SEASONAL CORRELATIONS BETWEEN *PUERARIA MONTANA* VAR. *LOBATA* AND AVIAN SPECIES DIVERSITY AND RELATIVE ABUNDANCE IN HAMILTON COUNTY, TENNESSEE

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ABSTRACT

Invasive species exist outside of their native ranges and can cause environmental harm where they have been introduced. One such species is kudzu (*Pueraria montana* var. *lobata*), an invasive vine in the southeastern U.S. Although kudzu is one of the most common invasive species management concerns in the Southeast, there is little quantitative data documenting its effects on native species. This study examines the seasonal correlations between kudzu and avian species diversity and relative abundance in Hamilton County, Tennessee. By measuring the characteristics of the overstory, midstory, and understory vegetation at sites with differing levels of kudzu coverage, I examined correlations between kudzu density and avian demographics. Kudzu coverage had a significant negative impact on avian diversity and species richness, as well as on native vegetation. Kudzu's alteration of vegetation structure, through the creation of a monoculture and subsequent reduction of structural diversity, was likely the cause of reduced avian diversity and richness due to a decrease in the availability of structurally oriented guilds.

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LIST OF ABBREVIATIONS

ANOVA, Analysis of Variance

CFI, CF Industries Holdings, Inc.

DBH, diameter at breast height

ES, Enterprise South

EST, Eastern Standard Time

HV1, Hickory Valley 1

HV2, Hickory Valley 2

TNT, Trinitrotoluene

TWRA, Tennessee Wildlife Resources Agency

USDA, United States Department of Agriculture

VAAP, Volunteer Army Ammunition Plant

CHAPTER I

INTRODUCTION

Threat of Invasive Plants

Invasive species are primary foci of much scientific research in the U.S. because of the threat they pose to native ecosystems and biodiversity (Ferdinands et al. 2005, Forseth and Innis 2004, Gordon 1998, Morse et al. 1995, NPS 2010, Sandlund 1999, Wilcox and Beck 2007). Invasive species are defined as species not native to the ecosystem under consideration, for which introduction is likely to cause environmental or economic harm (NISC 2008). While there are non-native plants in the U.S., particularly crop species, that are considered very beneficial both to human welfare and the economy, they are not classified as invasive species because of their perceived positive impact (NISC 2008, Pimentel et al. 2000). It has been estimated that there are approximately 50,000 non-native species that have been introduced to the U.S., although many are not considered harmful (Pimentel et al. 2000). An estimated 5,000 of these non-native plant species occur in natural habitats. Many of these invasive plants are spreading and invading new ecosystems, and are outcompeting and displacing native species (Morse et al. 1995, NISC 2008). Invasive plants threaten biodiversity of native plant communities and can alter ecosystems by decreasing structural integrity (Sandlund et al. 1999), modifying ecosystem function (Gordon 1998), changing ecosystem and evolutionary processes (Mooney and Cleland 2001), and causing a decline in native species success and diversity (Ferdinands et al. 2005, Wilcox and Beck 2007).

Invasive species also have substantial economic impacts in the U.S. An analysis of all non-native species in the U.S. estimated that damage, primarily loss of crop yield, and control costs from invasive species total $137 billion per year (Pimentel et al. 2000). This value does not include the cost of loss of biodiversity, species extinctions, aesthetics, and ecosystem services (e.g. carbon sequestration, decomposition, nutrient cycling, and water filtration), for which it is difficult to assign monetary values. In the southeastern U.S., the invasive vine kudzu (*Pueraria montana* var. *lobata*) is of great concern because of its ability to blanket entire plots of native vegetation, choking out both underlying herbaceous and woody species (Forseth and Innis 2004). Kudzu's current range in the United States extends northward to New York, south to Florida, and as far west as Texas and Oklahoma. Although it has occurred in the Northeast (Lamont and Young 2002), it is most commonly found in the southeastern U.S. because of its preference for mild winters, warm summers, and high annual rainfall (Forseth and Innis 2004, NPS 2010).

Kudzu has a variety of economic costs associated with it because of its effect on the forest industry and utility companies, and control costs associated with agriculture, national and state parks, and other natural habitats. For example, the loss of ecosystem and forest productivity due to the presence of kudzu is estimated to be between $100 and $500 million per year (Blaustein 2001, Forseth and Innis 2004). Costs of removal for power companies alone are estimated to be approximately $1.5 million per year (Britton et al. 2003), primarily because kudzu climbs up guy wires and distribution poles, weaving around the live wires and sometimes causing poles to fall, resulting in power loss (Blaustein 2001). National and state parks, wildlife refuges, and private landowners also dedicate considerable resources and money to controlling many invasive species, including kudzu (Blaustein 2001, Forseth and Innis 2004).

Related Literature

It is fairly well documented that invasive plant species can negatively impact native plant communities; however, the effects of invasive plants on native vegetation are often anecdotal and not experimental (Blossey et al. 2001, Forseth and Innis 2004). The response of native vertebrates, particularly avian species, to invasive species is even less well known. Most of these studies focus on the impact of invasive plants on specific bird species or bird communities. For example, monocultures of the invasive species *Agropyron cristatum* (crested wheatgrass) resulted in reduced reproductive success of *Calcarius ornatus* (Chestnut-collared Longspur) compared to their success in native prairie grasses (Lloyd and Martin 2005). In the northern Great Plains *Euphorbia esula* (leafy spurge) was shown to cause reduced diversity of several sparrow species (Scheiman et al. 2003). In a study in the Niobrara River Valley in Nebraska, survey areas with high *Juniperus virginiana* (Eastern red cedar) density had the lowest avian species richness and *Troglodytes aedon* (House Wren) abundance was the lowest at those sites (Frost and Powell 2011).

Invasive species also can cause declines of entire avian communities, such as the invasion of wetlands by *Lythrum salicaria* (purple loosestrife) and the associated decline of wetland bird communities (Blossey et al. 2001). Another wetland invasive, *Spartina alterniflora* (Smooth cordgrass), replaces native plant species and reduces food resources, resulting in lower avian species abundance and richness (Gan et al. 2010).

Conversely, there are instances where invasive species have been shown to have inconsequential or even beneficial effects on native avian species. In the previously mentioned study of Eastern red cedar in Nebraska, some species, such as *Seiurus aurocapillus* (Ovenbird) and *Vireo olivaceus* (Red-eyed Vireo), responded positively to increasing cedar density (Frost and Powell 2011). Similarly, the presence of *Lonicera* spp. (bush honeysuckles) had a positive effect on both breeding and migratory bird communities in an Illinois study. The bush honeysuckle created a denser understory, providing more nest sites and cover, and also provided a potential food source for overwintering birds (McCusker et al. 2010). In a study of *Ligustrum sinense* (Chinese privet) and its effects on songbirds in the southeastern U.S., it was discovered that the richness and abundance of songbirds was not significantly affected by privet density (Wilcox and Beck 2007). Avian species in Colorado River riparian habitats were shown to prefer areas with intermediate levels of the invasive species *Tamarix* spp. (Saltcedar) rather than the purely native vegetation areas, suggesting that the best management option for birds may not actually be complete removal of the invasive species (van Riper III et al. 2008).

One area of study lacking information is if and how invasive vine species may affect avian communities. With over 25 documented invasive vines in the United States, I was unable to find any studies of the effects of any one of these species on avian species (Bargeron et al. 2008). All related studies have examined how avian species contribute to the spread of many invasive vines. Given the limited research, there is no documented evidence of the effects of kudzu on avian diversity and species abundance.

Pueraria montana var. *lobata* Species Information

Kudzu is a perennial, leguminous, semi-woody twining vine with a native range limited to southern Japan and southeast China. Kudzu has large, ovate, two or three-lobed trifoliolate leaves with hairy undersides (Gleason and Cronquist 1972). Leaves grow to lengths of 5-20 cm. Its roots are large and tuberous, serve as a storage organ for water, carbon, and starches, and can make up over 50% of the plant’s biomass. Roots can reach up to 17.8 cm in diameter and penetrate soil to a depth of 1-5 m. At the soil surface, vines extend from ball-like root crowns and can grow to 10-30 m, with diameters up to 25 cm (Miller et al. 2010). Kudzu flowers from June to September with axillary clusters of lavender-colored flower pairs. Seeds are produced from September to January in small legume pods, each pod generally producing one to two viable seeds (Munger 2002). Kudzu also can reproduce asexually by spreading individual stolons from root nodes every few feet horizontally at the soil surface. It has been speculated that in the U.S. kudzu most often spreads asexually rather than spreading seeds; however, more research is needed to study this important aspect of its invasiveness (Munger 2002).

Also known as the "Foot-a-Day" vine in the Southeast, kudzu can grow up to 30 cm (approximately one foot) per day in the spring months totaling 10-30 m in a year (Miller et al. 2010, Munger 2002). Vines climb by twining around support structures such as tree trunks, most commonly structures or trees under 10 cm in diameter. The vines form dense mats over the ground, shrubs and other woody plants, and extend into canopies of mature trees. Leaves and small vines die back during the winter, but the matted dead vines persist. Larger climbing vines will overwinter in the canopy. Kudzu is found frequently in disturbed areas and edge habitats, often including highway and utility line right-of-ways and abandoned fields. It can dominate forest edges and gaps rapidly and prefers habitats with large amounts of sunlight (Foresth and Innis 2004).

Kudzu was first introduced to the U.S. at the 1876 Philadelphia Centennial Exposition as a part of the Japanese Pavilion. It was also featured at and first brought to the South for the 1883 New Orleans Exposition (Blaustein 2001). Originally, kudzu was marketed as an ornamental shade vine for planting next to porches (Miller and Edwards 1983). It was additionally marketed as fodder for cattle because of its high nutritional value (Bailey 1939, Blaustein 2001, Miles and Gross 1939). Beginning in the early 20th century, kudzu began to be used as erosion control measure as part of a government-aided program in the southeastern U.S., and was readily available through mail-order catalogs (Bailey 1939). In the 1930s and 1940s, the Soil Erosion Service recommended kudzu to control erosion on slopes and distributed over 85 million seedlings to private landowners. There were government incentives of up to $19.75 per ha for private landowners to plant kudzu to control erosion (Forseth and Innis 2004, Miller and Edwards 1983). Simultaneously, the Civilian Conservation Corps was tasked with planting kudzu on publicly owned parks and land. During this time kudzu was believed to be easily killed and not a pest species (Miles et al. 1939). By the late 1940s, more than 1.2 million ha had been planted with kudzu. It quickly spread through unmonitored growth in abandoned fields and edge habitats. By the early 1950s, there became a need for more grazing land followed by a futile effort to eliminate kudzu, prompting the USDA to remove kudzu from its list of permissible cover plants in 1953. Kudzu was officially listed as a weed in 1970, and it was listed by Congress as a Federal Noxious Weed in 1998. It is estimated that kudzu currently covers more than 3 million ha in the U.S., and could be increasing in coverage by 50,000 ha per year (Blaustein 2001, Mitich 2000). This estimate of increasing coverage is based on a mid-1990s approximation, so actual current increase in coverage could be different from this estimate.

Kudzu can have negative impacts on native species and ecosystems. Because of its ability to grow very quickly and envelop entire habitats, it can out-compete many native species and block sunlight from reaching underlying vegetation (VA-DCR 2001). Despite the numerous information sources about kudzu from national and state governments and conservation groups that report the threat of kudzu to native ecosystems, there are no quantitative studies actually showing these effects. It can be assumed, however, from the characteristics of kudzu and other similar invasive species, that it is harmful to native species. Vines can overtop and shade trees within a few years of establishment, altering forest canopy structure and causing trees to fall after the dense vine mats become too heavy. Kudzu's ability to recover rapidly allows it to dominate other vegetation post-disturbance, affecting some ecosystem processes. For example, dense stands of kudzu, a nitrogen-fixing species, potentially could alter nutrient cycling in adjacent terrestrial and riparian areas by creating excess soil nitrate (Forseth and Innis 2004). This excess nitrate can lead to long-term losses of soil fertility and leach into nearby streams altering aquatic biodiversity and accelerating the process of eutrophication. Vines also alter the spread of wildfires by creating fire ladders to the upper canopy and mature trees (Munger 2002).

Expanding knowledge on the effects of kudzu is critical, especially because of the high local biodiversity in many areas of the southeastern U.S. (Forseth and Innis 2004). Therefore, it is important that studies be conducted to better understand kudzu's effects on native biodiversity and ecosystem processes because the effects are currently not well known. In a study at the Oak Ridge National Laboratory in Tennessee, kudzu was the second most aggressive invasive species found in the study area (Drake et al. 2003). In the southern Appalachia region, kudzu was reported by 21 out of 35 governmental and private agencies to be their greatest management concern. This was the most often reported invasive plant by these agencies (Kuppinger 2000). It is widely agreed that kudzu causes shading and death of underlying vegetation (Blaustein 2001, Britton et al. 2003, Drake et al. 2003, Mitich 2000, Munger 2002, NPS 2010). By twining around saplings to reach the canopy, many young trees are killed and in the canopy, the weight of kudzu crushes larger competitors. Despite these observations, few quantitative studies exist that show actual declines in native species diversity. For example, Blaustein (2001) reported that kudzu destroys habitat for associated wildlife; however, no documented evidence of this was cited.

This study examined seasonal correlations between kudzu and avian community demographics in Tennessee. As no known studies currently exist that provide this information, this research will be instrumental in understanding how kudzu can affect particular native species and avian communities, and will be the first study to directly document the effects of kudzu on avian species. Studies of the interactions between other invasive plant species and native birds have shown a variety of responses to the presence of invasive species. Based on data collected from other studies on the relationships between invasive plants and birds, it is possible that avian species could have negative, positive, or negligible reactions to areas with differing coverage of kudzu. Kudzu could provide additional nesting, perching, or cover sites for birds, or could choke out preferred native substrates (Aslan and Rejmanek 2010, McCusker at al. 2010). Kudzu also could provide additional food sources for some species. For example, kudzu seeds comprised over 61% of the winter diet of *Colinus virginianus* (Northern Bobwhite) in Georgia (McRae 1980). Other than the study by McRae and a similar study by Speake (1967) on the diets of Northern Bobwhite, no other studies have shown kudzu seeds to be part of a species' diet. Therefore, it is more likely that kudzu could cause the decline of native food sources of many bird species by impacting native plant communities. Through this study I was able to examine correlations between kudzu coverage and breeding, migratory, and overwintering bird communities, and their associated native habitats, in the study area of southeastern Tennessee.

Study Objectives

I approached this project with three main objectives: 1) to address the lack of quantitative data documenting the possible effects of kudzu on native plant and avian species, 2) to examine correlations between kudzu coverage and avian diversity, community evenness, species richness, relative species abundances, and species guilds (species grouped by similar primary diet, foraging behavior, and primary nesting habitat), and 3) to examine any seasonal differences between kudzu coverage and avian communities. I hypothesized that sites with low or medium kudzu coverage levels would have higher diversity and more species. This was based on previously mentioned studies that showed higher avian diversity at areas with less invasive species, and I predicted that medium kudzu coverage could provide some advantageous effects such as additional shelter, predatory protection, or food resources. In addition, a study by van Riper III et al. (2008) showed sites with medium levels of the invasive species *Tamarix* spp. had the highest bird abundance and richness due to the more complex vegetative structure. I also hypothesized that sites with high levels of kudzu would have lower avian diversity and species abundances due to the creation of a monoculture and reduction in native flora. Vegetation composition and structure strongly influence the distribution of avian species (Dickson et al. 2009, MacArthur 1958, Rotenberry 1985). In MacArthur's (1958) study of warblers in the Northeast, different species of warbler were shown to use different components of the forest's vertical vegetation structure for feeding and nesting. Similarly, species diversity and richness tend to be higher in areas with more complex vegetative structure because of the available addition of more structurally-oriented guilds, as seen in comparisons of avian communities of arboreal and shrubsteppe habitats of Snively Canyon, Washington (Rotenberry et al. 1979). In another study, the probability of occupancy of *Selasphorus platycercus* (Broad-tailed hummingbird) suggests that habitat suitability for this species increases as structural complexity of vegetation increases (Dickson et al. 2009). Lastly, based on current knowledge of kudzu's ability to overrun native habitats, I hypothesized that kudzu would have a significant negative impact on native flora communities by reducing overall diversity.

CHAPTER II

MATERIALS AND METHODS

Study Area

The three study areas are located on land that was previously a part of the Chattanooga Volunteer Army Ammunition Plant (VAAP) in Hamilton County, Tennessee (Figure 2.1). The VAAP comprises more than 2,428 ha of land, approximately 60% of which is deciduous forest.

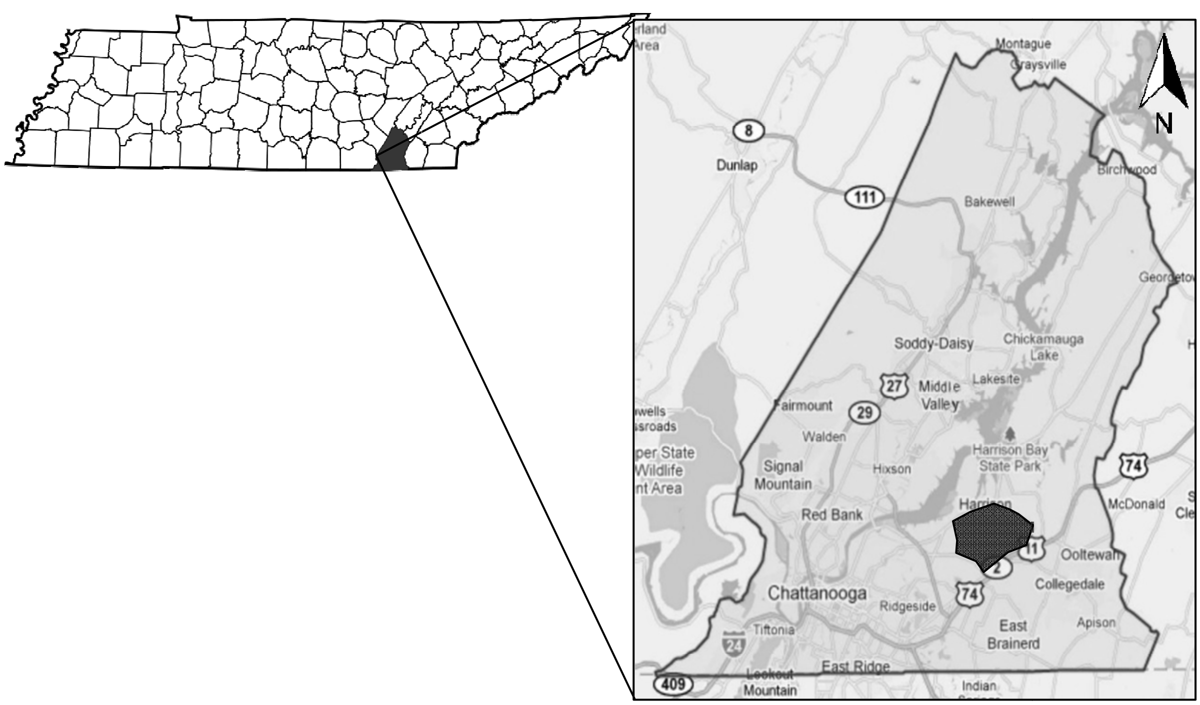

Figure 2.1 Location of the VAAP study area in Hamilton County, Tennessee. On left, Hamilton County is shown in dark gray, on right, VAAP land is shown in dark gray within Hamilton County

The VAAP was operated by the U.S. Army as a trinitrotoluene (TNT) manufacturing facility from 1942 to 1977. Sulfuric and nitric acid also were produced throughout this time. A private company, CF Industries Holdings, Inc. (CFI), leased an area of the VAAP from 1961 to 1982 to produce ammonium and urea. Both Army and CFI facilities were dismantled by the 1990s (Elmore 2001). It was after this time that the site began to open to civilian uses. Hickory Valley Road was opened through the site, and Hamilton County and the City of Chattanooga purchased more than 364 ha in 2000. A large portion of the site is home to the Enterprise South Industrial Park, which includes the Volkswagen Chattanooga Assembly Plant that began operation in 2011. Enterprise South Nature Park was created from 1,133 ha on the eastern side of the VAAP. The public park opened in 2010 and includes walking and biking trails, a scenic overlook, and a motorized vehicle driving tour around the perimeter of the park.

Nine sites were chosen on VAAP land for study (Figure 2.2). Each site was categorized as low, medium, or high density of kudzu based on approximate percent cover of the vine, with three sites chosen per density category. Low density sites contained <10% kudzu cover, medium density sites contained between 30-70% kudzu cover, and high density sites contained >90% kudzu cover (Appendix A-1). Coverage was estimated visually. Vegetation cover at high and low kudzu sites was relatively uniform, while vegetation at medium kudzu level sites was more clustered. However, different sites with the same kudzu level did have similar vegetation uniformity. Sites were chosen with a minimum 100 m buffer between sites so that avian point counts would not overlap. All sites were edge habitats, either adjacent to a road or railroad right-of-way. The study sites were grouped into three main locations, each location having one site per density category. Two locations were adjacent to Hickory Valley Road, referred to as HV1 and HV2, (approximately 35.10° N, 85.15° W and 35.08° N, 85.16° W) and the third location was within the Enterprise South Nature Park, referred to as ES (35.09° N, 85.12° W).

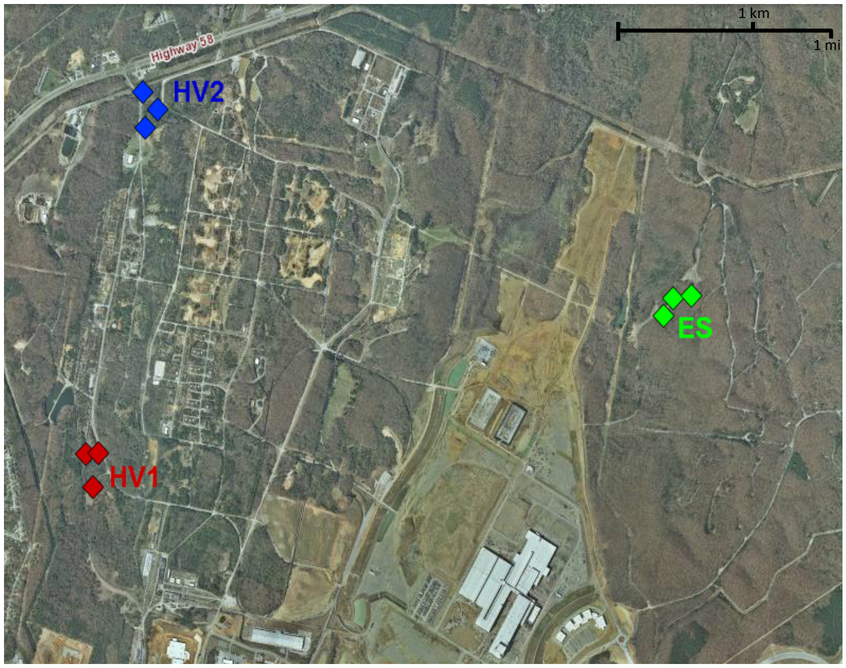

Figure 2.2 Nine study sites located on VAAP land in Hamilton County, Tennessee. Hickory Valley 1 location (bottom left), Hickory Valley 2 location (top left), and Enterprise South (right)

Avian Sampling

Avian point count locations were systematically placed in each of the nine sites based on uniformity of vegetation and distance from forest edge. The point count survey method was chosen because it is an easier way, compared to transect surveys, to make associations between bird counts and habitat data (Bibby et al. 2000). There was a fixed point count radius of 100 m. Before beginning each count, the time, site name, and weather conditions were recorded. Each avian point count survey lasted five minutes and recorded all birds seen or heard within the 100 m radius, recording the number of individuals, species, type of identification (i.e. seen, heard, or both), and estimated distance from the survey point. Each bird's distance from the survey point was recorded as either <50 m or >50 m. Birds that were flying over and did not land within the point count area were recorded separately as they were moving quickly and it was difficult to estimate distance, and were not included in analyses. Surveys were limited to five minutes to reduce the probability that individuals were counted multiple times (see Fuller and Langslow 1984). Before beginning a count, there was a one minute wait time to minimize disturbance to birds. Surveys at each site were conducted three times during each of the three seasonal survey periods: May 31st - June 31st, October 7th - November 2nd, and January 5th – February 2nd (see Buckland et al. 2001, Dickson et al. 2008, Siegel et al. 2001, van Riper III et al. 2009). The three seasonal periods correspond to when different focal avian communities inhabit the study area: spring breeding birds, fall migrants, and winter and year-round residents. Surveys did not begin until the end of May because kudzu does not fully leaf out until late May or early June (Miles et al. 1939). All survey times were between 6:00 and 11:00 a.m. EST, beginning no later than 30 minutes after sunrise and starting no later than 10:00 a.m. This standard time range for avian surveys corresponds to when birds are most active and vocal (Bibby et al. 2000). Surveys were not conducted during high wind, rainfall, or temperatures below -3°C (Ralph et al. 1993). The order of site sampling was rotated to prevent biased results.

Habitat Sampling

The circular sample-plot method was used as the basis for recording habitat variables at each of the study sites (Bibby 2000, James and Shugart 1970). The sample plot has a 12.62 m radius, covering 0.05 ha. The center of the habitat sampling plot aligned with each of the avian point count locations. Each site was surveyed once during each of the three survey periods.

Vegetation was divided into one of three categories: overstory, midstory, and understory.

Trees were classified as overstory using a wedge prism with a basal area factor of 10. A wedge prism can be used to sort standing trees by diameter. Looking through the prism at eye level, a portion of the tree is offset. If the offset portion and the actual tree trunk overlap, the tree is considered "in" and is measured (Mitchell et al. 1995). Genus, diameter at breast height (DBH), and height were recorded for each tree that was selected by the wedge prism method. Canopy layer height for each selected tree was measured using a rangefinder and tangent height gauge. Percent of canopy cover was estimated using a GRS Densitometer ™ (Geographic Resource Solutions™, Arcata, CA) at each avian point count location.

The midstory category was measured for horizontal vegetative density using a vegetation profile board similar to that described by Nudds (1977). The profile board consisted of a standard 1″ X 4″ board painted in five alternating segments of black and white (35 cm each) with a total height of 1.75 m. A stake was attached to the bottom so that the board could be inserted into the ground and surveys could be completed by one person (Appendix A-2). Samples were taken at a distance of 12.62 m from the center of the plot in each of the four cardinal directions, visually estimating the percent of each board segment covered by vegetation to the nearest 5%. Readings were taken with eye level at a height of one meter starting with the bottom segment and moving to the top (see Mitchell and Hughes 1995). The vegetation profile board method has been used in previous bird studies (MacArthur and MacArthur 1961, Recher 1969). Horizontal foliage measurements are a useful parameter for quantifying the vegetative structure of wildlife cover, and also can be used to compare the same habitat between seasons (Nudds 1977).

Leaf litter, bare ground, and herbaceous plants less than 30 cm fell into the understory category. This category was measured by estimating density in a 1-m^2 quadrat systematically placed 10 m from the center of the plot in each of the four cardinal directions. Within the 1-m^2 plot, percent cover of herbaceous plants, bare ground, and leaf litter were all estimated to the nearest 5% (Appendix A-3). Kudzu density already had been estimated for each site as part of the site selection process.

Statistical Analyses

Shannon's Diversity Index, which measures the number of different species and their relative abundances, was calculated using collected avian point count data for each of the point surveys. The Shannon Index is calculated as follows: $H' = -\sum p_i \ln(p_i)$, where p_i is the proportion of individual birds of the *i*th species. The diversity indices were then averaged for each site for each of the three seasons. Evenness, also referred to as Shannon's Equitability (*E*), was calculated by dividing Shannon's H' by the H'_{max} value. H'_{max} is the maximum possible value of H', calculated as $H'_{max} = \ln S$, where *S* is the total number of species detected. Evenness, also described as the relative abundance of species, was averaged for each site for each of the three seasons. Species richness, quantified as the number of different species, was determined for each of the point surveys and then cumulative, rather than average, species richness counts were calculated for each of the sites by season. Univariate three-way ANOVAs were used to analyze the relationship between kudzu level (low, medium, high), season (spring, fall, winter), location (HV1, HV2, ES), and any interactions between these factors, and avian diversity and species richness. Kudzu level, season, and location were all treated as fixed factors. Data for evenness were non-normal, so a non-parametric Kruskal-Wallis test was used. Relative abundance for each species was calculated cumulatively for the low, medium, and high kudzu level locations. Species were then ranked by their relative abundances for low and high kudzu sites by season to create rank-abundance curves. Birds also were grouped into categories based on primary diet, foraging behavior, and primary nesting habitat, as described by Erlich et al. (1988). Primary diet included the categories of insectivore, omnivore, granivore, and other (frugivore, nectarivore, and carnivore). Foraging behavior categories were ground gleaners, foliage gleaners, bark gleaners, hoverers, and other flyers (hawking, low patrol, and high patrol). Categories for primary nesting habitat included ground, shrub, canopy, and other (snag and human structure). The frequency of each category was compared across different kudzu levels, seasons, and locations using three-way ANOVAs. Vegetation data were averaged for the overstory, midstory, and understory categories for each site and for each of the three seasons. Univariate three-way ANOVAs also were used to analyze the relationship between vegetation data and kudzu level, season, location, and interactions between fixed factors. Tukey's HSD post-hoc test was performed in conjunction with all ANOVA tests to determine significant differences between means. All data were analyzed using IBM SPSS Statistics Version 21 software (IBM® Corporation, Armonk, NY).

CHAPTER III

RESULTS

Avian Species

A total of 786 individual birds comprising 59 different species were detected during the Spring 2012, Fall 2012, and Winter 2013 sampling periods. Of all individuals detected, 77.17% were identified aurally, 17.25% were identified visually, and 5.58% were both seen and heard (Appendix B-1). A breakdown of individual and species detections by kudzu level and by season are presented in Table 3.1. Although some trends in the data can be seen, individual and species detections were not significantly affected by kudzu level or season (all $p>0.05$). Observable trends included more individuals detected at low kudzu sites in the spring and fall, but more detected at high kudzu sites during the winter. Mean abundance of species (individual detections) and species richness (species detections) also are presented in graphical form (Appendix A-4).

Table 3.1 Number of avian individual and species detections by kudzu level (low, medium, high) and season (spring, fall, winter) on nine VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period

Individual Detections			
	Spring	Fall	Winter
Low Kudzu	87	113	94
Medium Kudzu	69	79	63
High Kudzu	70	74	137
Species Detections			
	Spring	Fall	Winter
Low Kudzu	26	29	25
Medium Kudzu	22	19	21
High Kudzu	17	23	23

The five most abundant bird species observed were determined for each kudzu category and season, as seen in Table 3.2. *Pipilo erythrophthalmus* (Eastern Towhee) and *Cardinalis cardinalis* (Northern Cardinal) were in the top five most abundant species for all three kudzu levels and all three seasons. *Thryothorus ludovicianus* (Carolina Wren) was most abundant in all but the spring season category. Other species were most abundant in two or more categories: *Cyanocitta cristata* (Blue Jay), *Poecile carolinensis* (Carolina Chickadee), *Spizella pusilla* (Field Sparrow), *Melospiza melodia* (Song Sparrow), and *Baeolophus bicolor* (Tufted Titmouse).

Table 3.2 Most abundant avian species by kudzu level (low, medium, high) and season (spring, fall, winter) on nine VAAP land study sites in Hamilton County, Tennessee, listed in order from most to least abundant. Species were observed during the 2012-2013 study period

Most Abundant Avian Species by Kudzu Level *All species are year-round residents		
Low Kudzu	Medium Kudzu	High Kudzu
Northern Cardinal	Carolina Wren	Eastern Towhee
Eastern Towhee	Northern Cardinal	Carolina Wren
Carolina Wren	Blue Jay	Field Sparrow
Field Sparrow	Eastern Towhee	Northern Cardinal
Carolina Chickadee, Tufted Titmouse	American Crow, Carolina Chickadee	Blue Jay, Song Sparrow
Most Abundant Avian Species by Season [1]= year-round resident, [2]= spring resident, [3]= winter resident		
Spring	Fall	Winter
Eastern Towhee[1]	Blue Jay[1]	Field Sparrow[1]
Northern Cardinal[1]	Carolina Wren[1]	Carolina Wren[1]
Tufted Titmouse[1]	Northern Cardinal[1]	Eastern Towhee[1]
Red-eyed Vireo[2]	American Robin[1]	Song Sparrow[1]
Indigo Bunting[2]	Eastern Towhee[1]	Northern Cardinal[1], White Throated Sparrow[3]

Rank-abundance curves for high and low kudzu levels for each season all show the same general shape. I did not create curves for medium kudzu sites because there were limited statistical differences between medium and high kudzu level sites. There were few species, such as the Eastern Towhee and Northern Cardinal, that were more abundant regardless of kudzu level or season, but most species detected were less abundant, with only one or two individuals detected per species. The rank-abundance diagrams for the spring seasonal period are presented below (Figure 3.1), and the diagrams for the other two seasonal survey periods are presented in Appendix A-5 through A-8. Although no statistical analyses were conducted, summary tables for those species found only at low kudzu sites or only at high kudzu sites are in Appendix B-2 and B-3. All species listed in those summary tables only had one or two individuals detected in total.

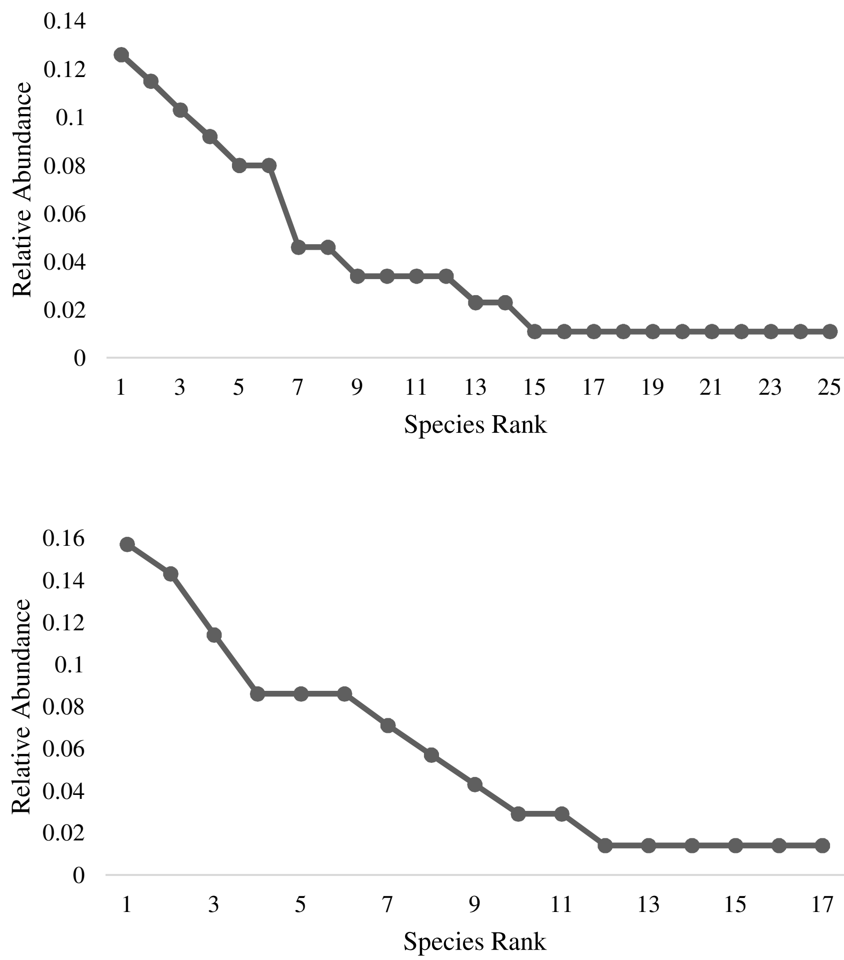

Figure 3.1 Rank-abundance curves for avian species detected at low kudzu (top) and high kudzu (bottom) levels during Spring 2012 on VAAP land study sites in Hamilton County, Tennessee. Curves show relative abundances and associated avian species' rank from 1, most abundant, to least abundant

Analysis of the effects of fixed factors (kudzu level, season, location) on avian diversity showed that there was a significant relationship between both kudzu level and season on diversity ($F_{2,20}$=12.845, p<0.001 and $F_{2,20}$=3.822, p=0.039, respectively; Table 3.3). However, there were no significant correlations between location or interactions of the fixed factors and avian diversity (p>0.15). Tukey's HSD post-hoc tests revealed that avian diversity of low kudzu level areas was significantly greater than diversity of medium and high kudzu level areas (p=0.001), but medium and high kudzu level areas were not significantly different (Figure 3.2). Avian diversity during the fall and winter also differed significantly from one another (p=0.039), but neither differed from the spring seasonal period in terms of diversity. Overall, avian diversity was lower during the winter than during the fall.

Table 3.3 Summary of three-way ANOVA results for mean avian diversity and correlations with kudzu level (low, medium, high), season (spring, fall, winter), and location (HV1, HV2, ES) during the 2012-2013 study period on VAAP land study sites

	Sum of squares	df	Mean square	F	*p*
Kudzu Level	0.596	2	0.298	12.845	0.000
Season	0.177	2	0.089	3.822	0.039
Location	0.106	2	0.052	2.287	0.127
Error	0.464	20	0.023		
Total	1.343	26			

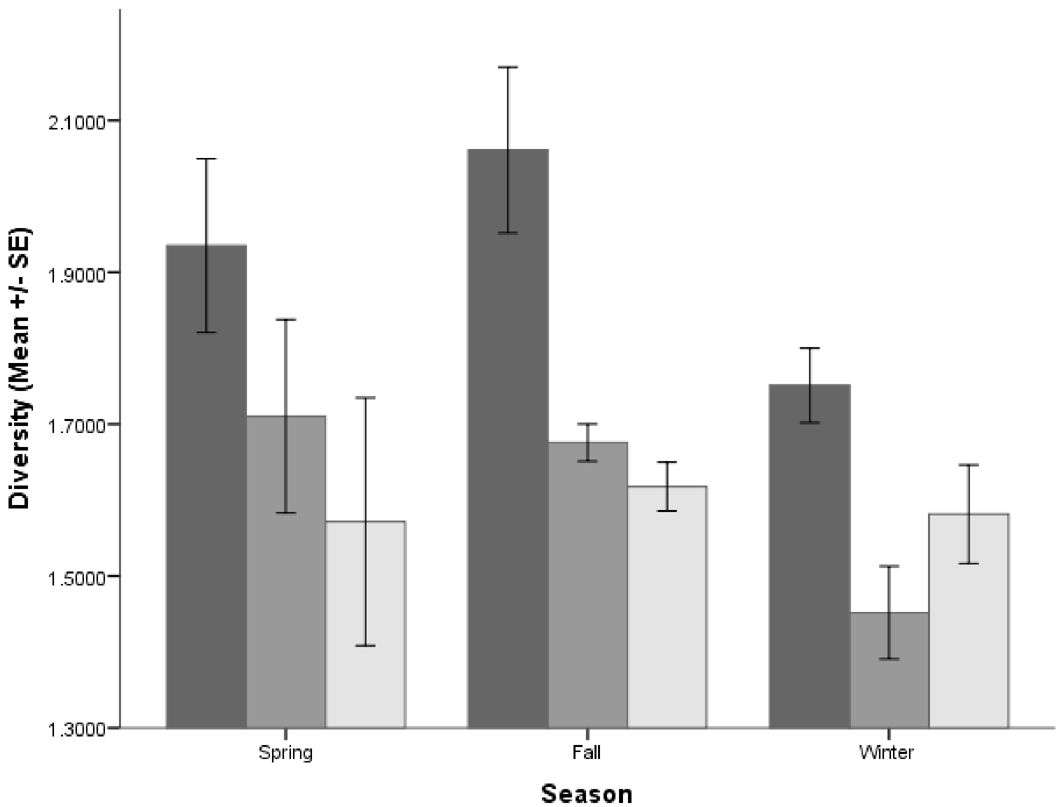

Figure 3.2 Mean avian diversity (+/- SE) for low kudzu (left columns/dark gray), medium kudzu (middle columns/medium gray), and high kudzu (right columns/light gray) levels grouped by season (spring, fall, winter) on nine VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period

Statistical analyses of species evenness showed that the independent fixed factors of kudzu level, season, and location were not significantly related to evenness (all $p>0.10$). Species richness, however, was significantly related to several independent fixed factors (Table 3.4). Kudzu level was significantly correlated with species richness ($F_{2,16}=16.133$, $p<0.001$), as was location ($F_{2,16}=5.826$, $p=0.013$; Figures 3.3 and 3.4). The Enterprise South (ES) location had less species detected than the two Hickory Valley (HV1 and HV2) locations. There was also a significant relationship between a kudzu level and location interaction and species richness ($F_{4,16}=3.187$, $p=0.042$). Species richness at low kudzu levels sites was greater at locations HV1 and HV2 compared to location ES. Tukey's HSD post-hoc tests revealed that richness was significantly greater in areas with low kudzu levels than in medium and high kudzu level areas (p=0.002), which did not differ from each other.

Table 3.4 Summary of three-way ANOVA results for mean species richness and correlations with kudzu level (low, medium, high), season (spring, fall, winter), location (HV1, HV2, ES), and a kudzu level/location interaction during the 2012-2013 study period on VAAP land study sites

	Sum of squares	df	Mean square	F	*p*
Kudzu Level	24.000	2	12.000	16.133	0.000
Season	4.025	2	2.012	2.705	0.097
Location	8.667	2	4.333	5.826	0.013
Kudzu Level*Location	9.481	4	2.370	3.187	0.042
Error	11.901	16	0.744		
Total	58.074	26			

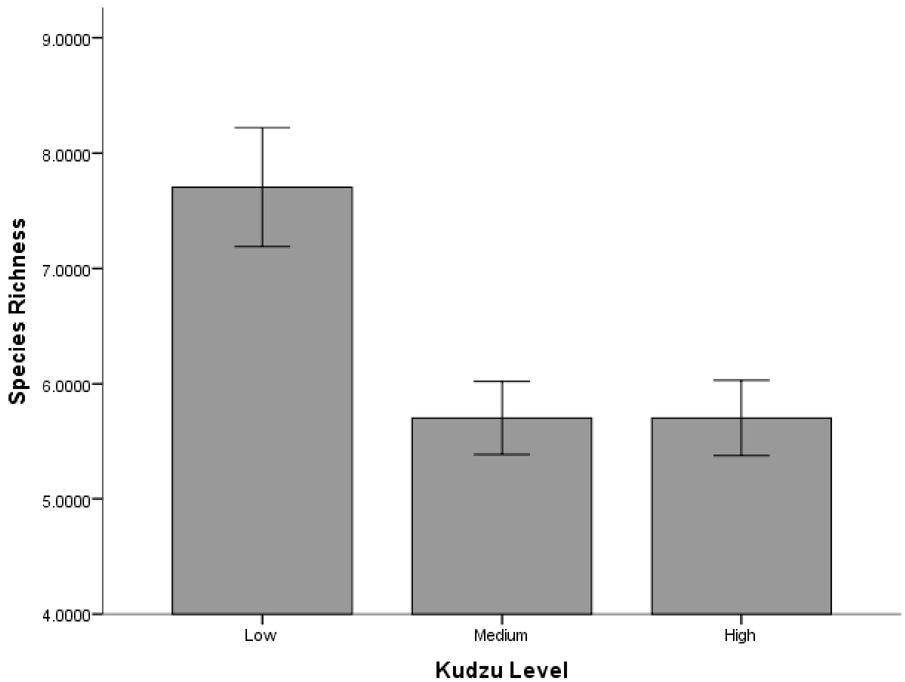

Figure 3.3 Avian species richness (mean +/- SE) by kudzu level (low, medium, high) on nine VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period

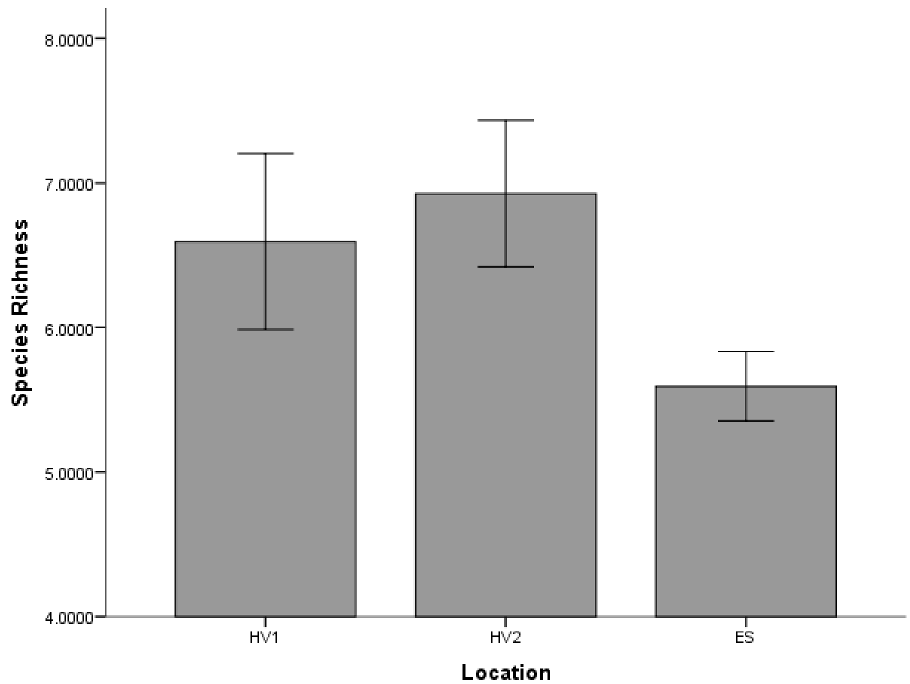

Figure 3.4 Avian species richness (mean +/- SE) by location (HV1, HV2, and ES) on VAAP land in Hamilton County, Tennessee during the 2012- 2013 study period

Analyses of guilds grouped by primary diet, foraging behavior, and primary nesting habitat showed significant differences between groups. The percentages of species in each primary diet category differed significantly between categories ($F_{3,32}$=39.147, p<0.001; Figure 3.5 and Appendix B-4), but kudzu level, season, and location all had no significant correlation with primary diet. Post-hoc tests revealed that insectivorous species made up a more significant percentage of avian communities than species with other diets. The mean percentage of insectivorous species was 79.6%, and the next highest percentage of species, omnivores, made up only 9.8% of all species detected, which equates to ~70% difference in insectivore and omnivore species. Granivores made up 7.6% and other diets only 2.9% of species detected. Species in all diet categories were not detected during each season or at every kudzu level.

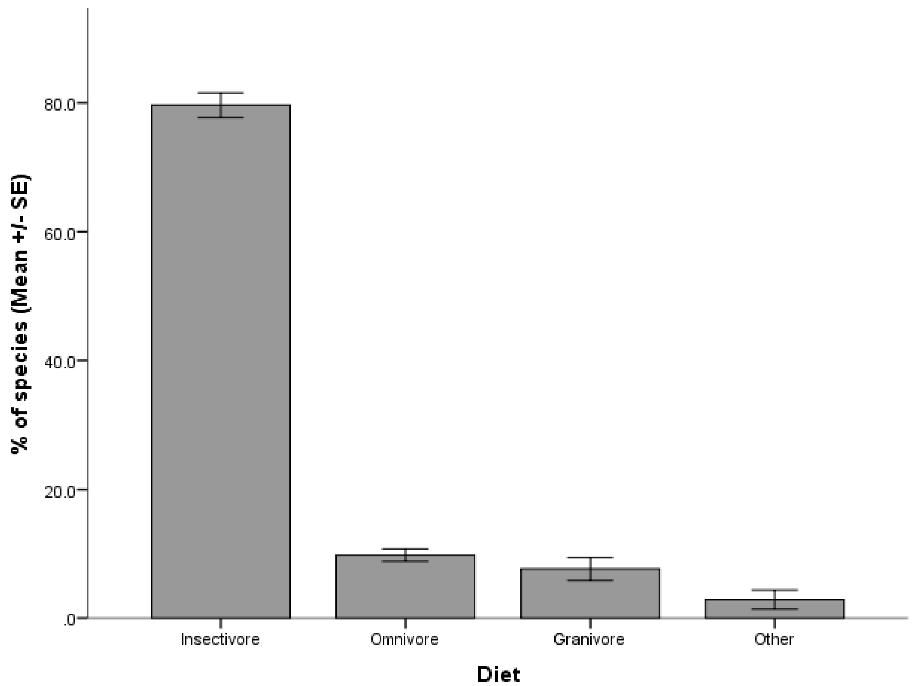

Figure 3.5 Percentage of avian species (mean +/- SE) grouped by diet detected on nine VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Diet categories are insectivore, omnivore, granivore, and other (frugivore, nectarivore, and carnivore)

Foraging behavior groups included ground gleaning, foliage gleaning, bark gleaning, hovering, and other flying techniques (hawking, low patrol, and high patrol). The frequency of species detected belonging to differing foraging groups significantly varied between groups ($F_{4,20}$=248.343, p<0.001; Figure 3.6 and Appendix B-5). Tukey's HSD post-hoc tests showed all five foraging behavior groups were significantly different from one another (all p<0.015). Ground and foliage gleaners made up almost 75% of all individuals detected, with bark gleaners, hoverers, and flyers making up the other ~25%. There were also significant relationships between kudzu level and foraging behavior ($F_{10,20}$=3.162, p=0.014) and between season and foraging behavior ($F_{10,20}$=5.900, p<0.001; Figures 3.7 and 3.8). Interactions between kudzu level and foraging behavior categories showed the percentage of ground gleaners was greater than all other categories at low and medium kudzu level sites, while at high kudzu level sites the percentages of ground and foliage gleaners were similar. The other remaining categories did not have many significant differences from one other. However, the percentage of species that forage by hovering was less at all kudzu levels. Similar interactions were observed between season and foraging behavior categories. The percentage of ground gleaners was greater than all other categories during the fall and winter, but during the spring the percentages of ground and foliage gleaners were similar while being greater than all other categories. Overall, the percentage of hovering species was less during all three seasonal periods.

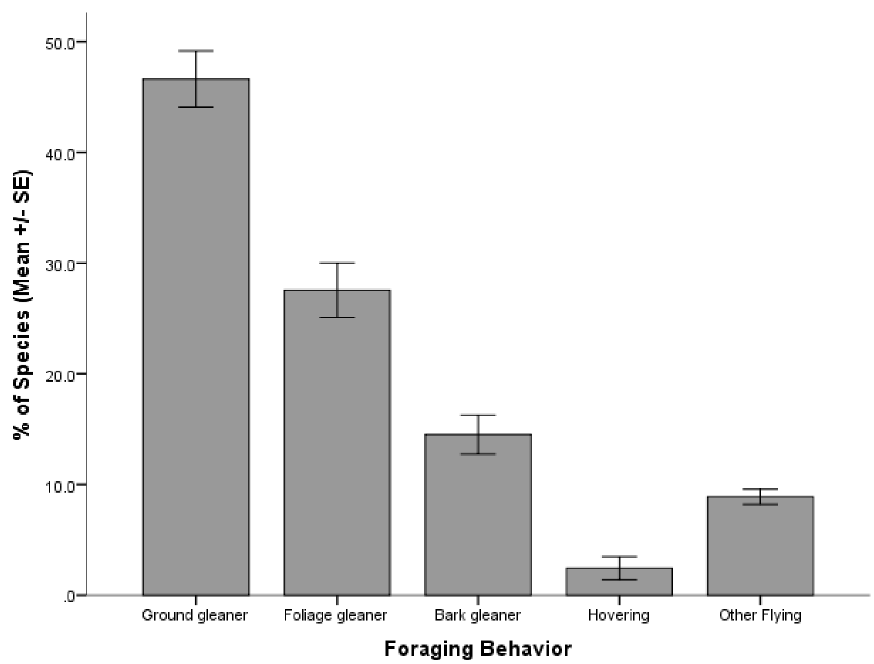

Figure 3.6 Percentage of avian species (mean +/- SE) grouped by foraging behavior detected at VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Foraging behavior categories are ground gleaners, foliage gleaners, bark gleaners, hoverers, and other flyers (hawking, low patrol, and high patrol)

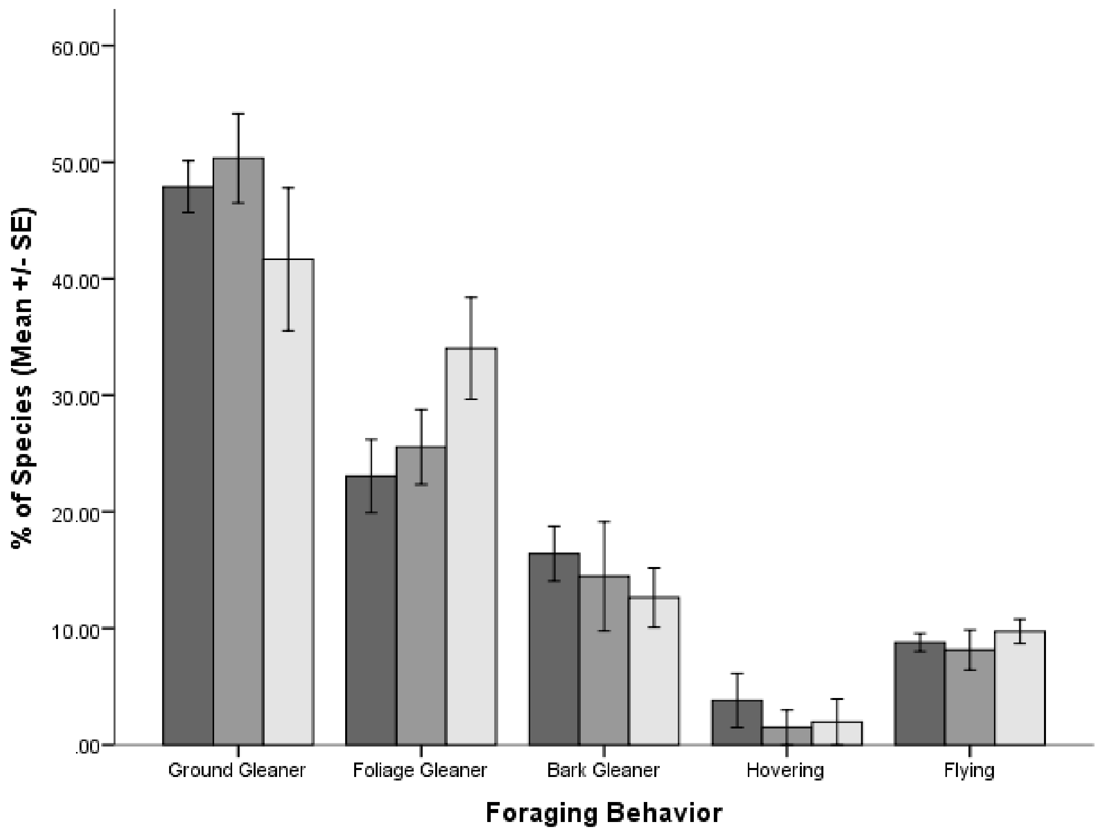

Figure 3.7 Percentage of avian species (mean +/- SE) detected at different kudzu levels grouped by foraging behavior categories on VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Dark gray bars represent low kudzu levels, medium gray bars represent medium kudzu levels, and light gray bars represent high kudzu levels

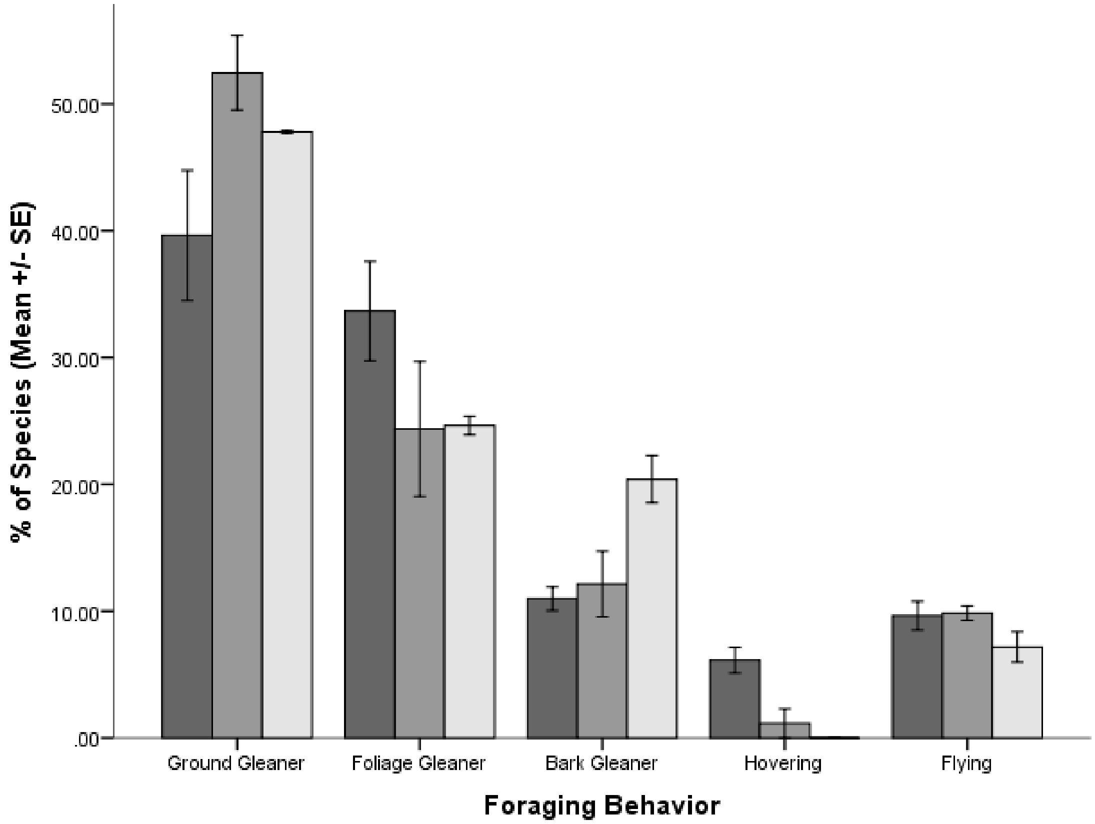

Figure 3.8 Percentage of avian species (mean +/- SE) detected during different seasons grouped foraging behavior categories on VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Dark gray bars represent Spring 2012, medium gray bars represent Fall 2012, and light gray bars represent Winter 2013

The percentage of species with differing primary nesting habitats also was analyzed. Percentages of all species detected differed significantly when grouped by nesting habitat categories ($F_{3,16}$=138.696, p<0.001; Figure 3.9 and Appendix B-6). A post-hoc test analysis showed that the canopy nesting habitat category had a significantly higher percentage of species than the other three categories (p<0.001). The three categories of shrub, ground, and other were not significantly different. Species that were primarily canopy nesters made up almost 50% of all species detected, over 30% more than any other single nesting category. There was also a significant correlation between nesting habitat and season ($F_{8,16}$=10.107, p<0.001; Figure 3.10 and Appendix A-9). There were fewer ground nesters during the spring season than during the fall and winter seasons. Percentage of shrub nesters also decreased from spring to fall to winter.

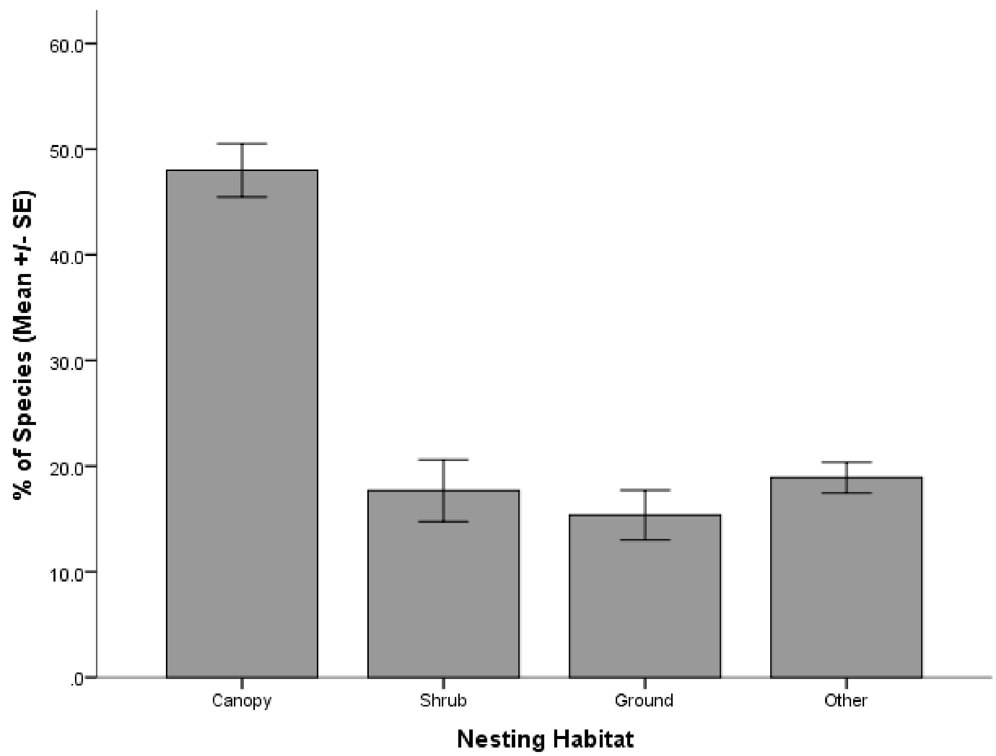

Figure 3.9 Percentage of avian species (mean +/- SE) grouped by primary nesting habitat observed on VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Nesting habitat categories are canopy, shrub, ground, and other (snags and human structures)

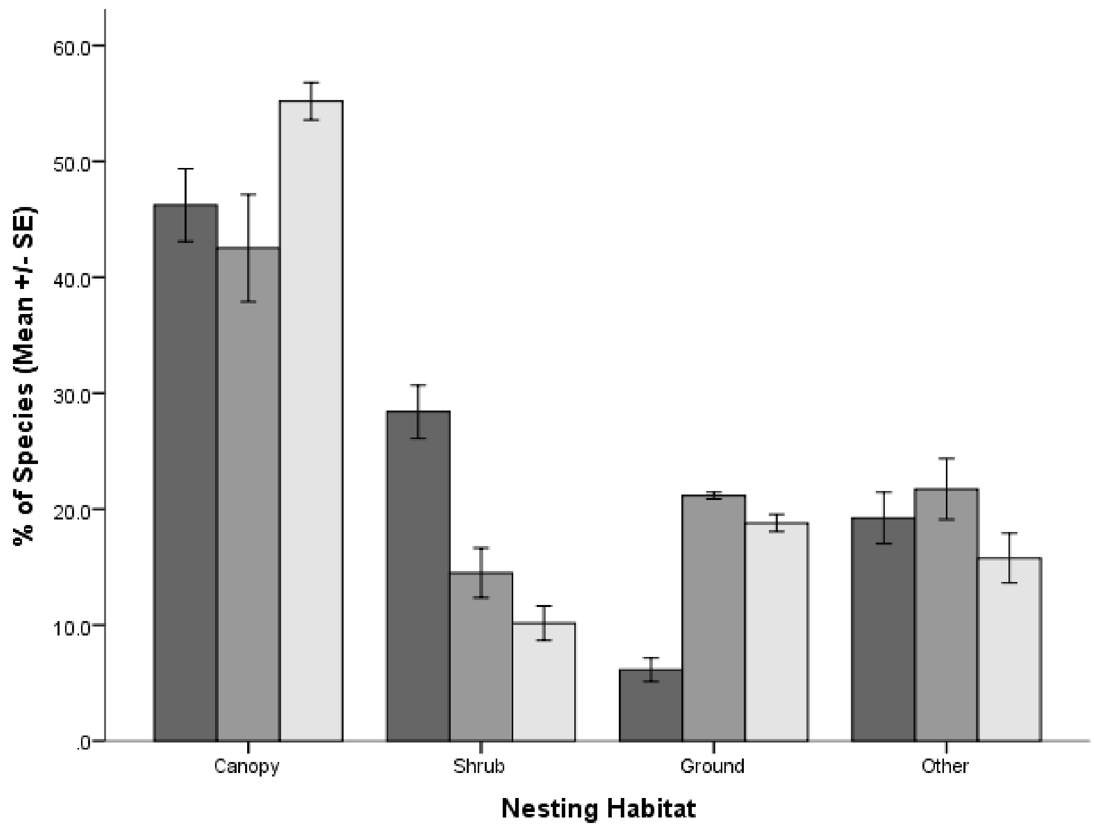

Figure 3.10 Percentage of avian species (mean +/- SE) in differing nesting habitat categories grouped by season observed at VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Dark gray bars represent Spring 2012, medium gray bars represent Fall 2012, and light gray bars represent Winter 2013. Nesting habitat categories are canopy, shrub, ground, and other (snags and human structures)

Vegetation

Statistical analyses of the relationships between fixed factors and vegetation overstory, midstory horizontal density, and understory ground cover data were conducted. For the overstory category, a total of 15 different tree genera were identified. Tree snags were excluded from all analyses because for many the genera could not be determined. Out of the 15 different genera, 10 were identified at low kudzu sites, 10 at medium kudzu sites, and 3 at high kudzu sites. A total of 70 individual trees were identified. Table 3.5 shows the genera identified for each kudzu level, the number of individuals of each, and the relative abundance of each genera.

Table 3.5 Genera, number of individuals, and relative abundances of trees observed at different kudzu levels at VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period

Tree Genera	Low Kudzu		Medium Kudzu		High Kudzu	
	Individuals	Relative Abundance	Individuals	Relative Abundance	Individuals	Relative Abundance
Ailanthus	0	-	1	0.027	0	-
Carya	5	0.172	2	0.054	0	-
Celtis	2	0.069	4	0.108	1	0.25
Cercis	1	0.034	0	-	0	-
Gleditsia	1	0.034	0	-	0	-
Juniperus	4	0.138	4	0.108	0	-
Liquidambar	0	-	1	0.027	0	-
Liriodendron	0	-	0	-	1	0.25
Mimosa	1	0.034	0	-	0	-
Morus	0	-	1	0.027	0	-
Pinus	1	0.034	2	0.054	0	-
Populus	0	-	4	0.108	0	-
Prunus	4	0.138	0	-	0	-
Quercus	8	0.276	14	0.378	0	-
Ulmus	2	0.069	4	0.108	2	0.5
Total # of Individuals	29		37		4	

Statistical analysis of genera and individual tree detection data showed that neither kudzu level nor location was significantly related to the number of genera in an area (p>0.05). Kudzu level was significantly related to the number of trees ($F_{2,4}$=8.387, p=0.037; Appendix B-7), but location was not. A post-hoc test showed that there were significantly more trees at medium kudzu level areas than at high kudzu level areas (p=0.037), but neither differed significantly from the number of trees at low kudzu level areas (Figure 3.11).

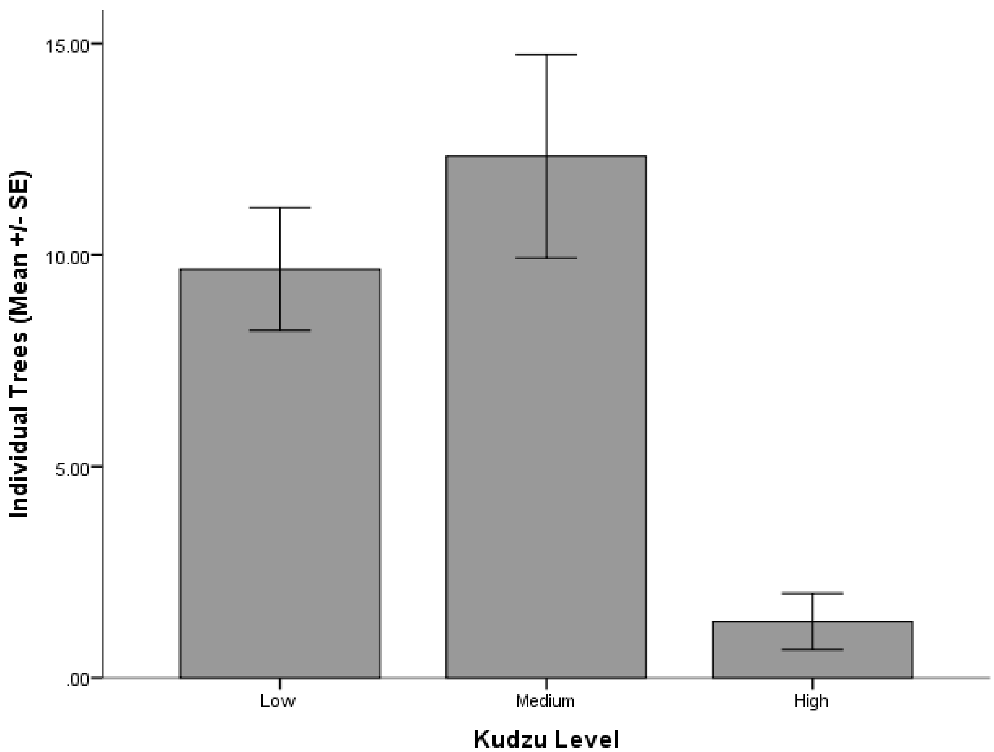

Figure 3.11 Number of trees (mean +/- SE) at nine different kudzu level sites (low, medium, high) on VAAP land in Hamilton County, Tennessee observed during the 2012-2013 study period

Thirty-seven trees were identified at medium kudzu level sites, 29 trees at low kudzu level sites, and only four were identified at low kudzu level sites. Tree height and diameter at breast height (DBH) were averaged for all trees grouped by kudzu level, and the averages are presented in Table 3.6.

Table 3.6 Average height (m) and DBH (cm) of trees measured on VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period

	Low Kudzu	Medium Kudzu	High Kudzu
Average Height (m)	13.51	12.97	20.15
Average DBH (cm)	47.03	27.44	57.47

For vegetation overstory, kudzu level was the only factor that was significantly related to canopy cover percentage ($F_{2,4}$=60.799, p=0.001; Table 3.7 and Figure 3.12). Average canopy cover was significantly less at high kudzu level areas than at low or medium kudzu level areas (p<0.004). Mean canopy cover at low and medium kudzu level areas was not significantly different. Mean canopy cover was 58.89% at low kudzu level areas, 75.56% at medium kudzu level areas, and 1.11% at high kudzu level areas. Although canopy coverage did decrease in the fall and winter, this decrease was not statistically significant.

Table 3.7 Summary of ANOVA results for mean canopy cover percentage and correlations with kudzu level (low, medium, high) and season (spring, fall, winter) for the 2012-2013 study period on VAAP land study sites

	Sum of squares	df	Mean square	F	*p*
Kudzu Level	9157.457	2	4578.728	60.799	0.001
Season	704.538	2	352.269	4.678	0.090
Error	301.240	4	75.310		
Total	10163.235	8			

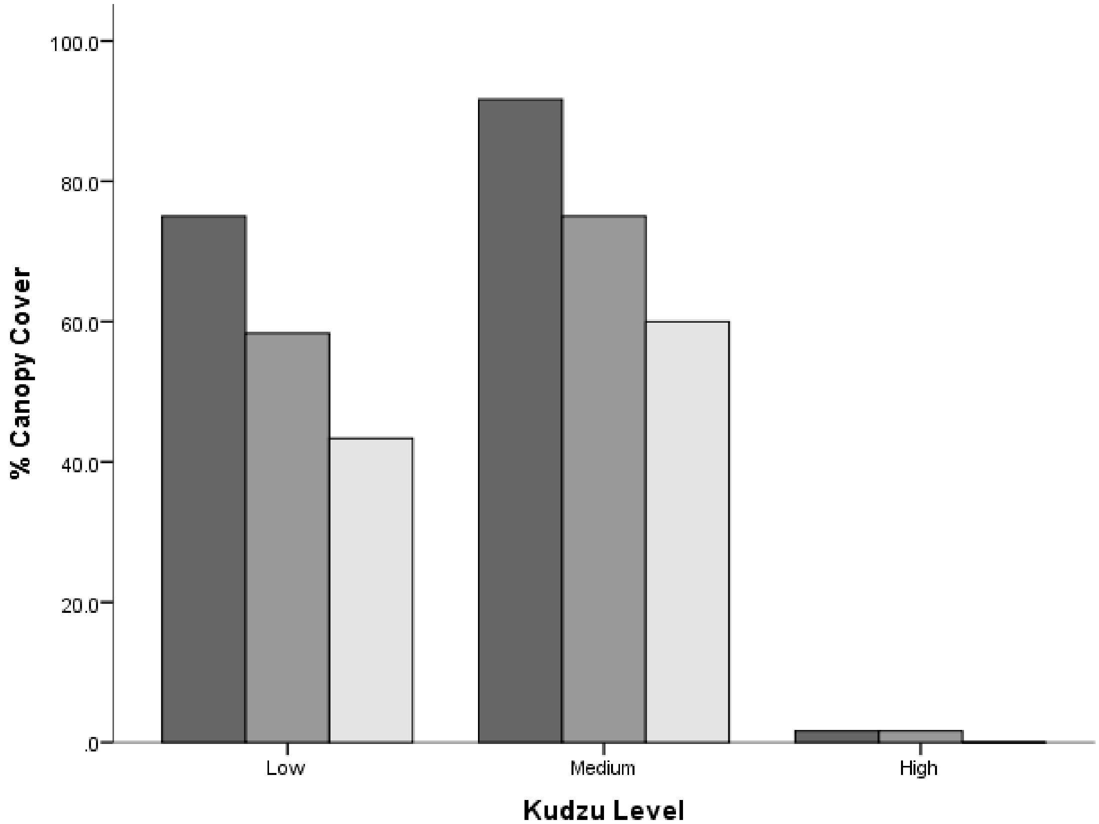

Figure 3.12 Percentage of canopy cover at differing kudzu levels for different seasons at nine VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Dark gray bars represent Spring 2012, medium gray bars represent Fall 2012, and light gray bars represent Winter 2013

Kudzu level also was the only variable to have a significant relationship with midstory cover percentage ($F_{2,4}$=7.960, p=0.040; Table 3.8 and Figure 3.13). Areas with high kudzu levels had a greater percentage of midstory cover, measured in terms of average horizontal vegetation density, than areas with low kudzu levels (p=0.042). Medium kudzu level areas were not significantly different from either low or high kudzu level areas. Mean midstory cover at high kudzu areas was 54.78%, mean coverage was 41.28% at medium kudzu areas, and low kudzu area mean midstory coverage was 32.03%.

Table 3.8 Summary of ANOVA results for mean midstory vegetation cover percentage and correlations with kudzu level (low, medium, high) and season (spring, fall, winter) during the 2012-2013 study period on VAAP land study sites

	Sum of squares	df	Mean square	F	*p*
Kudzu Level	785.347	2	392.673	7.960	0.040
Season	252.795	2	126.397	2.562	0.192
Error	197.316	4	49.329		
Total	1235.458	8			

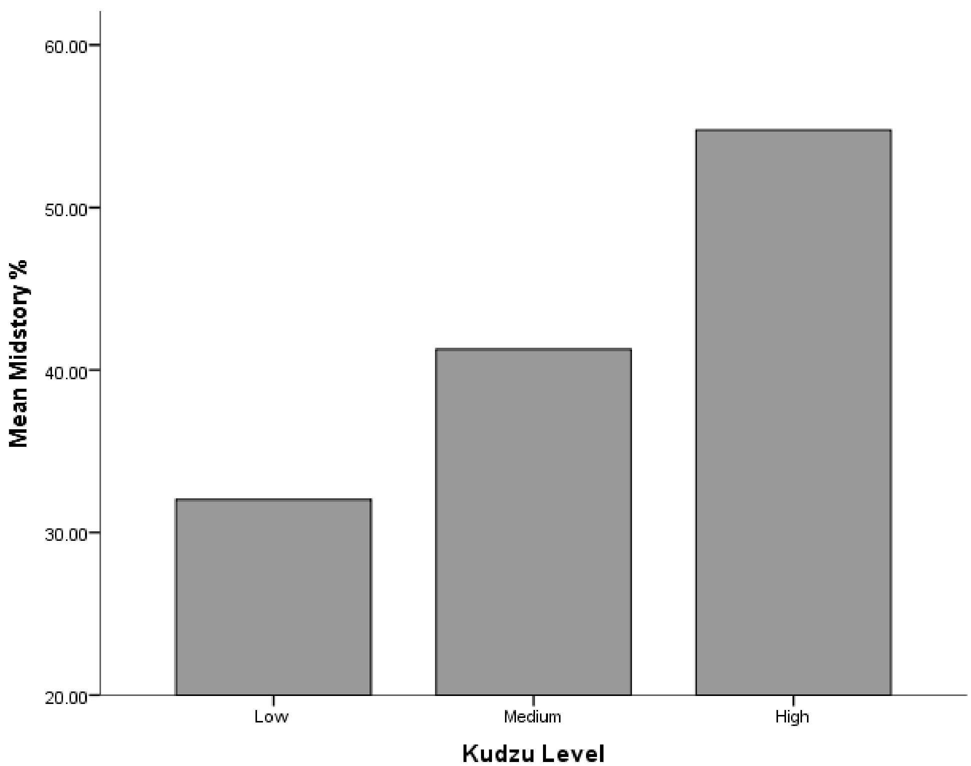

Figure 3.13 Mean percentage of midstory vegetation grouped by kudzu level (low, medium, high) at nine VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period

Ground cover data also were analyzed for statistical trends. Ground cover categories were herbaceous, bare ground, and leaf litter. The frequencies of different ground cover categories did differ significantly among categories ($F_{2,12}$=132.540, p<0.001; Figure 3.14). Mean percentage of bare ground (6.65%) was significantly less (p<0.002) than the mean percentages of herbaceous (42.48%) or leaf litter (50.92%) ground cover, which did not differ significantly.

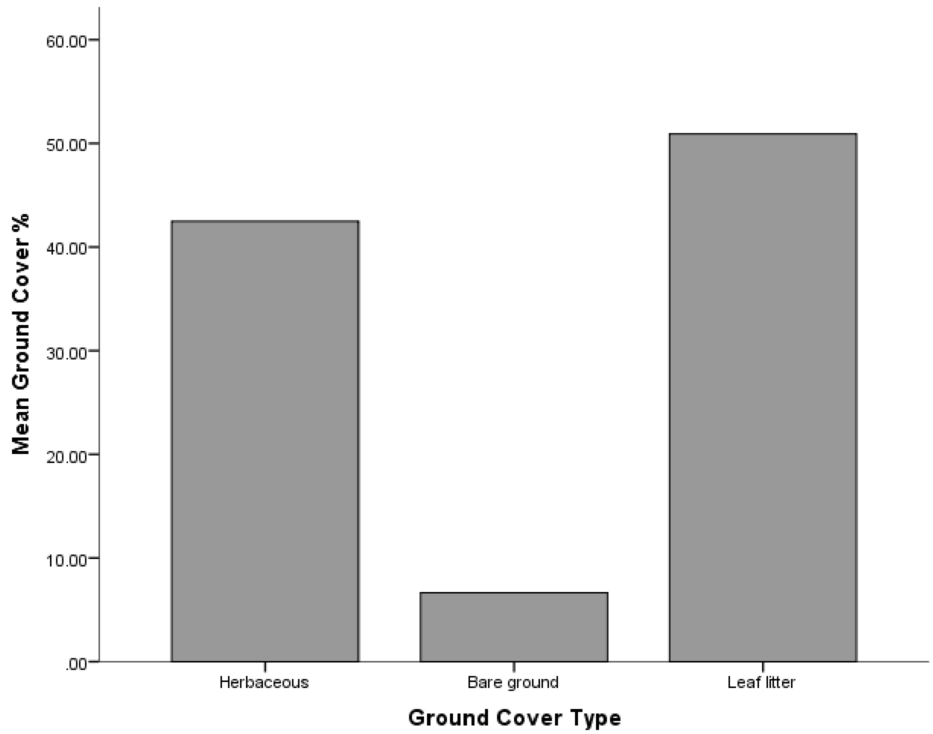

Figure 3.14 Mean percentage of ground cover types (herbaceous, bare ground, leaf litter) at nine VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period

There also were significant interactions between kudzu level and ground cover type ($F_{4,12}$=49.155, p<0.001; Figure 3.15) and between season and ground cover type on the percentage of ground cover at study sites ($F_{4,12}$=6.588, p=0.005; Appendix B-8). When comparing percentages of ground cover at differing kudzu levels, herbaceous ground cover made up a greater percentage of ground cover at high level kudzu levels. Specifically, herbaceous ground cover comprised 69.58% of total ground cover at high kudzu level areas, compared to 21.67% at medium kudzu level areas and 36.20% at low kudzu level areas. Percentages of bare ground did not differ significantly between areas of differing kudzu levels. Mean leaf litter percentage was lower at high kudzu level areas than medium and low kudzu areas.

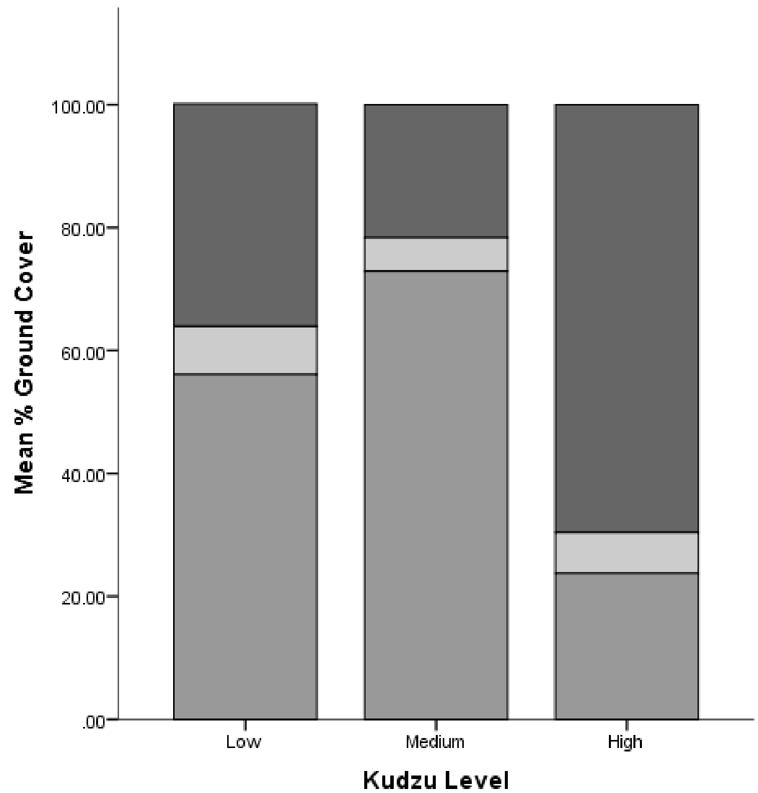

Figure 3.15 Mean percentage of ground cover, interactions shown between kudzu level (low, medium, high) and ground cover type at VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Top/dark gray bars represent herbaceous ground cover, middle/light gray bars represent bare ground, and bottom/medium gray bars represent leaf litter

Interactions between season and ground cover type show slightly more bare ground during the spring than in other sampling seasons (10.36% compared to 4.45% and 5.14% for fall and winter, respectively). There also was more leaf litter and correspondingly less herbaceous cover during the winter seasonal period than other seasons (Figure 3.16). Mean percentage of herbaceous ground cover was greatest in the fall at 48.47%, although the spring and winter did not differ from the fall by more than ~15%. Mean percentage of leaf litter was 61.61% in the winter, approximately 10% greater than in the fall and almost 20% greater than in the spring.

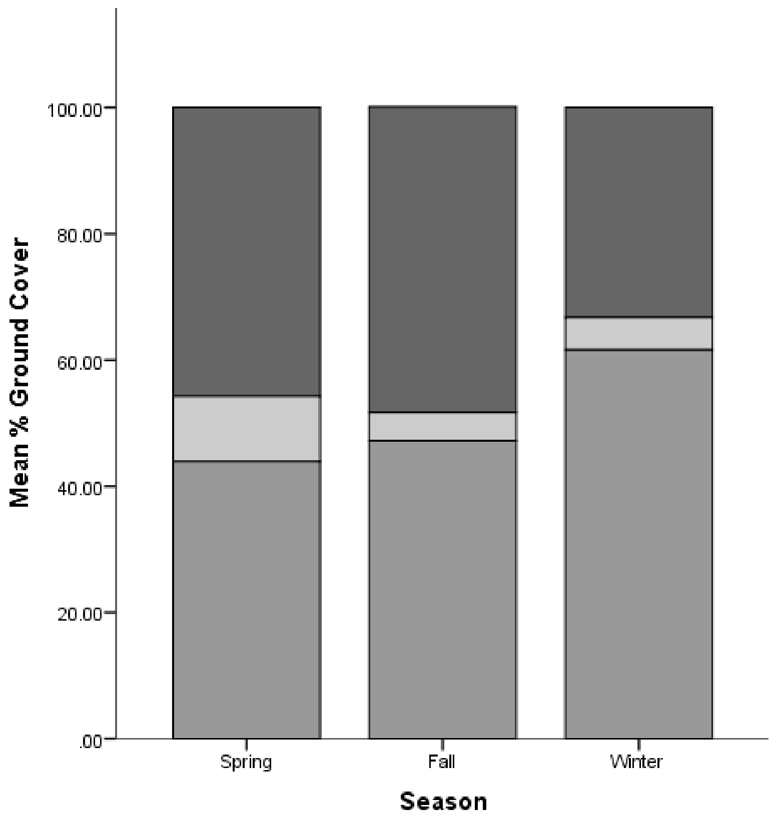

Figure 3.16 Mean percentage of ground cover, interactions between season (spring, fall, winter) and ground cover type at VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Top/dark gray bars represent herbaceous ground cover, middle/light gray bars represent bare ground, and bottom/medium gray bars represent leaf litter

CHAPTER IV

DISCUSSION AND CONCLUSION

Interpretation of Results

Overall, statistical analyses did show that kudzu was significantly related to both avian communities and native flora communities. Season and location also had some significant relationships. In terms of avian individual and species detections, observable trends included more individuals detected at low kudzu sites in the spring and fall, but more detected at high kudzu sites during the winter, likely due to the more open area that attracts species such as *Spizella pusilla* (Field Sparrow). Analyses of the data collected during this study showed that low kudzu levels did indeed correspond with greater avian diversity and species richness. However, medium kudzu coverage did not correlate with greater diversity or richness. There were no significant statistical differences between medium and high kudzu levels. I therefore conclude that any amount of kudzu coverage over 30%, which was the lower limit of the medium kudzu classification, can negatively impact avian diversity and community richness.

Avian diversity also differed between the fall and winter seasons, but not between spring and fall or spring and winter. Fall avian communities include a large number of migratory species and year-round residents, whereas winter avian communities only comprise those species that are year-round residents and few winter migratory residents such as *Zonotrichia albicollis* (White-throated Sparrow). One interesting result from this study was that species richness was lower at the Enterprise South location than at the Hickory Valley locations, although I expected lower richness at the Hickory Valley locations due to the fairly heavy road traffic, which was not present at Enterprise South. In numerous studies conducted globally, road noise has been associated with lower avian diversity and species richness, with both increasing as distance from roads increased (Francis et al. 2009, Polak et al. 2013, Reijnen et al. 1995). Enterprise South is adjacent to the Volkswagen Assembly Plant, which was constructed in 2009. Extensive construction activities could have disturbed the Enterprise South location and the site may not have had sufficient time to recover.

The other component of diversity, evenness, did not differ significantly by kudzu level, season, or location. Although some species were more abundant than others, the same few species were always the most abundant and the rarer species were always the rarest (Figure 3.1 and Appendices A5-A8). This suggests that the greater diversity at low kudzu sites is associated with increased species richness, not changes in evenness. The fact that evenness, or relative abundance of species, did not differ between any of the fixed factors suggests that kudzu does not attract a significant number of additional species that would not also be found in areas with no kudzu, and that kudzu simultaneously does not discourage many species from using that particular habitat. This especially applies to those species that were the most abundant, such as the Eastern Towhee, which was in the top five most abundant species at low, medium, and high kudzu level sites. This conclusion is similar to results from Wilcox and Beck (2007), where Chinese privet density did not affect the number of birds or number of species detected in a southeastern forest. The authors concluded that birds were not any more likely to be detected in high privet-density sites than in low privet-density sites. Alternatively, many studies show clear correlations between greater species evenness and the absence of invasive plants (Ferdinands et al. 2005, Gan et al. 2010, McCusker et al. 2010, van Riper III et al. 2008).

Grouping avian species by guilds did reveal some trends in the categories of species found at different kudzu levels and during different seasons. Although species grouped by primary diet did not differ by kudzu level or season, overall the majority of species detected were insectivores, making up almost 80% of all species. These results are not entirely surprising in that many avian species, particularly passerines and woodpeckers, are insectivorous. Because there were not more insectivorous species detected at high kudzu sites than other sites, I hypothesize that kudzu is not attracting additional insects, and therefore also not attracting avian species looking for additional food (insect) resources.

Grouping species by foraging behavior did reveal interacting relationships between kudzu level and season and the percentages of species with different foraging behaviors. All five foraging behavior groups were significantly different from one another. Species detected were very diverse in how they foraged for food, although ground and foliage gleaners did make up a larger percentage of all species detected. The percentages of species in some foraging groups were different across different kudzu levels and seasons. Ground gleaners were more prevalent at low and medium kudzu sites and during the fall and winter. At high kudzu levels and during the spring, the percentage of foliage gleaners was greater and similar to the percentage of ground gleaners. These results suggest that high kudzu level areas may attract more foliage gleaning species than low or medium level sites. Contrary to the results from primary diet analyses, this increase in foliage gleaners could be due to additional food resources, either insects or seeds/fruit, available at high kudzu areas. However, a likely explanation is that high kudzu areas could attract foliage gleaners due to the availability of increased vegetation surface area from which to glean food resources.

The last category analyzed, primary nesting habitat, did show that the percentage of species between the four nesting habitat categories was significantly different. Specifically, species that are canopy nesters made up the greatest percentage (almost 50%) of all species detected. However, the percentages of shrub nesters, ground nesters, and species nesting on other substrates (snags, human structures) were not different. The percentage of species in each nesting habitat category also differed slightly by season. There were fewer ground nesters during the spring than the fall and winter, and the percentage of shrub nesters dropped from spring to fall and again from fall to winter. The decrease in ground nesting species during the spring is somewhat surprising, as increased vegetation during the spring could provide more nest cover and protection. It is possible, however, that kudzu could create too much cover. Dense vegetation creates more visual obstruction, which reduces a bird's visibility of predators. This can increase predation risk and reduce foraging efficiency because of forced increased vigilance by birds to avoid predators (Lazarus and Symonds 1992). Dense vegetation can also limit movement and make food resources more inaccessible or difficult to detect (Whittingham and Evans 2004). The drop in shrub nesters from spring to winter does match expected results due to decrease in shrub cover during the fall and winter when there is less vegetative cover overall (Appendix A-10). It is important to note that species were placed into primary diet, foraging behavior, and primary nesting habitat based on information from Erlich et al. (1988). The authors make the disclaimer that not every individual of a species will exactly fit the overall species trends, and that the groupings represent the typical life histories of each species. For example, many species have differing components of their diet depending on season and food availability.

It has been suggested that kudzu does negatively impact native vegetation and alter vegetation structure (Blaustein 2001, Britton et al. 2003, Drake et al. 2003, Mitich 2000, Munger

2002, NPS 2010, VA-DCR 2001). In trend with those suggestions, the results from this study show that kudzu chokes out underlying vegetation and changes the composition and structure of native flora. Although kudzu did not significantly impact the number of genera identified at each location, kudzu level was related to the number of individual trees identified. There were significantly more trees at medium kudzu level locations (37) than at high kudzu level locations (4). Kudzu does kill trees over time and also grows along forest edges where there are less trees, both of which are factors that could explain the significantly fewer number of individual trees at high kudzu level areas. The presence of kudzu also was related to canopy coverage, with high kudzu level areas having much less canopy cover. This could be attributed to kudzu being an edge species, and edge habitats naturally have less canopy cover and more light availability. In addition, kudzu kills many large canopy trees over time. Although canopy cover was slightly greater at medium kudzu level areas, sites with medium and low kudzu level coverage did not differ significantly. Surprisingly, although leaves are not present on most trees in this study area during the winter, canopy coverage was not statistically different between the fall and winter.

Kudzu level was also the only fixed factor to be related to midstory horizontal vegetation coverage. Areas with high kudzu had significantly greater midstory coverage, likely due to the dense kudzu stands themselves and their leaf cover. Unexpectedly, midstory coverage did not differ between seasons, potentially due to the presence of evergreen midstory plant species such as Chinese privet or *Kalmia latifolia* (Mountain laurel). I anticipated less midstory coverage during the winter, particularly at high kudzu sites where kudzu no longer had leaves to make up a significant portion of the midstory vegetation.

In terms of ground cover, all sites had a greater percentage of herbaceous vegetation and leaf litter cover than bare ground. These results do match what would be expected, as the study sites were either covered by kudzu (herbaceous) or forested areas with a significant amount of leaf litter. There was a statistical relationship between both kudzu level and season interacting with ground cover categories. High kudzu level areas had a greater proportion of herbaceous ground cover, largely kudzu, than medium and low kudzu level areas. Correspondingly, high kudzu areas had a lesser proportion of leaf litter than medium or low kudzu areas. This corresponds with the lower canopy coverage at high kudzu sites, and less canopy cover will result in less leaf litter. The relationship between season and ground cover interactions with the percentages of each ground cover type, while significant, were less pronounced. During the spring there was slightly more bare ground than other seasons, possibly due to less leaf litter. In the winter there was a greater percentage of leaf litter and correspondingly less herbaceous cover. Increase in leaf litter would be due to the loss of tree leaves at the end of fall, and less herbaceous cover is expected during the colder months when fewer herbaceous plants grow.

Relationship Between Vegetation and Avian Communities

Kudzu's impact on native vegetation composition and structure is likely the main reason that areas with medium or high kudzu levels had lower diversity and species richness. Previous studies on the relationships between avian communities and their habitats have shown that vegetation structure and composition heavily influence the distribution of avian species. Particularly, both diversity and species richness tend to be higher in areas with more complex vegetative structure and composition. Studies by MacArthur and colleagues are classic examples of how vegetation structure can affect avian communities. MacArthur studied the distribution of warblers in coniferous trees, finding that different species used different vegetation height layers for feeding and nesting. Total warbler populations were also proportional to the volume of canopy foliage (MacArthur 1958). The MacArthur and MacArthur (1961) study of avian populations in multiple states showed that the addition of vertical vegetation layers corresponded with an increase in avian diversity. This study showed that although plant composition does influence diversity and richness, vertical structure and foliage density similarly influences avian communities. These studies by MacArthur show that the potential addition of more niches and structurally oriented guilds from more complex plant composition and structure allows for more species to live within an area.

There have been numerous other studies that have shown that vegetation structure, or physiognomy, influences avian community composition. James (1971) defined the "niche-gestalt" theory, in which a predictable relationship exists between the presence of a bird and its vegetation requirements or preferences. James studied 46 common breeding birds and found that percentage of canopy cover and canopy height were the most powerful variables to predict the niches of specific species. These and other certain structural vegetative features were consistently present where a specific species occurred, which showed structure strongly influences the distribution and presence or absence of species. Sturman (1968) similarly examined relationships between chickadee abundances and associated vegetation variables. For two species of chickadees (*Poecile atricapillus* and *P. rufescens*) in Washington, density of both species correlated most closely with percentage of canopy cover, average canopy height, and volume of midstory bushes, all structurally related variables. Breeding bird and associated habitat censuses by Willson (1974) showed that vertical vegetation profiles (height) and increased vegetation volume, primarily the addition of more trees, corresponded with the addition of more species. New guilds also accumulated as vegetation complexity increased. In Dickson et al. (2009) the probability of occupancy of species such as *Selasphorus platycercus*

(Broad-tailed Hummingbird), *Melospiza melodia* (Song Sparrow), and *Oporornis tolmiei* (MacGillivray's Warbler) increased as the structural complexity of riparian vegetation, primarily canopy and shrub components, increased.

Rotenberry has published several studies on the effects of flora taxonomic composition on avian community composition of semi-arid shrub-steppe habitat. For these studies, floristic composition affected avian communities more than the structure, or physiognomy, of the vegetation (Rotenberry 1985, Wiens and Rotenberry 1981). Because this study did not analyze flora species composition in depth, I can only assume that vegetation structure is a primary factor influencing avian communities.

The results support the idea that vegetation structure significantly influences avian communities, as areas with high kudzu coverage that are largely a monoculture had less species and less diversity. Kudzu creates less structural diversity because the twining vines collapse supporting plants and trees, resulting in a change in the vertical habitat structure (Gordon 1998). Low kudzu areas had greater diversity and richness because of the greater structural complexity of the vegetation. However, it is also important to note that individual species respond differently to vegetation floristics and physiognomy, so for some species native flora composition could be a strong determining factor in distribution, as individual species are often closely associated with specific plant species (Mills et al. 1991). Because my study focused on the structure of the vegetation rather than specific taxonomy, I can only make conclusions that vegetation structure does indeed impact avian communities in terms of diversity and species richness.

Management Implications

The results from this study have implications for habitat management and kudzu control in the southeastern U.S. It was previously believed that kudzu negatively impacted native vegetation, and my results support the related impact of kudzu on native birds. This information was not available prior to this study. As kudzu is one of the most common and aggressive management concerns in the Southeast, now federal, state, and even private landowners can use this information when making land management decisions (Drake et al. 2003, Kuppinger 2000). This study also provides information that will allow land managers to assess the biodiversity "costs" of the presence of kudzu monocultures. Those wishing to specifically manage for avian populations will be able to incorporate these results into kudzu management or eradication decisions.

Concerns over the decline of many songbird species should also be taken into account. Areas with kudzu should be surveyed to determine if any declining species are present, and if so, what management actions should be taken. For this study, *Passerina cyanea* (Indigo Bunting) were detected during the spring, and were predominantly found in the low kudzu sites. The Indigo Bunting is a declining species in Tennessee, as evidenced by North American Breeding Bird Survey trends over the last 40 years (Figure 4.1). This species has declined by 0.9% from 1966 to 2011 and 1.4% from 2001 to 2011 (Sauer et al. 2012). If the management goal is to ensure diverse populations of all avian species, including those in decline, my results support a course of action for complete kudzu removal. This will not only allow for an increase in avian diversity and species richness in those areas, but also will help to restore native flora communities. Maintaining complex vegetation structure, including ground cover, midstory shrubs, and forest canopy, may help maintain viable bird populations (Dickson et al. 2009).

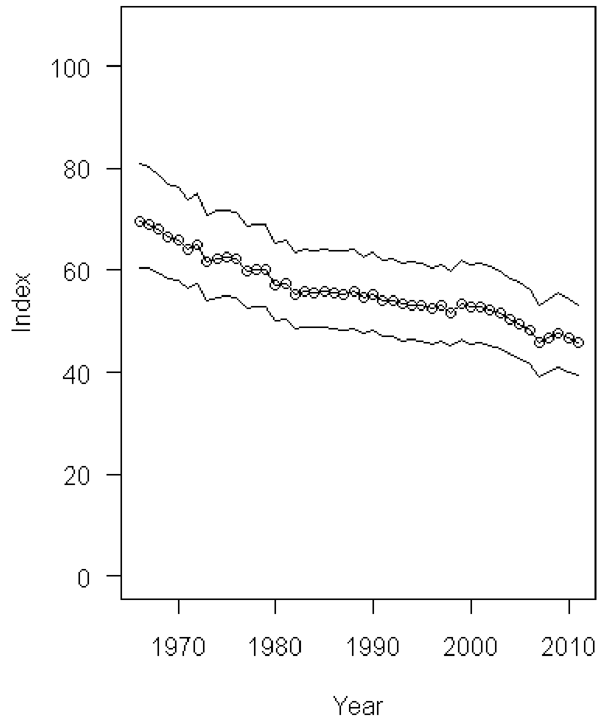

Figure 4.1 Breeding bird survey trend for *Passerina cyanea* (Indigo Bunting) in Tennessee from 1966 to 2011 (Sauer et al. 2012). The graph shows a decline of 0.9% from 1966 to 2011 and 1.4% from 2001 to 2011

Conclusions

With the completion of this study, there are suggestions I have for improvements that could be made or future work that could be done to further support the results of this project. To fully understand if detections suggested specific habitat associations between species or individuals and the presence or absence of kudzu, additional years of data collection would be required. Therefore, it would be beneficial for similar studies to be conducted in other parts of the Southeast with more replications. Results would be even more significant if similar correlations were seen over multiple years and at more sites. Mist netting and bird banding also could be incorporated into a similar research project to determine if the same bird species or individual birds use the same sites over extended periods of time. This could show specific individual's habitat preferences, and if those detected only at high or low kudzu sites chose those areas coincidentally or due to a specific structural component, resource, or plant species. In terms of the vegetation component of future studies, a more specific investigation of midstory and understory plant taxonomic composition also could reveal any trends in vegetation communities associated with any specific bird species. Taxonomically identifying all vegetation also could reveal any relationships between the presence of kudzu and the presence or absence of particular plant species.

Overall, this study addresses a lack of information of the effects of kudzu on native communities and provides significant results strongly suggesting that kudzu negatively impacts avian communities. Although this study was correlational in nature, the statistical relationships are consistent with kudzu affecting both avian and flora communities. In the Southeast, these results can be used when managing for avian conservation, particularly when wanting diverse avian communities or in areas with species of concern, and when managing current or future kudzu stands either for reduction in size or complete eradication.

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APPENDIX A

ADDITIONAL FIGURES

APPENDIX A

Appendix A-1 Examples of high (top), medium (middle), and low (bottom) kudzu level sites on VAAP land in Hamilton County, Tennessee during the 2012-2013 study period. All three pictures were taken during Spring 2012

High kudzu site (>90%)

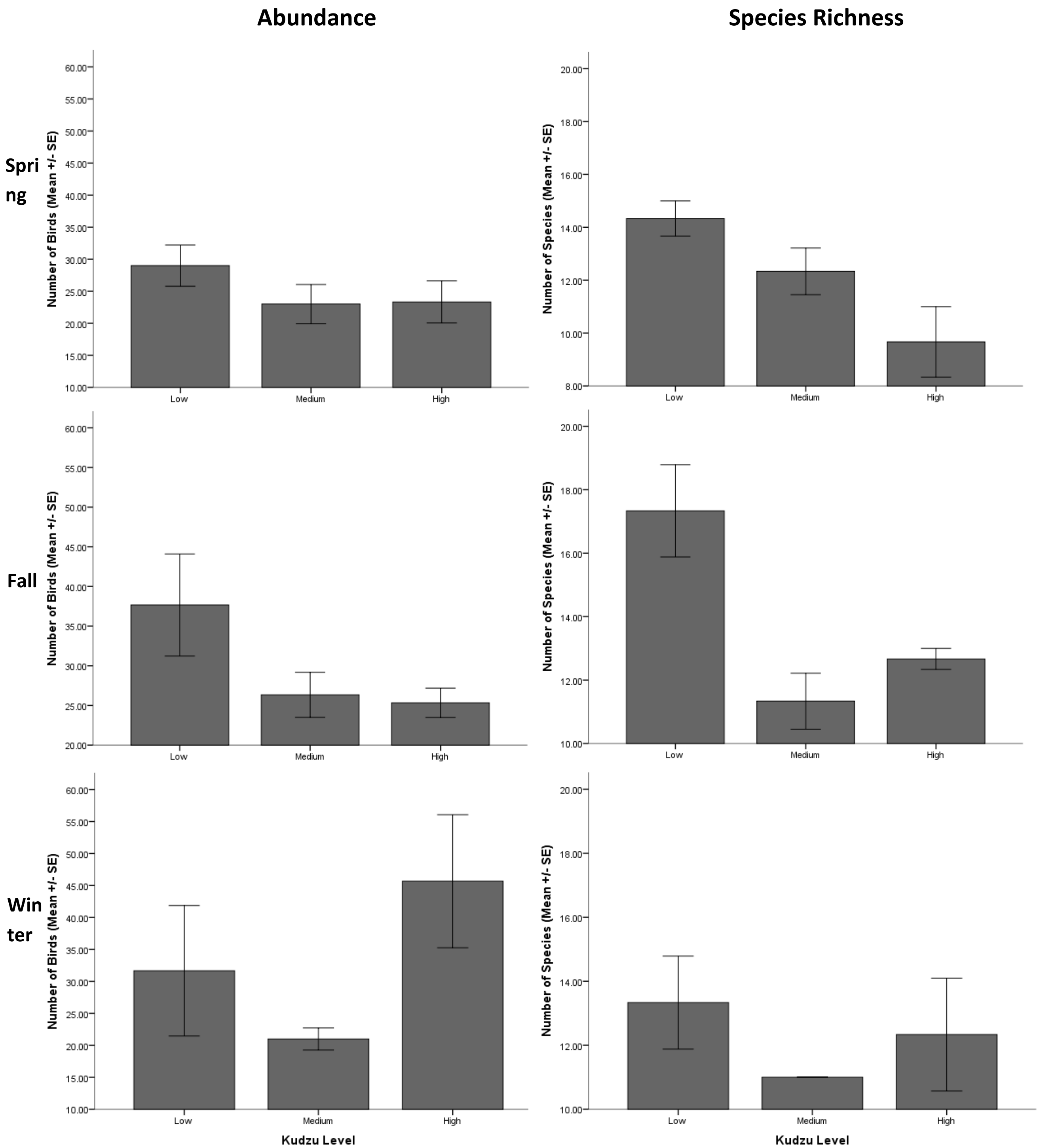

Medium kudzu site (30-70%)


Low kudzu site (<10%)

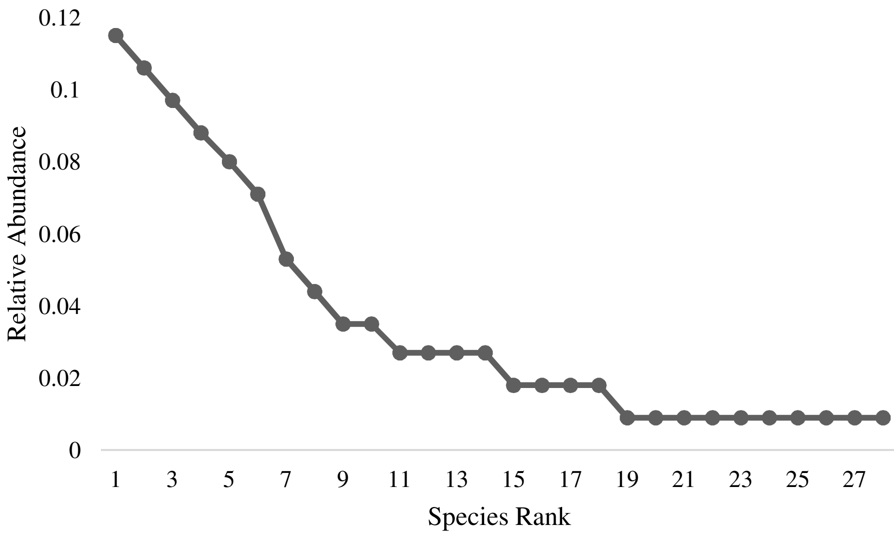
Appendix A-2 Vegetation profile board used to measure midstory vegetation at VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Profile board in use at a high kudzu site during the spring, left, and the stake attached to the bottom of the board, right.

Appendix A-3 1-m^2 quadrat used to quantify ground cover at a VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. This picture was taken at a high kudzu level site in Winter 2013

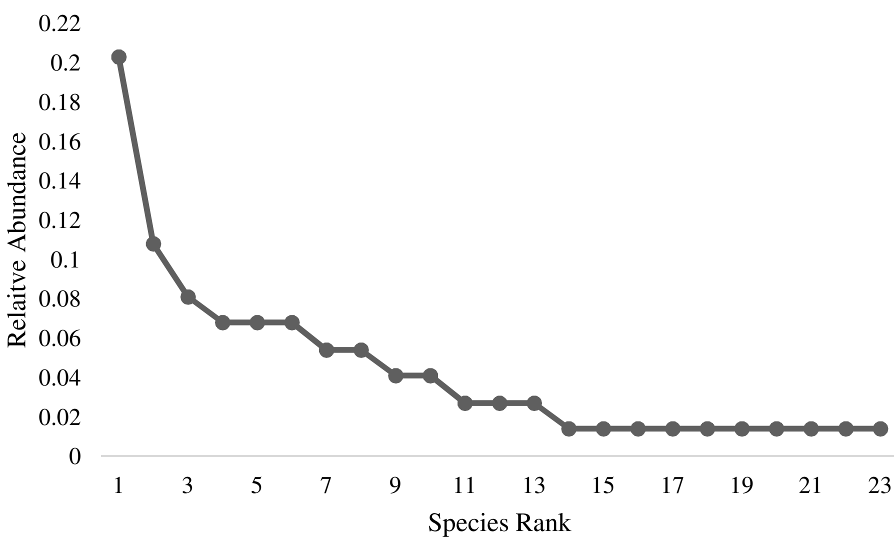
Appendix A-4 Mean (+/- SE) of avian species abundance (left) and species richness (right) grouped by both season and kudzu level on nine VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period



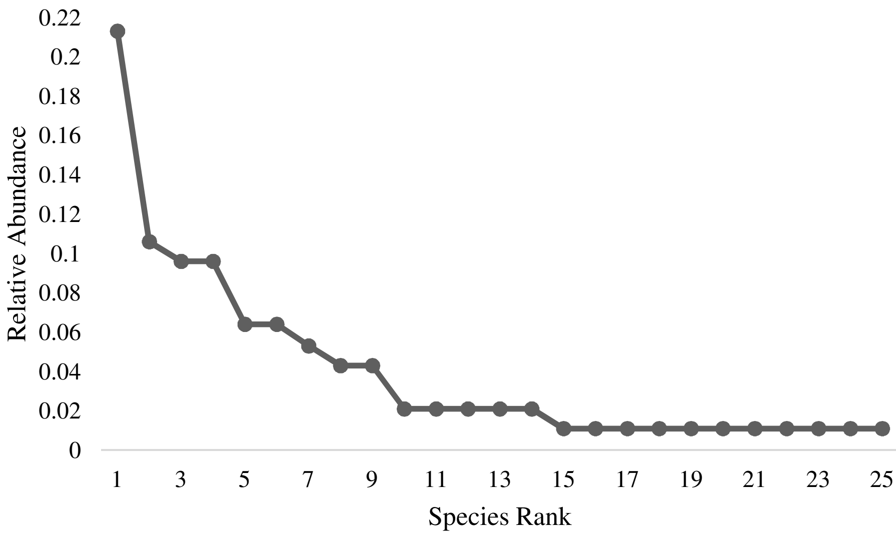
Appendix A-5 Rank abundance curve of avian species detected at low kudzu areas during the Fall 2012 study period on VAAP land study sites in Hamilton County, Tennessee. Curve shows relative abundances and associated avian species' rank from 1, most abundant, to least abundant



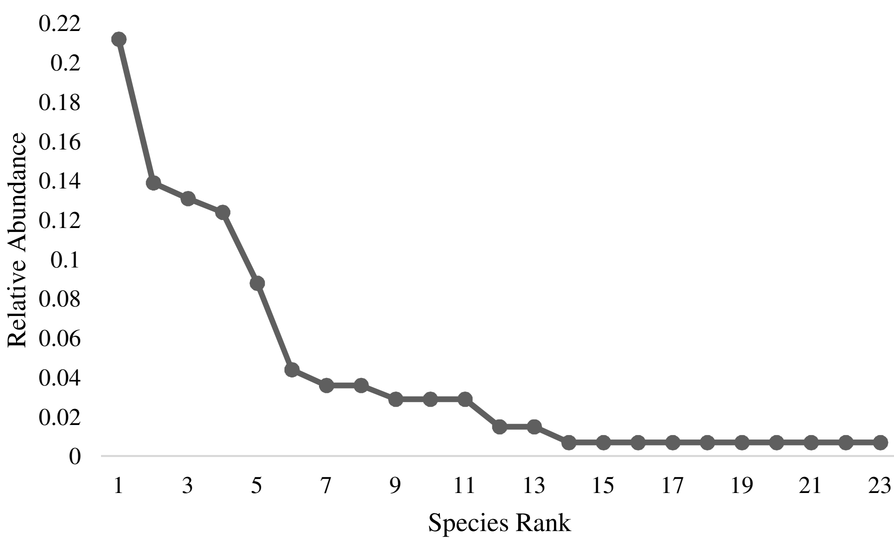
Appendix A-6 Rank abundance curve of avian species detected at high kudzu areas during the Fall 2012 study period on VAAP land study sites in Hamilton County, Tennessee. Curve shows relative abundances and associated avian species' rank from 1, most abundant, to least abundant



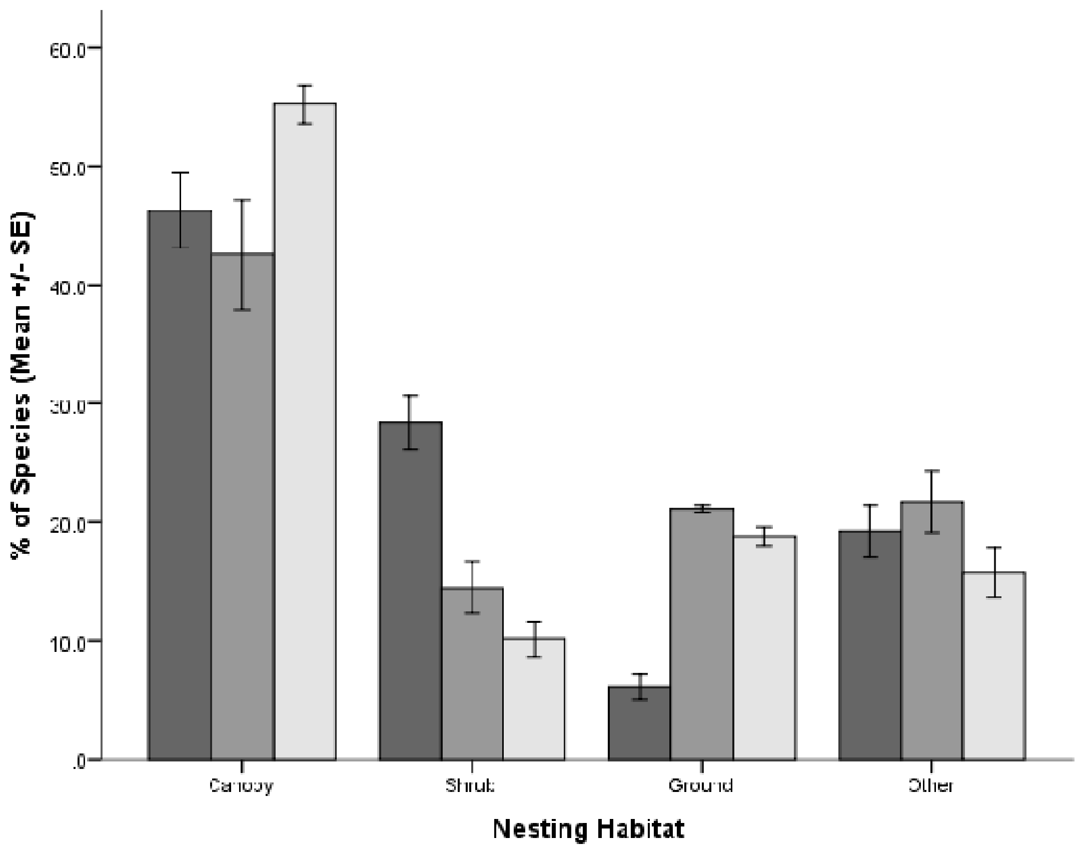
Appendix A-7 Rank abundance curve of avian species detected at low kudzu areas during the Winter 2013 study period on VAAP land study sites in Hamilton County, Tennessee. Curve shows relative abundances and associated avian species' rank from 1, most abundant, to least abundant



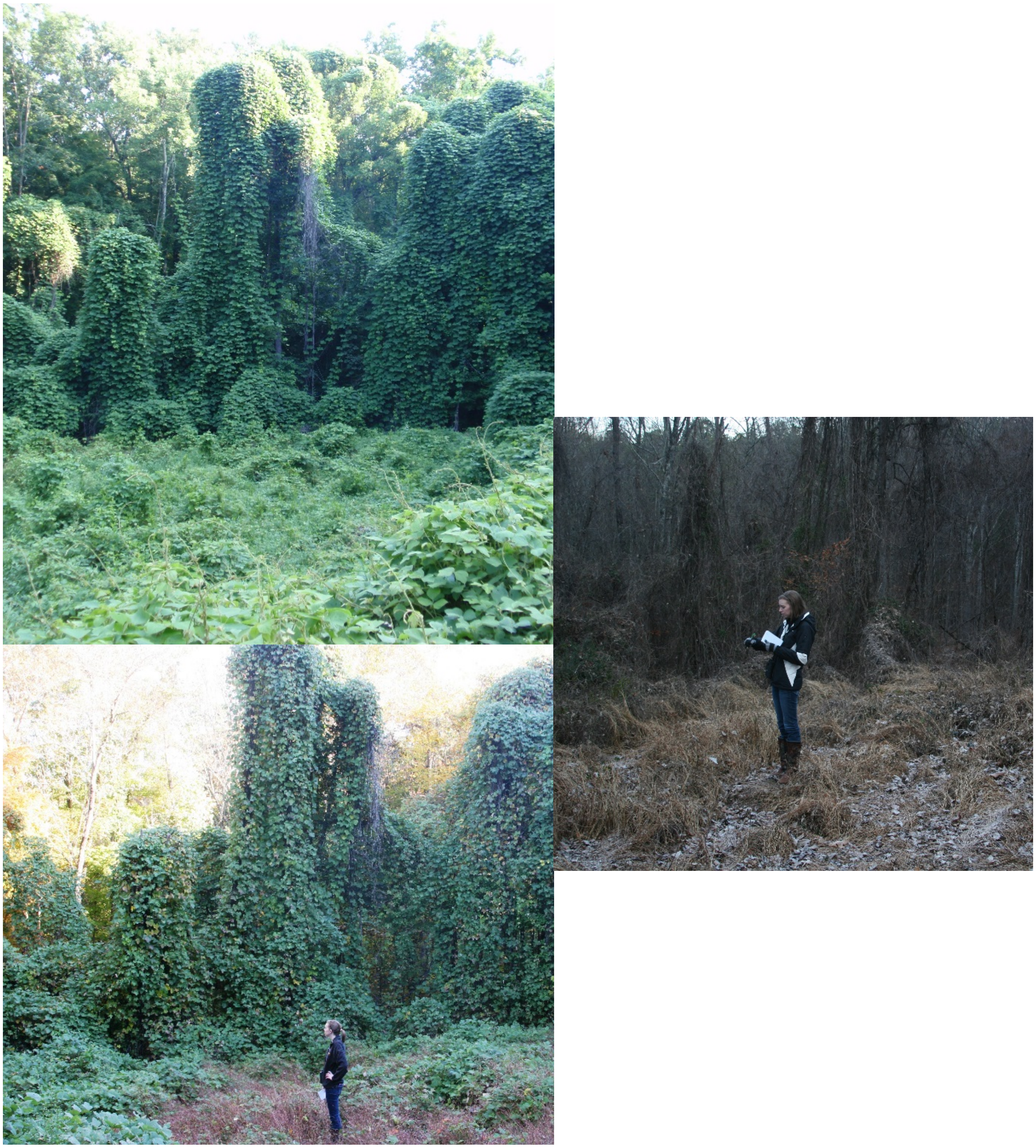
Appendix A-8 Rank abundance curve of avian species detected at high kudzu areas during the Winter 2013 study period on VAAP land study sites in Hamilton County, Tennessee. Curve shows relative abundances and associated avian species' rank from 1, most abundant, to least abundant



Appendix A-9 Percentage of avian species (Mean +/- SE) for each nesting habitat category (canopy, shrub, ground, other) grouped by season on VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period. Left/dark gray bars represent the spring season, middle/medium gray bars represent the fall season, and right/light gray bars represent the winter season.



Appendix A-10 Differences in kudzu growth and leaf cover between Spring 2012 (top left), Fall 2012 (bottom left), and Winter 2013 (right) at a high kudzu site (Enterprise South) on VAAP land in Hamilton County, Tennessee



APPENDIX B

ADDITIONAL TABLES

APPENDIX B

Appendix B-1 Percentages of individual avian detections (aurally, visually, both) for spring, fall, winter, and cumulatively at nine VAAP land study sites in Hamilton County, Tennessee during the 2012-2013 study period

Percentage of Individuals Detected Aurally, Visually, or Both				
	Spring	Fall	Winter	Cumulative
Aural	84.98	89.66	58.84	77.17
Visual	8.15	6.13	35.38	17.25
Aural + Visual	6.87	4.21	5.78	5.58

Appendix B-2 Avian species detected only at low kudzu sites on VAAP land in Hamilton County, Tennessee during the 2012-2013 study period. The number of individuals detected of each species are shown in parentheses

Species Detected Only at Low Kudzu Sites (Number of individuals in parentheses)		
Spring	Fall	Winter
Acadian Flycatcher (1)	Black-throated Green Warbler (3)	Hairy Woodpecker (1)
Great Crested Flycatcher (1)	Eastern Wood-Pewee (1)	Hermit Thrush (2)
Northern Flicker (1)	Field Sparrow (2)	Killdeer (1)
Ovenbird (1)	Gray Catbird (1)	Northern Flicker (1)
Scarlet Tanager (1)	Hairy Woodpecker (1)	White-breasted Nuthatch (2)
White-breasted Nuthatch (1)	Magnolia Warbler (1)	
	Ovenbird (1)	
	Pine Warbler (1)	
	Wood Thrush (1)	
	Yellow Bellied Sapsucker (1)	

Appendix B-3 Avian species detected only at high kudzu sites on VAAP land in Hamilton County, Tennessee during the 2012-2013 study period. The number of individuals detected of each species are shown in parentheses

Species Detected Only at High Kudzu Sites (Number of individuals in parentheses)		
Spring	Fall	Winter
Hooded Warbler (1)	American Goldfinch (1)	Cedar Waxwing (1)
	Chestnut-sided Warbler (1)	Northern Mockingbird (1)
	Tennessee Warbler (2)	Pileated Woodpecker (1)
	Yellow-rumped Warbler (1)	Red-shouldered Hawk (1)
		Red-tailed Hawk (1)

Appendix B-4 Summary of ANOVA results of the percentage of species in primary diet categories (insectivore, omnivore, granivore, and other) during the 2012-2013 study period on VAAP land study sites

	Sum of squares	df	Mean square	F	*p*
Diet	62.730	3	20.910	39.147	0.000
Error	17.093	32	0.534		
Total	79.823	35			

Appendix B-5 Summary of ANOVA results of foraging behavior groups (ground gleaning, foliage gleaning, bark gleaning, hovering, and flying) and correlations with the interacting relationships between kudzu level/foraging behavior and season/foraging behavior during the 2012-2013 study period on VAAP land study sites

	Sum of squares	df	Mean square	F	*p*
Forage	11064.176	4	2766.044	248.343	0.000
Kudzu Level*Forage	352.140	10	35.214	3.162	0.014
Season*Forage	657.153	10	65.715	5.900	0.000
Error	222.760	20	11.138		
Total	12296.230	44			

Appendix B-6 Summary of ANOVA results of the percentage of species with different primary nesting habitats (ground, shrub, canopy, and other) and correlations with the interacting relationships between nesting habitat/season and nesting habitat/kudzu level during the 2012-2013 study period on VAAP land study sites

	Sum of squares	df	Mean square	F	*p*
Nest Habitat	6406.349	3	2135.450	138.696	0.000
Nest Habitat*Season	1244.893	8	155.612	10.107	0.000
Nest Habitat*Kudzu Level	138.847	8	17.356	1.127	0.397
Error	246.347	16	15.397		
Total	8036.436	35			

Appendix B-7 Summary of ANOVA results of the number of individual trees detected and correlations with kudzu level (low, medium, high) and location (HV1, HV2, ES) during the 2012-2013 study period on VAAP land study sites

	Sum of squares	df	Mean square	F	*p*
Kudzu Level	197.556	2	98.778	8.387	0.037
Location	2.889	2	1.444	0.123	0.888
Error	47.111	4	11.778		
Total	247.556	8			

Appendix B-8 Summary of ANOVA results of the percentage of ground cover types (herbaceous, bare ground, leaf litter) and correlations with three fixed factors and interacting relationships between kudzu level/ground cover categories and season/ground cover categories during the 2012-2013 study period on VAAP land study sites

	Sum of squares	df	Mean square	F	*p*
Kudzu Level	0.013	2	0.007	0.000	1.000
Season	0.014	2	0.007	0.000	1.000
Ground Cover	9944.712	2	4972.356	132.540	0.000
Kudzu Level*Ground Cover	7376.434	4	1844.108	49.155	0.000
Season*Ground Cover	988.570	4	247.142	6.588	0.005
Error	450.191	12	37.516		
Total	18759.934	26			

VITA

Amelia Brianne Hudson was born in Longview, Texas to James D. and Melanie Hudson, and grew up for most of her life in Carthage, Texas. She attended Carthage High School, where she graduated as Salutatorian in 2007. She then attended Baylor University in Waco, Texas where she graduated *cum laude* with a Bachelor of Arts in Environmental Studies. She came to the University of Tennessee at Chattanooga in the Fall of 2011 to pursue her Master of Science degree. She completed her thesis under the guidance of Dr. David Aborn, and was a Graduate Teaching Assistant for environmental science labs during her time at UTC. Amelia graduated with a Master of Science degree in Environmental Science in December 2013. Her research interests include invasive species, avian conservation, and wildlife-habitat interactions in human-altered landscapes.