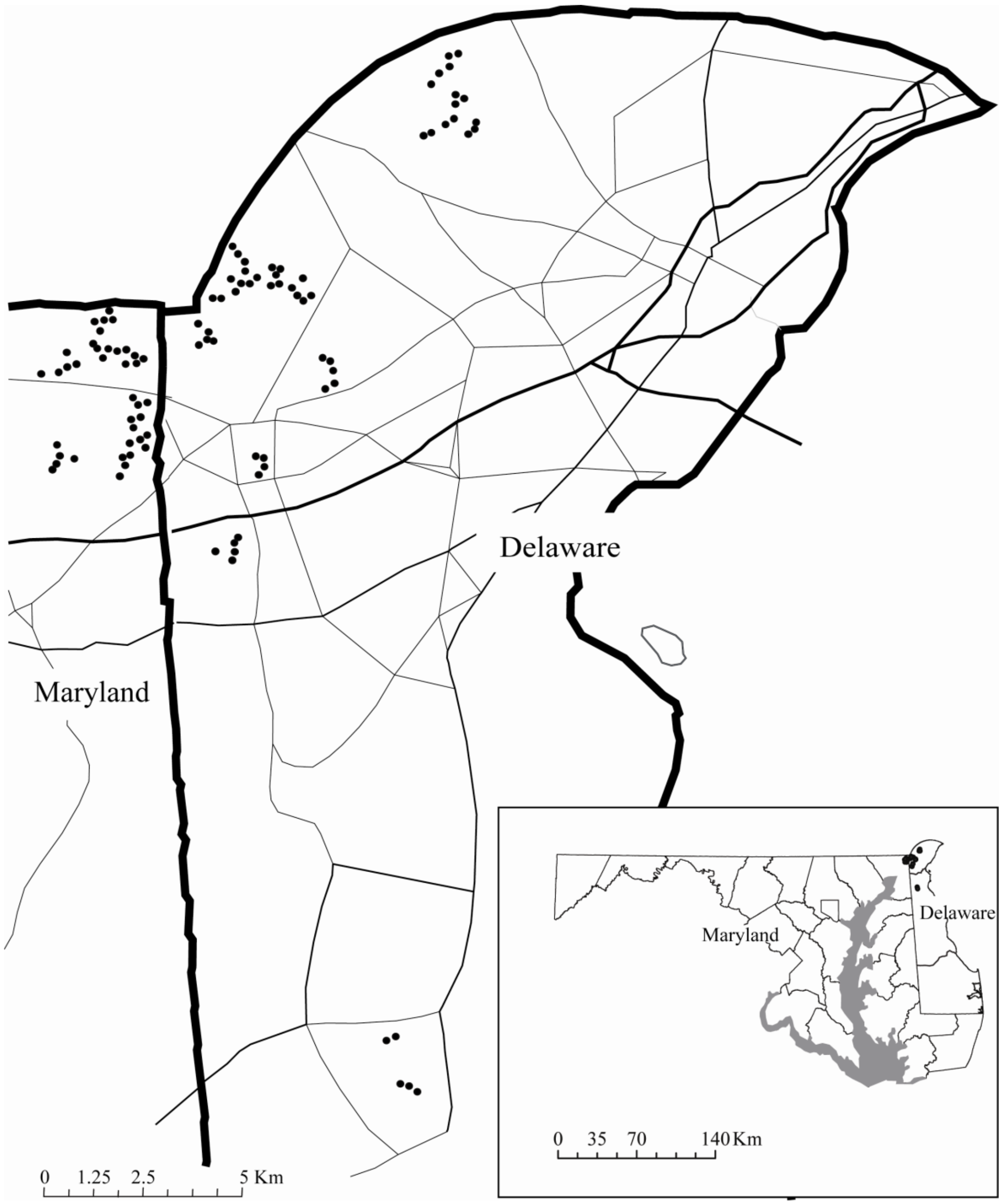

Figure 1. Map of study area in Maryland and Delaware, USA. Black circles indicate study sites where point counts for birds, vegetation sampling, and vacuum sampling for invertebrates were conducted from 15 May-7 August 2009−2010.

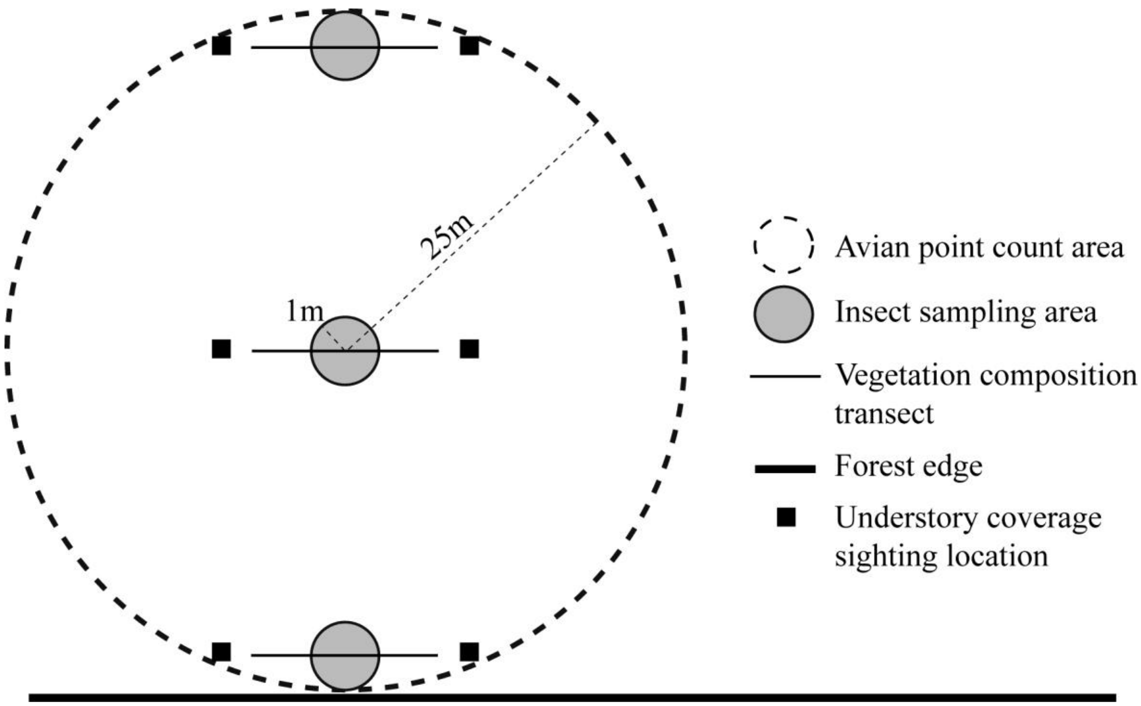

Figure 2 Design of study site for avian and vegetation surveys and invertebrate sampling within Delaware and Maryland forest fragments, 15 May-7 August 2009–2010.

Table 1 Survey and site covariates measured at study sites between 15 May-7 August 2009−2010 for use in developing occupancy models of 8 forest songbird species in Delaware and Maryland. Survey covariates were measured before each point count and site covariates were measured or calculated once across survey years.

Covariate	Units	Type
Time since sunrise (time)	Minutes	Survey
Wind	Binomial code	Survey
Temperature (temp)	°C	Survey
Cloud cover	%	Survey
Proportion of native plants (NPP)	%	Site
Native plant diversity (NPD)	Shannon Diversity Index	Site
Understory coverage (UC)	%	Site
Canopy coverage (canopy)	%	Site
Basal area (basal)	m/ha	Site
Non-vegetated ground (non-veg)	%	Site
Invertebrate biomass (inverts)	g	Site

Table 2 Model set used to estimate occupancy of 8 forest songbird species in forest fragments in Delaware and Maryland. Surveys conducted at 98 study sites during 15 May-7 August 2009−2010. Psi indicates occupancy covariates, and p indicates detection covariates.

Model	**Description**
psi(canopy),p(covariates)	Occupancy as a function of canopy coverage and detection covariates from models with ΔAICc ≤ 2
psi(basal),p(covariates)	Occupancy as a function of basal area and detection covariates from models with ΔAICc ≤ 2
psi(UC),p(covariates)	Occupancy as a function of understory coverage and detection covariates from models with ΔAICc ≤ 2
psi(NPP), p(covariates)	Occupancy as a function of native plant proportion and detection covariates from models with ΔAICc ≤ 2
psi(NPD), p(covariates)	Occupancy as a function of native plant diversity and detection covariates from models with ΔAICc ≤ 2
psi(inverts), p(covariates)	Occupancy as a function of invertebrate biomass and detection covariates from models with ΔAICc ≤ 2
psi(non-veg), p(covariates)	Occupancy as a function of non-vegetated ground and detection covariates from models with ΔAICc ≤ 2
psi(.), p(covariates)	Constant occupancy and detection covariates from models with ΔAICc ≤ 2
psi(global), p(covariates)	Occupancy as a function of all covariates and detection covariates from models with ΔAICc ≤ 2

Table 3 List of invertebrate taxa collected during vacuum sampling of vegetation in forest fragments in Delaware and Maryland during June 2009 and 2010. Sampling conducted once each year at 98 sites.

		Number of Individuals		
	Taxon	**2009**	**2010**	**Total**
Retained as bird food items	Diptera	1352	3233	4585
	Hemiptera	918	1536	2454
	Hymenoptera	614	1153	1767
	Araneae	498	718	1216
	Orthoptera	207	336	543
	Coleoptera	238	266	504
	Opiliones	235	233	468
	Lepidoptera	171	244	415
	Gastropoda	35	65	100
	Pulmonata	32	15	47
	Collembola	22	61	83
	Diplopoda	22	14	36
	Isopoda	15	7	8
Removed as non-food items	Dermaptera	5	10	15
	Psocoptera	2	16	18
	Neuroptera	7	1	8
	Acari (excluding Araneae)	2	6	8
	Mantodea	2	4	6
	Mecoptera	3	1	4
	Plecoptera	2	2	4

Table 4 Top ranked models (ΔAIC ≤ 2) of variables affecting detection of 8 forest songbird species during point count surveys in Delaware and Maryland from 15 May-7 August 2009−2010. Table presents Akaike's Information Criterion (AICc), the difference in AIC value compared to the top-ranked model (ΔAICc), the AIC model weight (W), and the number of parameters in the model (K).

Species	**Model**	**AICc**	**ΔAICc**	**W**	**K**
Wood thrush	psi(.),p(temp, time)	646.91	0	0.3306	4
	psi(.),p(time)	647.58	0.67	0.2365	3
Ovenbird	psi(.),p(time)	394.47	0	0.2168	3
	psi(.),p(temp)	395.52	1.05	0.1283	3
Eastern towhee	psi(.),p(cloud cover, temp)	653.15	0	0.3796	4
	psi(.),p(temp)	653.69	0.54	0.2898	3
	psi(.),p(global)	654.93	1.78	0.1559	5
Northern cardinal	psi(.),p(time)	638.84	0	0.3286	3
	psi(.),p(.)	639.6	0.76	0.2247	2
American robin	psi(.),p(.)	505.27	0	0.2604	2
	psi(.),p(cloud cover)	505.64	0.37	0.2164	3
	psi(.),p(temp)	506.37	1.1	0.1502	3
	psi(.),p(time)	507.12	1.85	0.1032	3
Carolina chickadee	psi(.),p(time)	473.92	0	0.7229	3
	psi(.),p(global)	475.84	1.92	0.2768	5
Gray catbird	psi(.),p(time)	736.77	0	0.6524	3
Carolina wren	psi(.),p(.)	428.37	0	0.3978	2

Table 5 Top ranked models of variables affecting occupancy of 8 forest songbird species during point count surveys in Delaware and Maryland from 15 May-7 August 2009−2010. Table presents corrected Akaike's Information Criterion (AICc), the difference in AIC value compared to the top-ranked model (ΔAICc), the AIC model weight (W), the number of parameters in the model (K), and the beta and standard error (β (SE)).

Species	Model	AICc	ΔAICc	W	K	β (SE)
Wood thrush	psi(NPP),p(time, temp)	639.67	0	0.4618	5	4.77 (1.72)
	psi(NPP),p(time)	640.15	0.48	0.3633	4	4.70 (1.69)
Ovenbird	psi(.),p(temp)	394.47	0	0.1302	3	0.65 (0.47)
	psi(basal),p(time)	394.98	0.51	0.1009	3	0.63 (0.45)
	psi(canopy),p(temp)	395.35	0.88	0.0839	4	6.49 (5.61)
	psi(NPP),p(temp)	395.51	1.04	0.0774	4	1.69 (1.68)
	psi(.),p(time)	395.52	1.05	0.077	3	0.65 (0.48)
	psi(basal),p(temp)	395.85	1.38	0.0653	4	0.53 (0.74)
	psi(non-veg),p(temp)	396.36	1.89	0.0506	4	1.14 (2.21)
	psi(NPP),p(time)	396.45	1.98	0.0484	4	1.78 (1.71)
Eastern towhee	psi(.),p(clouds, time)	653.15	0	0.0874	4	
	psi(NPD),p(clouds, time)	653.17	0.02	0.0865	5	2.30 (1.66)
	psi(NPP),p(clouds, time)	653.28	0.13	0.0819	5	-2.55 (2.23)
	psi(NPD),p(temp)	653.61	0.46	0.0694	4	2.31 (1.66)
	psi(.),p(temp)	653.69	0.54	0.0667	3	
	psi(basal),p(clouds, time)	653.71	0.56	0.066	5	0.59 (0.50)
	psi(NPP),p(temp)	653.77	0.62	0.0641	4	-2.51 (2.17)
	psi(basal),p(temp)	654.36	1.21	0.0477	4	0.54 (0.48)
	psi(canopy),p(clouds, time)	654.47	1.32	0.0451	5	-5.39 (6.60)
	psi(non-veg),p(clouds, time)	654.71	1.56	0.04	5	-1.44 (1.82)
	psi(.),p(global)	654.93	1.78	0.0359	5	
	psi(UC),p(clouds, time)	654.95	1.8	0.0355	5	-1.30 (2.03)
	psi(NPD),p(global)	654.96	1.81	0.0353	6	2.32 (1.67)

(continued)

Table 5. Continued

	psi(NPP),p(global)	654.99	1.84	0.0348	6	-2.69 (2.38)
	psi(canopy),p(temp)	654.99	1.84	0.0348	4	-5.21 (6.41)
	psi(non-veg),p(temp)	655.06	1.91	0.0336	4	-1.58 (1.83)
Northern cardinal	psi(.),p(time)	638.84	0	0.1901	3	
	psi(.),p(.)	639.6	0.76	0.13	2	
	psi(basal),p(time)	640.65	1.81	0.0769	4	-0.31 (0.54)
	psi(NPD),p(time)	640.83	1.99	0.0703	4	-1.19 (2.81)
American robin	psi(canopy),p(.)	498.24	0	0.2705	3	14.59 (4.47)
	psi(canopy),p(cloud cover)	498.93	0.69	0.1916	4	14.15 (4.17)
	psi(canopy),p(temp)	499.41	1.17	0.1507	4	14.46 (4.34)
	psi(canopy),p(time)	500.07	1.83	0.1083	4	14.60 (4.47)
Carolina chickadee	psi(canopy),p(time)	473.33	0	0.2405	4	11.05 (45.89)
	psi(.),p(time)	473.92	0.59	0.1791	3	
	psi(canopy),p(global)	475.2	1.87	0.0944	6	11.93 (1.51)
Gray catbird	psi(non-veg),p(time)	726.37	0	0.7848	4	1.75 (1.49)
Carolina wren	psi(inverts),p(.)	424.52	0	0.6576	4	2009: 8.02 (6.35)

Table 6 Variables in top models (ΔAIC ≤ 2) of occupancy for 8 forest songbird species during point count surveys in Delaware and Maryland from 15 May-7 August 2009−2010. Variables in top models indicated with an "X" and symbol in parentheses shows the direction of the relationship between occupancy and the covariate as positive (+), negative (-), or unresolved (0), indicating the 95% CI for beta of the model included zero.

	Site Covariates						
Bird species	Native plant proportion	Native plant diversity	Understory coverage	Canopy coverage	Basal area	Non-vegetated ground	Invertebrate biomass
American Robin				X (+)			
Carolina Chickadee				X (+)			
Carolina Wren							X (+/-)
Eastern Towhee	X (-)	X (+)	X (+)	X (0)	X (+)	X (0)	
Gray Catbird						X (-)	
Northern Cardinal		X (0)			X (0)		
Ovenbird	X (+)			X (+)	X (+)	X (0)	
Wood Thrush	X (+)						

APPENDIX A

BIRD SPECIES DETECTED DURING POINT COUNT SURVEYS THROUGHOUT DELAWARE AND MARYLAND. SURVEYS CONDUCTED THREE TIMES PER YEAR AT 98 SITES FROM 15 MAY-7 AUGUST 2009−2010.

Scientific Name	English Name	Number of Detections
Agelaius phoeniceus	Red-winged blackbird	31
Ardea herodias	Great blue heron	1
Baeolophus bicolor	Tufted titmouse	79
Bombycilla cedrorum	Cedar waxwing	2
Buteo lineatus	Red-shouldered hawk	2
Cardinalis cardinalis	Northern Cardinal	183
Catharus fuscescens	Veery	13
Coccyzus americanus	Yellow-billed cuckoo	1
Colaptes auratus	Northern flicker	19
Contopus virens	Eastern wood pewee	68
Corvus brachyrhynchos	American crow	15
Cyanocitta cristata	Blue jay	50
Dendroica caerulescens	Black-throated blue warbler	1
Dendroica cerulean	Cerulean warbler	1
Dendroica pensylvanica	Chestnut-sided warbler	5
Dendroica petechia	Yellow warbler	7
Dryocopus pileatus	Pileated woodpecker	4
Dumetella carolinensis	Gray catbird	549
Empidonax traillii	Willow flycatcher	4
Empidonax virescen	Acadian flycatcher	112
Geothlypis trichas	Common yellowthroat	19
Hylocichla mustelina	Wood thrush	186
Icterus galbula	Baltimore oriole	3
Melanerpes carolinus	Red-bellied woodpecker	50
Melospiza melodia	Song sparrow	12
Mimus polyglottos	Northern mockingbird	4

(continued)

Appendix A. Continued.

Mniotilta varia	Black and white warbler	1
Molothrus ater	Brown-headed cowbird	12
Myiarchus crinitus	Great crested flycatcher	23
Oporornis formosus	Kentucky warbler	9
Parkesia motacilla	Louisiana waterthrush	5
Passer domesticus	House sparrow	1
Passerina cyanea	Indigo bunting	37
Picoides pubescens	Downy woodpecker	46
Picoides villosus	Hairy woodpecker	23
Pipilo erythrophthalmus	Eastern towhee	219
Piranga olivacea	Scarlet tanager	1
Poecile carolinensis	Carolina chickadee	136
Polioptila caerula	Blue-grey gnatcatcher	27
Quiscalus quiscula	Common Grackle	1
Sayornis phoebe	Eastern pheobe	2
Seiurus aurocapillus	Ovenbird	73
Setophaga ruticilla	American redstart	30
Sialia sialis	Eastern bluebird	2
Sitta carolinensis	White-breasted nuthatch	40
Spinus tristis	American goldfinch	3
Spizella passerina	Chipping sparrow	3
Strix varia	Barred owl	1
Thryothorus ludovicianus	Carolina wren	82
Toxostoma rufum	Brown thrasher	21
Troglodytes aedon	House wren	13
Turdus migratorius	American robin	246
Vireo flavifron	Yellow-throated vireo	3
Vireo griseus	White-eyed vireo	19
Vireo olivaceus	Red-eyed vireo	75
Vireo solitarius	Blue-headed vireo	1
Wilsonia citrina	Hooded warbler	1
Zenaida macroura	Mourning dove	4

APPENDIX B

LIST OF PLANT SPECIES DETECTED DURING VEGETATION SURVEYS THROUGHOUT STUDY SITES IN DELAWARE AND MARYLAND. SURVEYS CONDUCTED IN JUNE 2009 AT 98 SITES. NATIVE STATUS APPLIES TO STUDY REGION.

Scientific Name	**Common Name**	**Native Status**
Acer negundo	Box elder	Native
Acer platanoides	Norway maple	Non-native
Acer rubrum	Red maple	Native
Agastache foeniculum	Licorice mint	Native
Alliaria petiolata	Garlic mustard	Non-native
Amphicarpaea bracteata	American hogpeanut	Native
Aralia nudicaulis	Wild sarsaparilla	Native
Arisaema triphyllum	Jack-in-the-pulpit	Native
Asclepias syriaca	Milkweed	Native
Barbarea vulgaris	Common wintercress	Non-native
Berberis thunbergii	Japanese barberry	Non-native
Betula lenta	Sweet birch	Native
Betula occidentalis	Water birch	Native
Carpinus caroliniana	Hornbeam	Native
Carya cordiformis	Bitternut hickory	Native
Carya glabra	Pignut	Native
Celastrus orbiculatus	Oriental bittersweet	Non-native
Cercis canadensis	Eastern redbud	Native
Circaea lutetiana	Enchanters nightshade	Native
Cirsium arvense	Canadian thistle	Non-native
Clematis virginiana	Virgin's bower	Native
Clethra alnifolia	Sweet pepperbush	Native
Conium maculatum	Poison hemlock	Non-native
Cornus florida	Flowering dogwood	Native

(continued)

Appendix B. Continued.

Crataegus spp.	Hawthorn spp.	Native
Diervilla lonicera	Bush honeysuckle	Native
Dryopteris carthusiana	Spinulose woodfern	Native
Elaeagnus umbellata	Autumn olive	Non-native
Euonymus americanus	Bursting heart	Native
Eurybia divaricata	White wood aster	Native
Fagus grandifolia	American beech	Native
Fragaria virginiana	Wild strawberry	Native
Fraxinus americana	White ash	Native
Galium spp.	Bedstraw	Native
Gleditsia triacanthos	Honey locust	Native
Hamamelis virginiana	Witch hazel	Native
Hedera helix	English ivy	Non-native
Hydrangea quercifolia	Oak-leaf hydrangea	Native
Ilex opaca	American holly	Native
Impatiens capensis	Jewelweed	Native
Juglans nigra	Black walnut	Native
Kalmia latifoli	Mountain laurel	Native
Leucothoe fontanesiana	Greensprite	Native
Lindera benzoin	Spicebush	Native
Liquidambar styraciflua	American sweetgum	Native
Liriodendron tulipifera	Tuliptree	Native
Lonicera japonica	Japanese honeysuckle	Non-native
Medeola virginiana	Indian cucumber root	Native
Mentha arvensis	Wild mint	Native
Microstegium vimineum	Japanese stilt-grass	Non-native
Mitchella repens	Partridgeberry	Native
Morus alba	White mulberry	Non-native
Neviusia alabamensis	Alabama snow wreath	Native
Nyssa sylvatica	Black gum	Native
Onoclea sensibilis	Sensitive fern	Native
Ostrya virginiana	Ironwood	Native
Pachysandra terminalis	Japanese pachysandra	Non-native
Parthenocissus quinquefolia	Virginia creeper	Native
Persicaria perfoliata	Mile-a-minute weed	Non-native
Persicaria virginiana	Virginia knotweed	Native

(continued)

Appendix B. Continued.

Phytolacca americana	American pokeweed	Native
Pinus strobus	Eastern white pine	Native
Platanus occidentalis	American sycamore	Native
Podophyllum peltatum	May apple	Native
Polemonium caeruleum	Jacob's ladder	Native
Portulaca oleracea	Little hogweed	Non-native
Prunus serotina	Black Cherry	Native
Quercus alba	White Oak	Native
Quercus prinus	Chestnut oak	Native
Robinia pseudoacacia	Black locust	Non-native
Rosa multiflora	Multiflora rose	Non-native
Rubus phoenicolasius	Wineberry	Non-native
Rubus spp.	Raspberry	Native/Non-native
Rudbeckia hirta	Black eyed susans	Native
Sanguinaria canadensis	Bloodroot	Native
Sassafras albidum	Sassafrass	Native
Silene stellata	Starry campion	Native
Smilax rotundifolia	Greenbriar	Native
Solidago virgaurea	Goldenrod	Native
Staphylea trifolia	American bladdernut	Native
Stylophorum diphyllum	Wood poppy	Native
Symplocarpus foetidus	Skunk cabbage	Native
Toxicodendron radicans	Poison ivy	Native
Trifolium spp.	Clover	Non-native
Tsuga canadensis	Eastern hemlock	Native
Urtica dioica	Stinging nettle	Native
Vaccinium angustifolium	Lowbush blueberry	Native
Viburnum acerifolium	Maple leaf viburnum	Native
Viburnum dentatum	Arrowood viburnum	Native
Viburnum pruniforum	Blackhaw	Native
Viola spp.	Violet	Native

APPENDIX C

MODELS OF VARIABLES AFFECTING PROBABILITY OF OCCUPANCY OF 8 FOREST SONGBIRD SPECIES DURING POINT COUNT SURVEYS IN DELAWARE AND MARYLAND FROM 15 MAY - 7 AUGUST 2009−2010. TABLE PRESENTS THE DIFFERENCE IN AICc VALUE COMPARED TO THE TOP-RANKED MODEL (ΔAICc), THE AIC MODEL WEIGHT (W), THE NUMBER OF PARAMETERS IN THE MODEL (K), AND THE SLOPE AND STANDARD ERROR OF THE RELATIONSHIP BETWEEN THE VARIABLE AND OCCUPANCY (Β).

Appendix C.1. Wood Thrush

Model	ΔAICc	W	K	β (SE)
psi(NPP),p(time, temp)	0	0.4618	5	4.77 (1.72)
psi(NPP),p(time)	0.48	0.3633	4	4.70 (1.69)
psi(basal),p(time, temp)	5.03	0.0373	5	1.26 (0.75)
psi(UC),p(time, temp)	5.48	0.0298	5	-6.83 (4.59)
psi(basal),p(time)	5.71	0.0266	4	1.20 (0.72)
psi(UC),p(time)	6.25	0.0203	4	-6.43 (4.30)
psi(.),p(time, temp)	7.24	0.0124	4	
psi(.),p(time)	7.91	0.0088	3	
psi(canopy),p(time, temp)	8.42	0.0069	5	6.87 (8.39)
psi(non-veg),p(time, temp)	8.52	0.0065	5	2.12 (2.24)
psi(canopy),p(time)	9.15	0.0048	4	6.28 (7.50)
psi(non-veg),p(time)	9.2	0.0046	4	1.96 (2.14)
psi(NPD),p(time, temp)	9.33	0.0044	5	0.96 (2.85)
psi(NPD),p(time)	10	0.0031	4	0.71 (2.57)
psi(inverts),p(time, temp)	10.46	0.0025	6	2009: 1.21 (1.17) 2010: -1.16 (1.69)
psi(global),p(time, temp)	10.49	0.0024	13	
psi(global),p(time)	10.49	0.0024	12	
psi(inverts),p(time)	10.84	0.002	5	

AICc of top model = 639.67

Appendix C.2. Ovenbird

Model	ΔAICc	W	K	β (SE)
psi(.),p(temp)	0.00	0.1302	3	0.65 (0.47)
psi(basal),p(time)	0.51	0.1009	3	0.63 (0.45)
psi(canopy),p(temp)	0.88	0.0839	4	6.49 (5.61)
psi(NPP),p(temp)	1.04	0.0774	4	1.69 (1.68)
psi(.),p(time)	1.05	0.077	3	0.65 (0.48)
psi(basal),p(temp)	1.38	0.0653	4	0.53 (0.74)
psi(non-veg),p(temp)	1.89	0.0506	4	1.14 (2.21)
psi(NPP),p(time)	1.98	0.0484	4	1.78 (1.71)
psi(UC),p(temp)	2.16	0.0442	4	0.20 (2.22)
psi(UC),p(temp, time)	2.28	0.0416	5	0.32 (2.18)
psi(non-veg),p(time)	3.08	0.0279	4	0.78 (2.16)
psi(UC),p(time)	3.22	0.026	4	-0.05 (2.23)
psi(NPD),p(time)	3.22	0.026	4	-0.11 (1.83)
psi(inverts),p(temp)	4.3	0.0152	5	2009: 0.29 (1.00) 2010: -0.21 (1.37)
psi(inverts),p(time)	5.34	0.009	5	2009: 0.28 (0.99) 2010: -0.28 (1.32)
psi(global),p(time)	14.23	0.0001	11	

AICc of top model = 394.47

Appendix C.3. Eastern Towhee

Model	ΔAICc	W	K	β (SE)
psi(.),p(clouds, time)	0	0.0874	4	
psi(NPD),p(clouds, time)	0.02	0.0865	5	2.30 (1.66)
psi(NPP),p(clouds, time)	0.13	0.0819	5	-2.55 (2.23)
psi(NPD),p(temp)	0.46	0.0694	4	2.31 (1.66)
psi(.),p(temp)	0.54	0.0667	3	
psi(basal),p(clouds, time)	0.56	0.066	5	0.59 (0.50)
psi(NPP),p(temp)	0.62	0.0641	4	-2.51 (2.17)
psi(basal),p(temp)	1.21	0.0477	4	0.54 (0.48)
psi(canopy),p(clouds, time)	1.32	0.0451	5	-5.39 (6.60)
psi(non-veg),p(clouds, time)	1.56	0.04	5	-1.44 (1.82)
psi(.),p(global)	1.78	0.0359	5	
psi(UC),p(clouds, time)	1.8	0.0355	5	-1.30 (2.03)
psi(NPD),p(global)	1.81	0.0353	6	2.32 (1.67)
psi(NPP),p(global)	1.84	0.0348	6	-2.69 (2.38)
psi(canopy),p(temp)	1.84	0.0348	4	-5.21 (6.41)
psi(non-veg),p(temp)	1.91	0.0336	4	-1.58 (1.83)
psi(UC),p(temp)	2.33	0.0272	4	-1.22 (2.00)
psi(basal),p(global)	2.45	0.0257	6	0.57 (0.50)
psi(canopy),p(global)	3.21	0.0175	6	-5.17 (6.48)
psi(non-veg),p(global)	3.33	0.0165	6	-1.52 (1.84)
psi(inverts),p(clouds, time)	3.57	0.0147	6	2009: 0.71 (1.00) 2010: -0.68 (1.03)
psi(UC),p(global)	3.65	0.0141	6	-1.28 (2.03)
psi(inverts),p(temp)	4.08	0.0114	5	2009: 0.67 (0.99) 2010: -0.65 (1.02)
psi(inverts),p(global)	5.48	0.0056	7	2009: 0.70 (1.00) 2010: -0.66 (1.03)
psi(global),p(clouds, time)	8.27	0.0014	12	
psi(global),p(temp)	8.69	0.0011	11	

AICc of top model = 653.15

Appendix C.4. Northern Cardinal

Model	ΔAICc	W	K	β (SE)
psi(.),p(time)	0	0.1901	3	
psi(.),p(.)	0.76	0.13	2	
psi(basal),p(time)	1.81	0.0769	4	-0.31 (0.54)
psi(NPD),p(time)	1.99	0.0703	4	-1.19 (2.81)
psi(global),p(time)	2.01	0.0696	11	
psi(non-veg),p(time)	2.03	0.0689	4	0.95 (2.53)
psi(canopy),p(time)	2.17	0.0642	4	0.30 (10.54)
psi(UC),p(.)	2.68	0.0498	3	-1.84 (4.28)
psi(non-veg),p(.)	2.71	0.049	3	1.09 (2.62)
psi(npp),p(.)	2.73	0.0486	3	-0.82 (2.14)
psi(NPD),p(.)	2.73	0.0486	3	-1.20 (2.96)
psi(canopy),p(.)	2.89	0.0448	3	0.58 (10.90)
psi(inverts),p(time)	2.92	0.0442	5	
psi(inverts),p(.)	3.4	0.0347	4	
psi(basal),p(.)	5.83	0.0103	3	-0.31 (0.54)
psi(global),p(.)	18.9	0	10	-1.19 (2.81)

AICc of top model = 638.84

Appendix C. 5. American Robin

Model	ΔAICc	W	K	β (SE)
psi(canopy),p(.)	0	0.2705	3	14.59 (4.47)
psi(canopy),p(clouds)	0.69	0.1916	4	14.15 (4.17)
psi(canopy),p(temp)	1.17	0.1507	4	14.46 (4.34)
psi(canopy),p(time)	1.83	0.1083	4	14.60 (4.47)
psi(non-veg),p(.)	3.62	0.0443	3	3.57 (1.69)
psi(non-veg),p(clouds)	4.3	0.0315	4	3.41 (1.64)
psi(non-veg),p(temp)	4.7	0.0258	4	3.56 (1.67)
psi(non-veg),p(time)	5.52	0.0171	4	3.56 (1.69)
psi(UC),p(.)	5.79	0.015	3	-3.08 (1.76)
psi(UC),p(clouds)	6.31	0.0115	4	-2.97 (1.72)
psi(global),p(.)	6.33	0.0114	10	
psi(NPP),p(.)	6.39	0.0111	3	2.11 (1.36)
psi(NPP),p(clouds)	6.91	0.0085	4	
psi(UC),p(temp)	6.99	0.0082	4	-3.03 (1.74)
psi(.),p(.)	7.03	0.008	2	
psi(.),p(clouds)	7.4	0.0067	3	
psi(global),p(temp)	7.51	0.0063	11	
psi(NPP),p(temp)	7.62	0.006	4	2.05 (1.33)
psi(UC),p(time)	7.66	0.0059	4	-3.08 (1.76)
psi(global),p(cloud)	7.68	0.0058	11	
psi(inverts),p(.)	7.71	0.0057	4	2009: -1.34 (0.95) 2010: 1.58 (1.16)
psi(.),p(temp)	8.13	0.0046	3	
psi(basal),p(.)	8.14	0.0046	3	0.37 (0.38)
psi(NPP),p(time)	8.22	0.0044	4	2.13 (1.37)
psi(inverts),p(clouds)	8.32	0.0042	5	2009: -1.32 (0.94) 2010: 1.52 (1.17)
psi(NPD),p(.)	8.47	0.0039	3	1.25 (1.6)
psi(basal),p(clouds)	8.7	0.0035	4	0.34 (0.36)
psi(inverts),p(temp)	8.73	0.0034	5	2009: -1.38 (0.95) 2010: 1.59 (1.15)
psi(global),p(time)	8.78	0.0034	11	
psi(.),p(time)	8.88	0.0032	3	
psi(NPD),p(clouds)	8.92	0.0031	4	1.17 (1.53)
psi(basal),p(temp)	9.39	0.0025	4	0.35 (0.37)
psi(NPD),p(temp)	9.55	0.0023	4	1.30 (1.60)

(continued)

Appendix C.5. Continued.

psi(inverts),p(time)	9.76	0.0021	5	2009: -1.32 (0.95) 2010: 1.56 (1.17)
psi(basal),p(time)	9.95	0.0019	4	0.39 (0.38)
psi(NPD),p(time)	10.38	0.0015	4	1.23 (1.59)
psi(.),p(global)	10.48	0.0014	5	

AICc of top model = 498.24

Appendix C.6. Carolina Chickadee

Model	ΔAICc	W	K	B (SE)
psi(canopy),p(time)	0	0.2405	4	11.05 (45.88)
psi(.),p(time)	0.59	0.1791	3	
psi(canopy),p(global)	1.87	0.0944	6	11.93 (1.51)
psi(NPD),p(time)	2.07	0.0854	4	2.20 (3.07)
psi(basal),p(time)	2.42	0.0717	4	-0.42 (0.83)
psi(.),p(global)	2.51	0.0686	5	-0.56 (3.09)
psi(non-veg),p(time)	2.73	0.0614	4	0.50 (2.74)
psi(inverts),p(time)	3.05	0.0523	5	2009: -1.79 (1.43) 2010: -0.80 (1.71)
psi(NPD),p(global)	4.01	0.0324	6	2.59 (3.64)
psi(NPP),p(global)	4.36	0.0272	6	-1.267 (2.02)
psi(basal),p(global)	4.64	0.0236	6	-0.29 (0.88)
psi(non-veg),p(global)	4.71	0.0228	6	-0.88 (3.44)
psi(UC),p(global)	4.74	0.0225	6	0.50 (2.74)
psi(inverts),p(global)	5.18	0.018	7	2009: -1.85 (1.48) 2010: -0.89 (1.83)

AICc of top model = 473.33

Appendix C.7. Gray Catbird

Model	ΔAICc	W	K	β (SE)
psi(non-veg),p(time)	0	0.7848	4	1.75 (1.49)
psi(inverts),p(time)	3.9	0.1117	5	2009: 2.23 (0.93) 2010: -2.33 (1.11)
psi(global),p(time)	4.83	0.0701	12	
psi(basal),p(time)	8.12	0.0135	4	-0.75 (0.37)
psi(UC),p(time)	9.83	0.0058	4	2.87 (1.78)
psi(.),p(time)	10.4	0.0043	3	
psi(canopy),p(time)	10.89	0.0034	4	-6.61 (5.71)
psi(NPP),p(time)	10.96	0.0033	4	-1.53 (1.24)
psi(NPD),p(time)	11.07	0.0031	4	1.75 (1.49)

AICc of top model = 726.37

Appendix C.8. Carolina Wren

Model	ΔAICc	W	K	β (SE)
psi(inverts),p(.)	0.00	0.6576	4	2009: 8.02 (6.35) 2010: -7.24 (5.26)
psi(.),p(.)	3.85	0.0959	2	
psi(NPD),p(.)	4.84	0.0585	3	3.74 (5.35)
psi(canopy),p(.)	5.37	0.0449	3	6.47 (11.16)
psi(basal),p(.)	5.46	0.0429	3	-0.54 (0.84)
psi(npp),p(.)	5.94	0.0337	3	-0.37 (1.92)
psi(UC),p(.)	5.96	0.0334	3	-0.44 (2.78)
psi(non-veg),p(.)	5.98	0.0331	3	0.04 (3.02)

AICc of top model = 424.52

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