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I am submitting herewith a thesis written by Elizabeth Anne Summers entitled "Evaluating Ecological Restoration in Tennessee Hardwood Bottomland Forests." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Wildlife and Fisheries Science.

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EVALUATING ECOLOGICAL RESTORATION IN TENNESSEE HARDWOOD BOTTOMLAND FORESTS

A Thesis
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Degree
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Elizabeth Anne Summers
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ABSTRACT

Hardwood bottomland ecosystems provide critical habitat for various wildlife among numerous ecosystem services. Since the 1800s, these forested wetlands have been logged and drained for agriculture. The federal government passed a series of legislative acts that protected wetlands and provided monetary support for restoration. The Wetlands Reserve Program (WRP) was established in 1990 with the goal of restoring ecological function in wetlands. Although several studies have measured plant and wildlife responses to WRP restorations, no standard protocol has been developed to monitor the state of ecological restoration at sites. Index of biotic integrity (IBI) models are commonly used to evaluate ecological function by assigning scores derived from biological characteristics measured at disturbed sites and comparing them with reference sites. Therefore, the objectives of my study were to: (1) characterize vegetation, amphibian and bird communities among 17 WRP restoration and 4 reference bottomland sites, and (2) develop IBI models for these communities to use in monitoring ecological restoration. My study was conducted across 10 counties in western Tennessee from March – August 2008, and communities were measured using standard sampling techniques. I detected 15 amphibian and 95 bird species at bottomland WRP sites, which ranged 2 – 21 years old. Anurans were common among sites, but salamanders were only detected at reference sites containing mature forests. The bird community changed predictably in response to succession, with grassland birds dominating young restoration sites and scrub-shrub and forest birds dominating older restoration and reference sites. Vegetation structure was related to site age, and a good predictor of bird community composition. Variables retained in the vegetation IBI model included density of snags, logs and overstory trees, basal area, and percent vertical cover measured using a profile

board. The bird IBI model contained relative abundance of bark feeding, branch nesting, and twig nesting guilds. Presence of salamanders was the only variable in the amphibian IBI model. My results indicate that the WRP is contributing to the regional biodiversity of western Tennessee. The IBI models that I developed can be used for monitoring ecological restoration in Tennessee hardwood bottomlands; however, their applicability outside this region should be validated.

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CHAPTER I

INTRODUCTION

Hardwood bottomland ecosystems are forested wetlands that occur in the floodplains of rivers and streams (Allen et al. 2001). These forests are dynamic, productive systems due to frequent overbank flooding and consequent deposition of allochthonous matter (Taylor et al. 1990). Historically, hardwood bottomlands were common wetlands in the central and southeastern United States, especially in the Mississippi Alluvial Valley (MAV, Sharitz and Mitsch 1993). Today, over 70% of hardwood bottomland acreage in the MAV has been destroyed (King and Keeland 1999, Stanturf et al. 2000), primarily for agricultural production (Tiner 1984). The creation of reservoirs and dams for flood control, conversion to production pine stands, and urban development have contributed to hardwood bottomland declines (Allen et al. 2001). The development of levees and stream channelization also has reduced the rate of new wetland formation by restricting natural channel migration (King et al. 2005). In Tennessee, 59% of wetlands have been lost, most of which were hardwood bottomland forests (Johnson 2007).

Hardwood bottomlands provide many important environmental and ecological functions. These systems filter contaminants from water, stabilize riverbanks, store eroded sediments, produce biomass and nutrients, and sequester carbon which may help buffer global warming (Taylor et al. 1990, Hyberg and Riley 2009). Bottomlands also are important for the storage of surface water and flood control, and function as groundwater recharge sites (Taylor et al. 1990).

Hardwood bottomlands also support diverse biological communities. Approximately 70 bird species, including 30 Neotropical migrants, breed in hardwood bottomland forests (Pashley

and Barrow 1993). Several species of Neotropical migrants that use hardwood bottomlands (e.g. Swainson's warbler, *Limnothlypis swainsonii* and cerulean warbler, *Dendroica cerulea*) are in need of conservation due to population declines (Askins 1990, Robbins et al. 1992). Bottomland hardwood forests also are important sites for amphibians (Wharton 1982), which are declining globally (Stuart et al. 2004). Recent studies estimate that 43% of the world's amphibian species are declining (Stuart et al. 2004). At least 15 anuran and 40 salamander species use hardwood bottomlands in Tennessee (Tennessee Amphibians Monitoring Protocol 2004). There are also 101 fish species in Tennessee that are federally threatened or endangered (Widlak 2008); many of these species use hardwood bottomlands during flood events (Leao 2005). Mammals, such as the white-tailed deer (*Odocoileus virginianus*), beaver (*Castor canadensis*), raccoon (*Procyon lotor*), swamp rabbit (*Sylvilagus aquaticus*), gray squirrel (*Sciurus carolinensis*), river otter (*Lutra canadensis*), and mink (*Mustela vison*) frequently use hardwood bottomlands to meet their life cycle needs (Fischer et al. 1999). In sum, hardwood bottomland ecosystems provide essential habitat for many fish and wildlife species.

Due to the recognized benefits of hardwood bottomlands, there is growing interest to restore these ecosystems (King et al. 2009). For example, over 30,000 ha of hardwood bottomlands have been reforested in the MAV for purpose of carbon sequestration (Shoch et al. 2009). The Wetlands Reserve Program (WRP) is the largest conservation program in the United States that provides monetary incentives for hardwood bottomland restoration (Schoenholz et al. 2001). A primary goal of the WRP is ecological restoration. In particular, restoration of the avian community is a priority due to widespread population declines in bird species (Sauer et al. 2005). To my knowledge, 6 studies have been published to date on bird responses to hardwood

bottomland restoration (Nuttle 1997, Buffington et al. 2000, Twedt et al. 2002, Hamel 2003, Snell-Rood and Cristol 2003, Hoover 2009). Also, only one published study exists that measured amphibian responses to riparian restoration (Bowers et al. 2000). None of these studies have been conducted in Tennessee or the Upper MAV. Understanding vegetation responses at bottomland sites also is fundamental to ensuring restoration success (Stanturf et al. 2001). Some studies have documented vegetation responses to bottomland regeneration (e.g., Battaglia et al. 2002, 2004), but comparison of vegetation characteristics across a continuum of site ages has not been performed. Few studies also have related vegetation characteristics at bottomland restoration sites to vertebrate populations (Nuttle 1997).

Studies of avian responses to hardwood bottomland restoration suggest that avian species occurrence in early, mid, and late successional stages is different. Twedt et al. (2002) found that grassland birds dominated restoration sites that were $\leq$4 years old, but the bird community changed to one dominated by scrub-shrub and early successional forest birds from 5 – 9 years after planting. Twedt et al. (2002) projected that bird communities in hardwood bottomland restorations should be similar to reference sites in about 25 years. In support of this inference, Nuttle (1997) found that the bird community in 21- and 27-year-old stands planted with oaks was similar to mature hardwood bottomland forests. These studies indicate that bird community structure may be a good indicator of ecological restoration at hardwood bottomland sites.

Despite an estimated $4.9 billion allocated to the WRP since 1990, no protocol exists to evaluate or monitor ecological restoration at WRP sites (NRCS 2010). The United States Environmental Protection Agency (EPA) has established standard protocol for evaluating ecological function in wetlands (EPA 2002a,b,c,d). This bioassessment procedure involves

development of index of biotic integrity (IBI) models that quantify the structure of biological communities across a disturbance gradient (Karr 1981). Although never applied to bottomland restoration, presumably IBI models could be developed along a restoration disturbance gradient and used to monitor ecological restoration at bottomland sites. Ecological assessment using IBI models by natural resource practitioners requires knowledge of the biological community being measured (EPA 2002c). To encompass various aspects of habitat quality and maximize application by natural resource agencies, multiple IBI models are typically developed, with vegetation IBI models requiring the least expertise.

Although some studies exist which examine plant and vertebrate responses to bottomland restoration, more information is needed on the biological communities at WRP bottomland sites, especially in the Upper MAV. Additionally, monitoring protocol is needed to evaluate and monitor the state of ecological restoration at bottomland restoration sites and determine whether the WRP is meeting objectives (King et al. 2006). Thus, the goal of my research was to develop IBI models for vegetation, amphibian and avian communities to be used for monitoring the stage of ecological restoration in hardwood bottomlands. I present these results along with instructions on how to use the IBI models in Chapter II. I also quantified the relationship between various amphibian and bird community metrics with vegetation and abiotic characteristics at sites. These results are presented in Chapter III and provide a characterization of the biological responses to bottomland restoration in Tennessee. Chapters II and III are written in manuscript style, and possible outlets include *Restoration Ecology, Conservation Biology, Ecological Applications* or *Wetlands.*

CHAPTER II

INDEX OF BIOTIC INTEGRITY MODELS FOR EVALUATING ECOLOGICAL RESTORATION IN HARDWOOD BOTTOMLANDS

INTRODUCTION

Hardwood bottomlands are floodplain wetlands adjacent to riverine systems that provide habitat for wildlife, including mammals (Fischer et al. 1999), birds (Pashley and Barrow 1993) and amphibians (Wharton 1982). Hardwood bottomlands also provide various ecosystem services, such as floodwater storage, water filtration and carbon sequestration (Taylor et al. 1990). Historically, these wetlands covered about 10 million ha in the conterminous United States, with the greatest coverage in the Southeast (Sharitz 1992). Coverage of hardwood bottomlands has decreased substantially since European settlement due to deforestation and draining for agriculture (Tiner 1984). For example, >70% of the hardwood bottomlands have been destroyed in the Mississippi Alluvial Valley (Hefner and Brown 1985). In the 1970s, the Clean Water Act protected hardwood bottomlands from being drained or dredged without a federal permit, and subsequent legislation known as the "Farm Bills" created several conservation programs that provided funds to landowners to restore floodplain wetlands (Stanturf et al. 2001).

A large percentage of hardwood bottomland restorations have occurred through the Wetlands Reserve Program (WRP). This program was established by 1990 Farm Bill and is administered by the USDA Natural Resources Conservation Service (NRCS). The WRP is a voluntary program that offers landowners technical and monetary support to restore and enhance wetlands that were previously drained for agriculture (NRCS 2008). For permanent easements,

NRCS pays landowners the appraised value of the land and covers all restoration costs. As of October 2009, 888,151 ha have been enrolled in WRP since the program's creation (K. Murray, NRCS, unpublished data).

In Tennessee, wetland restoration associated with the WRP began in 1995 (NRCS 2005). Since then, restoration activities have been performed on a total of 13,541 ha of wetlands statewide, most of which have been hardwood bottomlands (NRCS 2008). These restorations have consisted mainly of replanting with native hardwood species, and in some cases, restoring hydrology through the use of ditch plugs, levee breaches and water control structures.

The goal of ecological restoration is to create conditions such that the structure, function, diversity, and dynamics of an ecosystem prior to human disturbance return (National Research Council 1992). To determine if restoration objectives are met, monitoring protocol must be established to evaluate restoration effectiveness (Allen et al. 2001). Monitoring can lead to implementing adaptive management techniques if restoration goals are not being achieved. To date, no monitoring protocol has been established for the WRP or exists for evaluating hardwood bottomland restorations (NRCS 2010).

Biological assessments (i.e., bioassessments) are one technique to evaluate the state of ecological restoration (EPA 2002a). Bioassessments use community composition of plants or animals at a site as an index of the underlying health of the ecosystem. Community metrics (e.g., abundance and species diversity) combined with biological knowledge of the species present can provide insight into relative ecological function. For example, in disturbed systems, the number of disturbance-intolerant taxa typically decreases and the proportion of tolerant species increases (Karr 1981, Karr and Dudley 1981). Bioassessments are useful for monitoring ecological

restorations because they use biological communities, which tend to reflect the cumulative effect of multiple stressors that may be present during restoration. Moreover, biologists can use bioassessments to track the recovery time to restoration and identify features that facilitate restoration success (EPA 2002a). One drawback of bioassessments is that they require expert knowledge of the taxa being measured (EPA 2002a).

Index of biological integrity (IBI) modeling is one type of bioassessment that is being used increasingly by state and federal natural resource agencies and non-government conservation organizations. An IBI model combines several biological metrics to give a site a summary score, which is an indicator of the overall integrity or relative ecological function (Karr 1981). Biological integrity is defined as the ability of a site to support and maintain a balanced adaptive community of organisms having a species composition and functional organization similar to undisturbed sites within a region (Karr and Dudley 1981). The process of developing an IBI model includes selection of sites along a gradient of human disturbance. Plant or animal assemblages are sampled at the sites, and biological metrics are chosen that show a predictable and empirical response to increasing human disturbance (Karr 1981). Each metric is assigned an individual score (i.e., a subindex), and subindices are combined to form an overall index that can be used to compare the ecological function among wetlands of the same type (EPA 2002a).

Although the WRP was developed with the goal of restoring the ecological function of wetlands to pre-agricultural disturbance, no evaluation protocol has been developed for monitoring the outcome of these restorations (King et al. 2006). The proposed ecological benefits of the WRP include restoring native plant and animal communities, with special priority given to providing habitat for migratory birds. One of the major barriers preventing WRP sites

from being monitored is the lack of a standard monitoring protocol for NRCS personnel. To evaluate whether the WRP is meeting its goals and is a successful conservation program, it is necessary to develop a standardized method for measuring ecological function on easements. Thus, the goal of my study was to create IBI models for avian, amphibian and plant communities for use in monitoring ecological restoration in hardwood bottomlands in Tennessee and perhaps elsewhere in the southeastern United States.

METHODS

Study Area

My study was conducted in western Tennessee in the Mississippi Alluvial Valley and Tennessee River Valley drainages from March – August 2008 (Figure 2.1). Study sites were randomly selected using a multi-stage sampling approach. The first level of randomization was the first year of WRP restoration, which included 1995 – 2005. The second level of randomization was WRP easement size: small (<40 ha) or large (>40 ha). Sites were randomly selected within years and size classes. Sixteen sites were randomly selected from all WRP sites in western Tennessee (Table 2.1). In some years (1996, 1999, 2005), sites were not available for random selection. Only 1 site was available for selection in 1995, 1997, 2003, 2004, and 2006. Also, there was an opportunity to sample 1 large restoration site (177 ha) that was originally enrolled in the Conservation Reserve Program and planted in 1987. Thus, in total, 10 large and 7 small acreage sites located across 10 western Tennessee counties were used for sampling (Table 2.1, Figure 2.1). Planting information was available for 13 of the 17 restoration sites included in this study. When enrolled in WRP, these sites were replanted with mixtures of cherrybark oak (*Quercus pagoda*), overcup oak (*Q. lyrata*), Nuttall oak (*Q. nuttallii*), swamp chestnut oak (*Q.*

michauxii), pin oak (*Q. palustris*), Shumard oak (*Q. shumardii*), water oak (*Q. nigra*), willow oak (*Q. phellos*), bald cypress (*Taxodium distichum*) and green ash (*Fraxinus pennsylvanica*; Tennessee NRCS, unpublished data). In general, bare-root seedlings were used and planting was performed manually. Average seedling density at planting was 795 seedlings/ha (SD = 121.4), and planted seeding density and composition was similar among the 13 sites with planting information (Tennessee NRCS, unpublished data). Minor hydrological restoration occurred at 9 sites, and constituted either plugging drainage ditches or breaking drainage tiles (Tennessee NRCS, unpublished data).

I established 4 reference sites within the Hatchie National Wildlife Refuge, which had not experienced extensive logging since the 1960s (L. Karnuth, U.S. Fish and Wildlife Service, unpublished data). I chose these reference sites because the Hatchie River is the longest unchannelized tributary of the lower Mississippi River (The Nature Conservancy 2007), thus it represented the least hydrologically disturbed tributary in western Tennessee available for sampling (Johnson 2007). I also chose the bottomland at the Hatchie National Wildlife Refuge because it was a younger secondary forest (mean stand age = 51 years), which provided a more reasonable target for restoration than older sites. Further, use of older reference sites could have increased the uncertainty of IBI model predictions by creating a larger gap between restoration and reference data. A possible disadvantage of all reference sites being located in the Hatchie River bottomland is that IBI predictions may be limited to this inferential space. However, inasmuch as the plant species and hydrology in the Hatchie River bottomland are typical of the historic conditions in riverine systems of western Tennessee and much of the Mississippi

Alluvial Valley (Johnson 2007), I assume that IBI models based on these reference conditions provide a reasonable target for restoration.

I systematically placed (≥930 m separation) 4 reference sites in the Hatchie River bottomland within the refuge boundaries (Figure 2.1). Partial thinnings occurred on the refuge at several locations since the 1960s (L. Karnuth, unpublished data), so I estimated stand age at each reference site by counting rings from tree cores for 6 overstory trees per site. Mean overstory age was 48.2 (SD = 15.9), 57.8 (SD = 13.6), 40.8 (SD = 19.5), and 55.3 (SD = 19) for the 4 reference sites. Reference sites 1 and 2 were dominated by water hickory (*Carya aquatica*), site 3 by water hickory and American sweetgum (*Liquidambar styriciflua*), and site 4 by American sweetgum and swamp chestnut oak (*Quercus michauxii*).

Sampling

The EPA Biological Assessment of Wetlands Working Group recommends sampling at least 2 biotic assemblages when developing IBI models (EPA 2002a); thus, I sampled vegetation, amphibian, and bird communities at 17 restoration and 4 reference sites. All of these communities are known to be impacted by human disturbance (Askins and Philbrick 1987, Welsh and Ollivier 1998, Canham and Marks 1985), hence they had a high likelihood of being correlated with the state of ecological restoration. Sampling was performed at 1 – 2 plots per site. One plot was placed within the lowest and highest 0.305-m contour per site if plot separation was at least 250 m, which ensured bird sampling (discussed later) was independent. At smaller sites where plots could not be placed at least 250 m apart within the site boundary, 1 plot was established at the center of the site. For sites with 2 plots, the variables discussed below were averaged between plots before analyses were performed.

Vegetation.— I measured 15 vegetation structure and composition variables at each site for IBI model development. They included percent horizontal cover of 5 vegetation life forms and bare ground; density of understory, midstory and overstory woody plants; overstory basal area, height, and canopy closure; percent vertical cover of understory vegetation; and number of snags and logs. All variables were measured once between May – June 2008. In addition, horizontal cover of herbaceous vegetation, vertical vegetation structure, and canopy closure were measured between July – August 2008 to incorporate seasonal variation in these metrics into the analyses. I chose the aforementioned variables because their measurement followed standard forestry procedures (discussed below), hence use of the resulting IBI model would require very little training by most natural resource organizations.

Percent horizontal cover of dead organic matter, grass (Poaceae), forbs (non-Poaceae herbaceous plants), vines, woody plants, bare ground, and total percent cover of live vegetation were visually estimated within a 1-m^2 frame (Daubenmire 1976) that was located 8 m from plot center in a randomly selected direction (Figure 2.2). Species-specific density of understory (<1.4 m tall), midstory (<11.4 cm DBH and >1.4 m tall) and overstory (>11.4 cm DBH) woody plants was counted in concentric 0.004-, 0.01-, and 0.04-ha plots, respectively, around plot center (Figure 2.2). Number of snags and logs (>11.4-cm DBH) within 100 m of plot center (i.e., 3.14-ha plot) were counted. I measured basal area of the overstory at plot center using a 2.5 m^2/ha (10 BAF) prism. Overstory height was measured for the nearest overstory tree to plot center using a clinometer. Percent canopy closure was estimated using a densiometer at plot center and 10 m from center in all 4 cardinal directions. Finally, I used a 2 × 0.18-m profile board to measure percent vertical cover of understory vegetation by placing the board at plot center, and inspecting

the board from a kneeling position at 10 m in each of the 4 cardinal directions. The profile board was divided into 4 height strata (1 = 0 to 0.5 m, 2 = 0.5 to 1.0 m, 3 = 1.0 to 1.5 m, and 4 = 1.5 to 2.0 m). Each 0.5-m strata contained 30 5 × 5 cm alternately colored boxes. Percent vertical cover in each stratum was estimated by counting the number of boxes per strata that were covered ≥50% by vegetation and dividing the number of covered boxes by 30 per strata. Additionally, mean vertical cover was estimated by averaging percent cover among the 4 strata. I averaged percent canopy closure and vertical cover among cardinal sampling locations for each plot prior to analysis.

Amphibians.—Amphibians were measured at each site once every 2 weeks from March – August 2008, which encompassed most of the amphibian breeding season in Tennessee (Redmond and Scott 1996, Burton 2007). For data analysis, I recorded data separately for spring (March – April), early summer (May – June), and late summer (July – August). These seasonal periods corresponded to typical changes in the amphibian community associated with breeding phenology in Tennessee (Redmond and Scott 1996, Burton 2007). I used a combination of advertisement call surveys, PVC tubes for tree frogs, coverboards, and area searches to index the amphibian community (Dodd 2009). Breeding calls were recorded using a Marantz® PMD 670 device (Mahwah, NJ) placed at plot center prior to sunset. I programmed the device to record for 5 minutes at 0.5, 2.5 and 4.5 hours after sunset (Burton et al. 2007, Dorcas et al. 2009). Amphibians heard on the recording were given an abundance index of 1, 2, or 3 depending on the number of individuals that could be heard. One represented no overlap of calls, 2 was overlap in calls but individuals were distinguishable, and 3 was a chorus in which the number of individuals could not be distinguished (Dorcas et al. 2009). Abundance of treefrogs (*Hyla* spp.)

also was measured using 2 PVC tubes (6.4-cm dia.) that had one end buried ca. 15 cm in the ground with ca. 1 m extending aboveground (Moulton et al. 1996). I placed 2 pairs of 0.56-m^2 untreated plywood coverboards within each plot to index salamander (Ambystomatidae and Plethodontidae) communities (Fellers and Drost 1994). Coverboards and PVC tubes were placed 7 m from plot center at a random azimuth in opposing cardinal quadrants >1 month before sampling started (Figure 2.3), and were checked during recorder deployment.

Amphibian composition also was documented using area searches (Marsh and Haywood 2009). Each plot was divided into 4 cardinal quadrants, and 2 opposing quadrants searched after recorder deployment. Quadrants were systematically searched in a zigzag pattern until the edge of the 100-m radius plot was reached or 10 minutes elapsed. Searches were standardized by area and time so that abundance estimates were consistent among plots. If amphibian microhabitat was encountered (i.e., logs, rocks, debris piles), it was overturned or searched thoroughly for amphibians (Marsh and Haywood 2009).

Amphibian community metrics used for IBI model development included species richness and diversity, and relative abundance of amphibian families. Species richness was calculated as the total number of unique species detected at each site using all sampling methods. I calculated the Shannon-Wiener diversity index (Morin 1999) separately for breeding call surveys and all other methods combined (area searches, cover boards and tree frog tubes), because breeding call surveys were based on an index (1 – 3) rather than a number of individuals. To combine these 2 diversity values, I summed them to obtain a cumulative index. Similarly, to calculate familial abundance, I summed all call indices among species in a family and added it to the combined sum of individuals detected using the other methods. All metrics

were calculated for each site every 2 weeks, and averaged among 4 sampling dates within each 2-month seasonal period prior to analysis. The exception was species richness, which was estimated as the total number of unique species detected among all sampling dates within each 2-month period.

Avifauna.—Composition of the bird community was measured at each site every 2 weeks using 10-minute, fixed-radius point counts extending to 50 m from plot center (i.e., 0.79-ha plot, Ralph et al. 1993). Point counts were performed between sunrise and 5 hours following sunrise (Ralph et al. 1993). To ensure detected birds were located in the 0.79-ha plot, a laser rangefinder (1-m accuracy; Yardage Pro 450, Bushnell, Overland Park, KS) was used to establish a reference of distances from plot center, and location of detected birds was estimated in relation to these reference points. Detected birds beyond 50 m were excluded from the analysis (Schieck 1997). Although it is unknown if all birds within the 0.79-ha plot were detected during point counts, I assumed detection was similar among sites hence abundance estimates were comparable. To verify this assumption, an independent observer played recordings of the 5 most commonly detected species at my study sites: common yellowthroat (*Geothlypis trichas*), indigo bunting (*Passerina cyanea*), blue-gray gnatcatcher (*Polioptila caerulea*), eastern towhee (*Pipilo erythrophthlalmus*), and red-winged blackbird (*Agelaius phoeniceus*). The volume of each recording was adjusted to peak at 90 dB at 1 m from the speaker using a digital SPL meter (CM-130, Galaxy Audio, Wichita, KS), which is approximately the sound power of songbird calls (Leonardo and Konishi 1999, Illes et al. 2010). I stood at plot center and recordings were played at increasing distances from my location. At all sites, playbacks were heard $\geq$56 m from plot center, thus validating my equal detection assumption. Bird sampling occurred from March –

August, which encompassed habitat use by wintering and migrant birds (March – April), breeding birds (May – June), and the post-fledging community and early-fall migration (July – August) in Tennessee (Sauer et al. 2005).

Bird community metrics used to develop the IBI model were species richness and diversity and relative abundance of functional guilds. Species richness and diversity were calculated identical to amphibians except that only one sampling method (i.e., point counts) was used. Functional guilds were 3 feeding and 5 nesting guilds (DeGraaf and Chadwick 1984, Ehrlich et al. 1988; Table 2.2). Relative abundance was estimated as the total number of detected individuals belonging to each guild per site. Similar to amphibians, all metrics except for species richness were averaged among sampling dates for each 2-month sampling period per site prior to analyses. Species richness was the total number of unique bird species detected during each 2-month period.

Analysis

Development of IBI models generally requires identification of a human disturbance gradient that is strongly correlated with values of the community metrics (EPA 2002c). Because my study sites were distributed across a range of restoration ages, I chose site age as the measure of human disturbance, with the assumption that disturbance was greatest at the time of initial restoration and decreased over time since restoration activities were initiated. This was a reasonable assumption because pre-restoration activities included row-crop agriculture and after WRP restoration no human activities occurred on the sites except occasional recreation (e.g., waterfowl and deer hunting). For the purposes of model development, the vegetation, amphibian

and bird communities in the Hatchie River bottomland were set as the reference condition, thus predictions on the state of restoration are dependent on this system.

I used linear least-squares regression in SAS® (SAS Institute, Cary, NC) at $\alpha = 0.05$ (Littell et al. 1991) to quantify the relationship between site age and vegetation, avian and amphibian community metrics among restoration and reference sites. To incorporate seasonal variation into the IBI models, mean metric values for each 2-month sampling period were used in the analysis. I assigned a categorical predictor variable to the seasonal data sets (1 = March – April, 2 = May – June or 3 = July – August) to partition this variation from the error term and increase explanatory power of models (Sokal and Rohlf 1995). Given that the total sample size for these regressions exceeded 20, I did not test for normality of residuals because analysis-of-variance associated with the *F*-test in regression analysis is robust to departures from normality (Underwood 1997). I also did not test for constant variance because I was uninterested in using the parameter estimates from the regression models. Regression analysis was merely used to identify if site age explained significant variation in biological community metrics. For my analyses, I assumed a linear relationship existed between site age and community metrics.

I created separate IBI models for vegetation, bird and amphibian communities. Metrics were included in the IBI model if they were significantly related to site age and the adjusted coefficient of determination (R^2) was $\geq$50% of the maximum R^2 among all metrics for that community. The metric with the maximum R^2 also was included. This decision rule (i.e., "50% criterion") is a novel approach to selecting IBI metrics, and always ensured that multiple metrics were included in the final IBI model, which is a desirable attribute (EPA 2002c).

Following identification of IBI metrics, I scored the metrics from 1 – 4, with numerical thresholds at the 25th, 50th, and 75th percentiles for observed values of each metric (e.g., 0 – 25th percentile = 1, 26th – 50th percentile = 2, 51st – 75th percentile = 3, and >75th percentile = 4, Karr et al. 1986). If metrics had too few observed values to designate 4 divisions (e.g. 25th and 50th percentile = 0), metrics were scored 1 – 3 (e.g., 0 – 33.3rd percentile = 1, 33.4th – 66.7th percentile = 2, and > 66.7th percentile = 3). If 3 categories were not possible, metrics were scored 1 – 2 (e.g. 0 – 50th percentile = 1 and > 50th percentile = 2). For metrics which were negatively related with site age, large values represent degraded ecological conditions. Thus, scoring was reversed so that low values of metrics were assigned high scores and vice versa.

Bird community composition often is affected by vegetation characteristics (Cody 1981, Finch 1991, Coppedge et al. 2008). Thus, to determine if vegetation and bird IBI models were possibly redundant, I calculated IBI scores for each study site and tested if vegetation scores explained significant variation in bird scores using simple linear regression. I also summed IBI scores from all models for a site, and tested if site age explained significant variation in the combined index using simple linear regression. This analysis provided internal validation of my IBI scoring protocol.

RESULTS

Of the 18 vegetation characteristics that were measured, 7 were positively related and 5 were negatively related with site age (R^2_{adj} = 0.10 – 0.89, $P \leq 0.043$; Table 2.3). Abundance of Ambystomatidae and Plethodontidae were positively related with site age (R^2_{adj} = 0.30 and 0.37, $P < 0.001$; Table 2.4). Bird species diversity and richness were positively related with site age (R^2_{adj} = 0.15 and 0.28, $P \leq 0.003$; Table 2.5). Abundance of 3 nesting guilds (cavity nesters,

branch nesters, twig nesters) was positively and one (ground nesters) was negatively related with site age (R^2_{adj} = 0.17 – 0.83, $P < 0.001$; Table 2.5). Abundance of 2 feeding guilds (branch feeders, canopy feeders) was positively and 1 (ground feeders) was negatively related with site age (R^2_{adj} = 0.12 – 0.76, $P \leq 0.009$; Table 2.5). No other metrics were significantly related with site age ($P \geq 0.069$).

There were 6 vegetation metrics (logs, snags, overstory trees, basal area, mid-level vertical cover, low vertical cover) which met the criteria for inclusion in the vegetation IBI model (Table 2.6, Figure 2.4). Of these, 4 metrics (logs, snags, overstory trees, basal area) were positively and 2 metrics (mid-level vertical cover, low vertical cover) were negatively related with site age. There were 2 vegetation metrics (snags, overstory trees) which were scored 1 – 3; all others were scored 1 – 4. Abundance of Ambystomatid and Plethodontid salamanders was included in the amphibian IBI (Table 2.7, Figure 2.5). These families were only detected at the reference sites, thus these metrics were scored 0 – 1 (1 = present, 0 = absent). There were 3 bird metrics (bark feeders, branch nesters, twig nesters) retained for the bird IBI model; all were positively related with restoration age (Table 2.8, Figure 2.6). Of these, 1 metric was scored 1 – 3 and 2 were scored 1 – 4. For my study sites, there was a strong, positive relationship between vegetation and bird IBI scores (R^2= 0.72, $P \leq 0.001$, Figure 2.7). Combined IBI scores for vegetation, amphibians and birds at my study sites were strongly related with site age (R^2 = 0.82, $P < 0.001$; Figure 2.8).

DISCUSSION

There were 6 vegetation, 2 amphibian and 3 bird community metrics that were included in the final IBI models. Vegetation metrics included density of snags, logs and overstory trees, basal area, and low- and mid-level vertical cover. All variables were strongly positively related with restoration age, except for vertical cover, which was negatively related. Succession was undoubtedly a factor driving these relationships. Numerous studies have reported an increase in logs, snags, basal area and overstory tree density with succession in forested systems (Odum 1969, Christensen and Peet 1984, Guariguata and Ostertag 2000). Further, vertical cover of understory vegetation tends to decrease in later seral stages in forests due to light limitations (Anderson et al. 1969). The occurrence of Ambystomatid and Plethodontid salamanders also was an indicator of reference conditions. Most salamander species are disturbance intolerant and many depend on intact forests for survival and reproduction (Petranka et al. 1993, deMaynadier and Hunter 1995, Petranka 1998). Several studies have reported negative impacts of clearcutting on salamanders (e.g., Knapp et al. 2003, Semlitsch et al. 2008); however, site colonization can occur as early as 12 years following timber harvest if source populations exist within dispersal distance (Morris and Maret 2005). Lastly, there was a strong positive relationship between the relative abundance of bark feeding, branch nesting, and twig nesting bird guilds and age of restoration and reference sites. Representative bark feeding species at my sites included hairy woodpecker (*Picoides villosus*) and white-breasted nuthatch (*Sitta carolinensis*, Table 2.2). Representative branch nesting species were blue-gray gnatcatcher (*Polioptila caerulea*), American robin (*Turdus migratorius*) and yellow-rumped warbler *(Dendroica coronate*). Typical twig nesting species at my sites were eastern wood-pewee (*Contopus virens*), Acadian

flycatcher (*Empidonax virescens*) and ruby-crowned kinglet (*Regulis calendula*, Table 2.2). All 3 guilds are specialists which are known to require mid to late-successional forests (O'Connell et al. 1999). In general, abundance of specialist guilds tends to increase with forest age (May 1982). For example, Canterbury et al. (2000) found that species richness of both branch nesters and bark feeders was positively related with canopy closure and tree basal area. Collectively, these results indicate that my IBI models contained metrics that are good indicators of hardwood bottomland restoration.

The IBI models that I developed can be used to monitor ecological restoration in hardwood bottomlands in Tennessee and perhaps elsewhere. Each IBI model contained several biological metrics, which likely incorporated various aspects of habitat quality and collectively reflected cumulative changes in habitat characteristics associated with restoration (Croonquist and Brooks 1991). Data collection for vegetation, amphibian and bird IBI models requires different levels of expertise and effort. The vegetation IBI requires the least amount of expertise and measurements are taken following standard forest inventory protocol. Knowledge of plant identification is not required. Based on sampling associated with my project, I estimated it would take about one hour per site to collect the data for this IBI model. Salamander detection requires a combination of cover boards and area searches. Cover boards should be deployed one month prior to sampling (Wilson and Gibbons 2009), and it took about one hour to complete the area-constrained searches per sampling plot. Required salamander identification is to the family level only, which is not difficult. Sampling bird communities requires the greatest level of expertise. Observers must be competent with identifying birds by call and sight for species in eastern North America. Further, after sampling is completed, detected birds must be classified

into ecological functional guilds (DeGraaf and Chadwick 1984, Ehrlich et al.1988). One advantage of bird sampling is that individual surveys are faster than vegetation or amphibian sampling, taking only 10 min per point count; however, sites should be visited multiple times for an accurate estimate of bird composition. Vegetation metrics can be measured anytime between May and August, and amphibians and birds can be sampled between March and August. Two individuals are required for sampling vegetation whereas only one individual is needed for amphibian or bird sampling.

Inasmuch as vegetation, amphibian and bird IBI models incorporate slightly different aspects of habitat quality, the most comprehensive measure of hardwood bottomland restoration may be using all 3 models. Karr and Chu (1999) recommended combining metrics from different models into a multimetric index to achieve greater accuracy in predictions. A combined index can be calculated by summing IBI scores from all 3 models to create a total score per site. Due to constraints such as the time and expertise required to identify species, sampling avian, amphibian and vegetation communities may not be feasible. Given that vegetation and bird IBI scores for my study sites were strongly correlated, I recommend sampling vegetation over birds because the former requires less expertise and can be accomplished with one site visit. I do not recommend using the amphibian model alone, because it contains merely 2 levels of restoration status (i.e., absent = not reference condition, present = reference condition). Also, colonization of restorations sites is highly dependent on the availability of a source population, which may not exist in agricultural landscapes (Gray et al. 2004a,b). Lack of salamander detection also may not imply lack of reference conditions,

because many species are fossorial and only active aboveground during autumn or winter (Petranka 1998).

My IBI models were developed using hardwood bottomlands in western Tennessee hence their use should be limited to this region until performance has been evaluated elsewhere (Beutel et al. 1999). I recommend that future research focus on validating these models by comparing model predictions to independent datasets collected at hardwood bottomland sites in western Tennessee and elsewhere. To validate models, I recommend collecting data at new sites for metrics in Tables 2.6 – 2.8 following sampling procedures outlined in the Methods. Sites should differ in restoration age, and reference sites should be included. Scores for each metric should be calculated following my protocol in the Methods. Specifically, values for each metric should be divided into percentiles, IBI scores assigned to each percentile range, and total IBI scores calculated for each new site. Next, total IBI scores should be calculated for each site using my models in Tables 2.6 – 2.8. If the total scores calculated with my models are similar to those derived from the independent data set, then it provides evidence that my models are robust and their applicability may extend beyond the western Tennessee region. This determination could be made by testing for the difference in IBI predictions at each site using a paired *t*-test (Sokal and Rohlf 1995), with high *P*-values suggesting robustness of my models and low *P*-values indicating regional specificity in predictions.

My models were developed using mature hardwood bottomland forests as a reference standard for restoration, thus early successional stages are penalized in model predictions. A variety of species use early successional bottomlands such as Henslow's sparrow, dickcissel (*Spiza americana),* blue grosbeak (*Passerina caerulea*) and northern bobwhite (*Colinus*

virginianus). Thus, if managing these species is a priority, predictions from my IBI models will not be useful.

PRACTICAL APPLICATION

The models in Tables 2.6 – 2.8 can be used to monitor ecological restoration at hardwood bottomland sites. For all IBI models, I recommend establishing the sampling plot at the geometric center of the site. For the vegetation IBI model (Table 2.6), the 6 metrics should be measured once between May and August following the design and techniques provided in the Methods. Field measurements are compared to the ranges in Table 2.6 and an IBI restoration score assigned for each metric. Restoration scores are summed for a cumulative IBI score for the site. Minimum and maximum scores for the vegetation IBI model are 6 and 21, respectively. Dividing this range into 4 states of restoration, 6 – 9 = early restoration, 10 – 13 = mid restoration, 14 – 17 = late restoration, and 18 – 21 = reference condition. For the amphibian IBI model, there are only 2 restoration values. I recommend using area searches and cover boards for salamander detection, with sampling occurring at least 4 days and allowing one week separation between surveys. Sampling should be performed between March and August. If Ambystomatid or Plethodontid salamanders are detected, the site is declared to be at reference condition. For the bird IBI model, I also recommend sampling at least 4 days with one week separation between surveys. Point counts should be performed between March and August, and follow the design and techniques outlined in the Methods. Detected bird species will need to be assigned to functional guilds using Table 2.2, DeGraaf and Chadwick (1984) or Ehrlich et al. (1988). Bird density per 0.79-ha for each guild is compared to ranges for field measurements is Table 2.8. If sampling occurs on >1 day, density per guild should be averaged. Similar to

vegetation, restoration scores are summed, with minimum and maximum scores for the bird IBI model equaling 3 and 11, respectively. Thus, 3 – 4 = early restoration, 5 – 6 = mid restoration, 7 – 8 = late restoration, and 9 – 11 = reference condition.

When possible, I recommend that all IBI models are used to achieve the most robust prediction of ecological restoration in hardwood bottomlands. If this is done, restoration scores should be summed across communities. Minimum and maximum values for a multimetric IBI that uses vegetation, amphibian and bird communities are 9 and 34, respectively. Thus, 9 – 14 = early restoration, 15 – 20 = mid restoration, 21 – 26 = late restoration, and 27 – 34 = reference condition. An example of multimetric IBI model use is presented below.

Suppose a site contained 2 logs, 3 snags, and 2 overstory trees, tree basal area = 2, low vertical cover = 90%, and mid-level vertical cover = 50% in a sampling plot. Using Table 2.6, the respective vegetation IBI scores would be 2, 3, 2, 2, 3 and 2, and the total vegetation IBI score = 14. If area searches for salamanders were performed and 2 Ambystomatid and 0 Plethodontid salamanders were found, the amphibian IBI score = 1 (Table 2.7). Finally, if point counts resulted in an average of 0.5 bark feeding, 1.5 branch nesting, and 0 twig nesting species per 0.79-ha plot, the respective bird IBI scores would be 3, 3 and 1 for a total IBI = 7 (Table 2.8). To obtain a multimetric IBI score for the site, IBI scores for all three assemblages would be summed for a total score of 22 (14 + 1 + 7), which indicates the site is in late restoration when compared to the ranges above.

CHAPTER III

ECOLOGICAL CHARACTERISTICS OF HARDWOOD BOTTOMLAND RESTORATION SITES IN TENNESSEE

INTRODUCTION

Hardwood bottomland ecosystems are floodplain wetlands adjacent to tributaries that provide critical habitat for various fish and wildlife (Hoover and Killgore 1998, Wigley and Lancia 1998). It is estimated that about 80% and 50% of the breeding and migratory birds, respectively, in the United States rely on wetlands (Wharton et al. 1982, Smith et al. 1993), with the majority of these species depending on hardwood bottomlands during part of the annual cycle (Mitsch and Gosselink 2000). Amphibians are another community that is strongly linked with riparian wetlands. The greatest number of amphibian species in the United States exists in the Southeast (Dorcas and Gibbons 2008, Mitchell and Gibbons 2010), where the primary breeding habitat is forested wetlands (Shepard et al. 1998). Despite the ecological value for wildlife, hardwood bottomlands have been logged, drained and converted to agricultural lands for over 100 years (Hefner and Brown 1985). Currently, less than 25% of the hardwood bottomlands remain in the southeastern United States (Stanturf et al. 2000).

Recognizing the value of wetlands for wildlife and other environmental services (e.g., flood control, groundwater recharge; Hyberg and Riley 2009), the United States Department of Agriculture established the Wetlands Reserve Program (WRP) in 1990 (NRCS 2008). The WRP provides compensation to landowners who stop farming agricultural lands that were previously wetlands (NRCS 2008). In the southeastern United States, the dominant wetland type is

hardwood bottomlands (Mitch and Gosselink 2000); thus, the majority of WRP conservation efforts in the Southeast have focused on reforestation of hardwood bottomlands (King and Keeland 1999).

Although WRP was established 20 years ago, only a handful of studies have measured bird or amphibian responses to hardwood bottomland restoration (e.g., Nuttle 1997, Buffington et al. 2000, Twedt et al. 2002, Hamel 2003). Moreover, few studies have attempted to relate vegetation or abiotic characteristics at bottomland restoration sites to wildlife responses. Twedt et al. (2002) found that hardwood bottomlands that were planted with cottonwood (*Populus deltoides*) seedlings were used by forest birds sooner than those planted with oaks, because forest structure established faster due to the rapid growth of the former tree species. Nuttle (1997) reported that it took about 20 years for the bird community in hardwood bottomlands that were replanted with oak seedlings to begin resembling those found in mature bottomland hardwood forests. Early successional hardwood bottomlands also are important for grassland birds (Twedt et al. 2002), many of which are in decline (Sauer et al. 2005). Buffington et al. (2000) found that the greatest species richness and use of hardwood bottomland restoration sites by grassland birds was within the first 2 years following planting. To my knowledge, only one study has been published on amphibian responses to bottomland restoration (Bowers et al. 2000), and this study was not associated with the WRP. Several studies have reported negative impacts of forest removal on salamanders (Ash 1997, Semlitsch et al. 2008), but anurans appear to colonize wetland restoration sites rapidly (Petranka et al. 2003). To date, no studies have quantified amphibian and bird responses to bottomland restoration simultaneously nor related responses of these communities to site characteristics. Relating characteristics of restoration sites to wildlife

responses is fundamental to evaluating the effectiveness of conservation programs (NRCS 2010), and allows adaptive strategies to be formulated that facilitate ecological restoration.

One approach to evaluating ecological restoration is developing habitat models that relate vegetation or abiotic characteristics (i.e., microhabitat components) to wildlife community characteristics (e.g., species diversity, Morrison 2002). For some species, macro-habitat or landscape characteristics (e.g., patch size) also can be important (vanDorp and Opdam 1987). Models can be used to identify habitat characteristics that are important for certain wildlife species, guilds, or communities (Morrison 2002). Models also can be used to predict wildlife responses at future sites by estimating habitat parameters from field data, which tends to be easier than sampling and identifying invertebrate or vertebrate taxa (e.g., Chapter II). Thus, habitat models can be useful in monitoring ecological restoration (Morrison 2002).

To evaluate wildlife responses to restoration, taxa should be chosen that are known to respond to a disturbance gradient (EPA 2002c). Amphibians are considered excellent indicator species of ecosystem health due to their susceptibility to stressors (Welsh and Ollivier 1998). Characteristics such as highly permeable skin, unshelled eggs, limited dispersal capability, and a biphasic life history that requires aquatic and terrestrial habitats cause amphibians to be easily affected by habitat degradation (EPA 2002b). Similarly, birds are good indicators of ecological function, because the composition of their community can reflect the cumulative effects of multiple environmental stressors (EPA 2002d). Many birds occupy high trophic levels thus can reveal disturbances at lower levels (Pettersson et al. 1995). Both birds and amphibians also are sensitive to forest fragmentation (Askins and Philbrick 1987, Lehtinen et al. 1999) and changes

in vegetation cover (Finch 1991, Werner and Glennemeier 1999). Thus, amphibian and avian communities are likely reliable indicators of ecological restoration in hardwood bottomlands.

Habitat models can be constructed using different parameter selection procedures. Two of the most common procedures are stepwise selection and use of Akaike's Information Criterion (AIC; Burnham and Anderson 2002, Luoto et al. 2004). Stepwise selection was commonly used in the 1980s and 1990s; however, models developed using AIC has become increasingly popular. In a literature search using Web of Science® (Thomson Reuters, New York, NY) for these selection procedures, I found 220 citations for stepwise parameter selection and 1060 citations for AIC. There were 26, 25, and 31 papers published in 2007, 2008, and 2009, respectively, using stepwise selection, while 125, 150, and 140 papers were published during the same respective years using AIC. Ninety percent of the AIC papers were published since 2000. Criticisms of stepwise selection have been: (1) parameter selection is influenced by the order in which variables enter into the model, and (2) sequential *F*-tests are not independent which inflates the Type I error rate (Anderson et al. 2000). A possible advantage of stepwise selection is that one final model is constructed hence explanation of the relationship between explanatory variables and the dependent variable is not difficult. One of the advantages of AIC modeling is that all combinations of explanatory variables or a subset of variables deemed as important by the researcher are tested (Kadane and Lazar 2004). However, parameter selection using AIC can be problematic if one final model is desired, because this procedure typically results in a group of candidate models. Additionally, rarely are other information statistics (e.g., adjusted R^2, MSE) provided with models, and statistical significance of variables usually is not tested. Lastly, variables retained in AIC models are rarely screened for multicollinearity. To my

knowledge, no studies have developed models using both methods from the same data set, and compared variables, performance statistics, and collinearity diagnostics in the final models.

Over 100 WRP sites exist in Tennessee, most of which are in hardwood bottomlands (Tennessee NRCS, unpublished data). Although several studies have examined wildlife use of WRP restorations in the Mississippi Alluvial Valley (Twedt et al. 2002, Hamel 2003, Fleming 2010), no studies have quantified wildlife responses to WRP restoration in Tennessee. Further, only a few studies exist nationwide that developed models relating wildlife community responses to bottomland restoration. Thus, the objectives of Chapter III were to (1) develop inventory lists of amphibians and birds detected at 17 bottomland WRP sites in western Tennessee, (2) identify habitat variables that explained significant variation in wildlife community metrics, and (3) develop models that could be used to predict wildlife responses at future sites. I also developed models using stepwise and AIC parameter selection, and compared performance between these methods.

METHODS

Field Sampling

I conducted my study at 17 WRP and 4 bottomland reference sites in western Tennessee from March – August 2008 (Figure 2.1). Site selection, general characteristics of restoration and reference sites, and location of sampling plots were discussed in Chapter II. Vegetation, amphibian, and bird data used in Chapter III were identical to Chapter II, hence collection techniques and data treatment were the same. For the purpose of constructing species inventory lists, I reported all birds and amphibians detected, except flyovers for birds because habitat use was unknown. For habitat models, amphibian community metrics included family richness and

diversity, and relative abundance of Bufonidae, Hylidae, Ranidae, Ambystomatidae and Plethodontidae. For birds, community metrics included species richness and diversity, and relative abundance of cavity nesting, branch nesting, twig nesting, ground nesting, shrub nesting, air feeding, ground feeding and canopy feeding species (Table 2.2). Vegetation variables included percent horizontal cover of dead organic matter, grass, forbs, vines, woody plants, bare ground, and total live vegetation (Chapter II). I also measured density of understory (<1.4 m tall), midstory (<11.4 cm DBH and >1.4 m tall) and overstory (>11.4 cm DBH) woody plants, number of snags and logs (>11.4-cm DBH), tree basal area, overstory height, percent canopy closure, and percent vertical cover in 4 height strata (Chapter II).

Bottomland hydrology can influence vegetation, amphibians and birds (Wakeley and Roberts 1994), so I also measured surface and groundwater depths twice per day (1200 and 0000 hrs) from 4/2007 – 7/2009 using PVC wells and Infinities USA water-level meters (Pressure Water Level Data Logger, Infinities, Port Orange, FL). The PVC well (10 cm dia) was placed at center of each site and extended 0.9 m belowground. Water-level meters were mounted to the top of the PVC wells (ca. 2 m aboveground), and a sensor extended to the well base. Holes in the PVC allowed water to percolate in and out of the well. During installation, polyurethane window screen was wrapped around wells belowground and up to 1 m aboveground to reduce sediment deposition in the wells. Data were downloaded from the loggers periodically using handheld units (48G+ Pocket Calculator, Hewlett-Packard, Palo Alto, CA).

For each 2-month seasonal period (March – April, May – June, and July – August) that amphibians and birds were measured (Chapter II), average belowground and aboveground water depth and hydroperiod duration (i.e., number of days water was aboveground) were calculated.

Additionally, total area of all depressions was estimated using a tape measure in a 3.14-ha plot around plot center. Depressions capable of holding water were identified by observation. In 2008, all of my sites flooded so depressions were identified in sampling plots as the water receded to the adjacent tributary. To standardize estimates among sites, I defined depressions as areas that retained water after two weeks following water recession.

Water quality can influence vegetation growth (Lambers and Poorter 1992) and amphibian communities (Brodman et al. 2003, Lambers and Poorter 1992, Camargo et al. 2005, Taylor et al. 2005). Thus, I measured water quality in standing water at the approximate center of the lowest elevational contour at each site. Water quality was measured once at each site in March, May and July 2008, corresponding with the seasonal biological sampling periods. In the absence of standing water, I measured water quality at the nearest permanent water source on the site, which sometimes was the tributary that flooded the site. I used portable YSI® meters (YSI, Alpha, OH) to measure dissolved oxygen, pH, conductivity and temperature. I also collected water samples and measured turbidity, ammonia, nitrite, nitrate, and phosphate within 12 hours of collection using a SMART2 colorimeter (LaMotte, Chestertown, MD).

The amount of forest on a landscape can impact community composition of birds (Twedt and Loesch 1999, Debinski et al. 2001, Luoto et al. 2004) and amphibians (Martin and McComb 2003, Homan et al. 2004). Thus, I estimated percent forested area within 1-km and 10-km of the center (314 and 31,416 ha plot) for each site. I chose these distances because percent forest cover within a 10-km radius has been shown to influence bird distributions (Howell et al. 2000) and nesting success (Robinson et al. 1995, Hartley and Hunter 1998), and landscape composition within 1 km of a site can influence amphibian abundance and species composition (Burton

2007). Area was estimated by importing Digital Orthophoto Quadrangles (DOQQ, Tennessee Federal GIS Users Group 2008) for each site into ESRI® ArcGIS 9.1 (ESRI, Redlands, CA). Forest area was estimated by photo interpretation and digitizing polygons around each parcel of intact forest. Area was summed among parcels for each plot size for an estimate of total forested area.

Statistical Analyses

All statistical analyses were performed using the SAS® system (SAS Institute, Cary, NC). In total, I measured or calculated 18 vegetation and 14 water variables, site age, and percent forest cover at 2 scales, many of which were likely correlated. Thus, prior to model development, I reduced the number of variables using cluster analysis on principal components (PROC VARCLUS; Romesburg 1989, SAS Institute 2008). Number of final clusters was determined as the maximum number of clusters with at least one cluster that contained a second eigenvalue >1 (SAS Institute 2008). From each cluster, I selected the variable with the highest within-cluster correlation and lowest between-cluster correlation (i.e., lowest 1-R^2 value, SAS Institute 2008) as the most representative variable. These variables were used as possible explanatory variables in amphibian and bird habitat models. In addition, I included a categorical predictor variable that represented seasonal variation associated with the 2-month biological sampling periods (1 = March – April, 2 = May – June or 3 = July – August, Sokal and Rohlf 1995).

I used linear least-squares regression to develop all models (Kutner et al. 2004). Models were developed using forward stepwise selection (entry and stay at $\alpha = 0.05$) and AIC (Kutner et al. 2004). Because most forest birds are not directly impacted by water characteristics at a site

(Robinson and Holmes 1982), I did not use hydrology or water quality variables for creating models for birds. All vegetation and water variables were included in model development for amphibians. For AIC models, I performed separate analyses for vegetation and water variables in order to limit the number of variables in final candidate models, and because these variables can act independently on amphibian communities (Bosch and Martinez-Solano 2003, Burton 2007). Development of AIC models based on *a priori* perceived differences in variable categories is common (e.g. Holloran et al. 2005, Duff and Morrell 2007). Within categories, all possible models were generated and ranked according to the lowest AIC (Burnham and Anderson 2002). A list of candidate models was generated for each amphibian and bird response variable within 2 AIC units of the minimum AIC (Burnham and Anderson 2002). For all final models, I presented the un-standardized and standardized parameter estimates, *P*-value, partial R^2 and variance inflation factor (VIF) for each explanatory variable. I also presented the model adjusted R^2 for both procedures and model weights (w_i) for AIC selection (Burnham and Anderson 2002). The selection of AIC candidate models is not dependent on statistical significance, which can result in models that explain very little variation is the response variable (Guthery et al. 2005). To avoid this problem, I only presented AIC models that had at least 1 explanatory variable that explained significant variation ($P<0.05$).

Given that the total sample size for these regressions exceeded 20, I did not test for normality of residuals because analysis-of-variance associated with the *F*-test in regression analysis is robust to departures from normality (Underwood 1997). I also did not test for constant variance because I was uninterested in using the parameter estimates from the

regression models. The primary goal of these regression analyses was to identify site characteristics that were associated with amphibian and bird community metrics.

RESULTS

A total of 22 amphibian and 107 bird species were detected at restoration and reference sites (Tables 3.1 – 3.2). For amphibians, 7 species were only detected at reference sites; all of these were salamander species. However, 5 anuran species were detected only at restoration sites (Table 3.1). Reference sites supported 12 bird species that were not detected at restoration sites. However, there were 48 bird species which were detected only at restoration sites (Table 3.2). Restoration sites provided habitat for at least 3 amphibian families (15 species) and 28 bird families (95 species) from March – August 2008. The green treefrog (*Hyla cinerea*) was the most widespread amphibian species, occurring at 16 out of 17 sites. I detected crawfish frogs (*Rana areolata*) at an 8-yr old restoration site. This species is declining throughout its range (Crawford et al. 2009), and is a species of conservation concern in Tennessee (Tennessee Wildlife Resources Agency 2005). The most widely detected bird species were American crow (*Corvus brachyrhynchos*), common yellowthroat (*Geothlypis trichas*), indigo bunting (*Passerina cyanea*), and northern cardinal (*Cardinalis cardinalis*). I detected 16 bird species at restoration sites which are listed as regional species of concern in the Mississippi Alluvial Valley, including Swainson's warbler (Partners in Flight 2006). I detected Swainson's warblers (*Limnothlypis swainsonii*) at 3 restoration sites (13, 11 and 10 yrs in age).

Ten independent variables were identified using cluster analysis (Figure 3.1). These variables were site age, percent vertical cover of vegetation (1.0 – 1.5 m), number of midstory trees, percent canopy closure, percent cover of dead organic matter and forbs, water salinity,

water turbidity, and concentrations of phosphate and nitrate in the water. All 10 of these microhabitat characteristics were used as possible explanatory variables of amphibian community characteristics, and the 6 vegetation variables were used as possible explanatory variables for bird community metrics.

Stepwise Selection Models

Final amphibian habitat models for stepwise selection explained 8 – 38% of the variation in species diversity or familial abundance (Table 3.3). All models were simple, containing only one variable each. Two vegetation variables, 1 water quality variable, and site age explained significant variation in at least 1 amphibian community metric (Table 3.3). Amphibian diversity and relative abundance of tree frogs (Hylidae) were negatively related with percent canopy closure, while the relative abundance of true frogs (Ranidae) and toads (Bufonidae) were positively related with percent cover of forbs and concentration of phosphate, respectively. Relative abundance of Ambystomatid and Plethodontid salamanders was positively related with site age (Table 3.3). Amphibian species richness was not significantly related with any of the explanatory variables tested.

Final bird habitat models for stepwise selection explained 13 – 84% of the variation in community metrics (Table 3.4). Most models were relatively parsimonious. Of the 11 final models, 6 contained 1 variable, 4 contained 2 variables, and 1 model contained 4 variables. Species richness, relative abundance of cavity, branch and twig nesting species, and relative abundance of bark and canopy feeding species were positively related with site age. Species diversity was positively related with canopy closure and season, the latter implying that diversity increased from March – August. Percent vertical cover of vegetation from 1 – 1.5 m was

positively related with relative abundance of ground and shrub nesting species and negatively related with air feeding species. Midstory tree density was negatively related with ground nesting and ground feeding species. Relative abundance of ground nesting species also was negatively related to canopy closure and increased from March – August (Table 3.4).

AIC Models

A total of 75 and 89 candidate models were generated for amphibian and bird community metrics, respectively, using AIC parameter selection (Tables 3.5 – 3.9). Of these, 147 models (90%) contained variables that did not explain significant variation in the community metrics. Number of variables per model ranged from 1 – 7. There was no evidence of collinearity among variables in final AIC models (Tables 3.5 – 3.9).

The top amphibian models based on the largest AIC weight (w_i) explained 9 – 38% of the variation in species diversity or familial abundance (Tables 3.5 – 3.6), which was similar to the model performance for stepwise models. Of the 6 significant models developed using stepwise selection (Table 3.3), all top AIC models contained the same variables (Tables 3.5 – 3.6). In 3 cases, the AIC model contained one additional variable, which was not significant for 2 of the models (Table 3.5). Two amphibian models were generated by AIC that were not detected by stepwise selection. Fifteen percent of the variation in species richness was explained by a 4-variable AIC model (2 variables were not significant), and 9% of the variation in Bufonidae abundance was explained by percent cover of forbs (Table 3.4). The latter result was a consequence of running water quality variables separate from vegetation variables for AIC models.

The top bird models based on w_i explained 11 – 86% of the variation in species diversity, richness or abundance (Tables 3.7 – 3.9). Of the 11 significant models developed using stepwise selection (Table 3.4), 9 of the 89 top AIC models contained the same variables (Tables 3.7 – 3.9). Of these 9 AIC models, 8 of them contained 1 – 3 additional variables; only the model for air feeding species was identical to the stepwise model. For the AIC models with additional variables, 30% of the variables were not significant. Interestingly, the additional variables in the AIC models only resulted in 3 – 10% more variation explained for 10 of 11 community metrics. The exception was species diversity where an additional 16% of the variation was explained by the AIC model compared to the stepwise selection model that had 2 fewer variables. There were 2 top AIC models (species diversity and ground feeding species) that did not contain variables (site age and midstory stem density, respectively) found to be significant in the stepwise models (Tables 3.4, 3.7 and 3.9).

DISCUSSION

Hardwood bottomlands associated with 17 WRP restoration sites in western Tennessee supported a large number of species, including 16 avian and 1 amphibian species of concern. One species of concern that was absent from my study sites was the cerulean warbler (*Dendroica cerulea*). This species requires mature forests and large forest patch sizes (>647 ha) for breeding habitat (Askins et al. 1987). Given that all of my restoration sites were $\leq$21 years old and smaller than 214 ha, it is not surprising that I did not detect this bird species. Overall, my results indicate that the WRP is contributing to the regional biodiversity of western Tennessee, and providing habitat for several amphibian and bird species of conservation concern.

Below is a discussion of the habitat relationships that I documented for amphibian and bird communities. Inasmuch as the stepwise models explained similar variation in amphibian and bird community metrics compared to the AIC models, the former were more parsimonious, and AIC models included non-significant variables, I focused my discussion of habitat relationships according to the vegetation and abiotic variables retained in the stepwise models. On occasion, I discuss AIC model components where these results supplemented interpretation. A discussion of stepwise versus AIC model development also is provided.

Habitat Associations

Amphibians.—Similar to Chapter II, I found that relative abundance of Ambystomatidae and Plethodontidae was positively related with site age, emphasizing the importance of mature forests in the Southeast for these salamanders. The relationship between forest age and salamander abundance is well documented (Dupuis et al. 1995, Ash 1997, Harper and Guynn 1999, Petranka et al. 1993, 2003, Steele et al. 2003). Harper and Guynn (1999) suggested that at least 20 years is necessary for salamander populations to recover in forested sites after a clearcut. Other investigators have suggested longer durations (e.g., >60 years; Petranka et al. 1993, Homyack and Hass 2009). Factors that may negatively affect salamanders in early successional bottomlands include lower invertebrate abundance, increased likelihood of desiccation, and greater predation risk associated with more open habitats (Semlitsch et al. 2008). In my study, salamanders were only found at reference sites, which were on average 50 years old. My oldest restoration site was 21 years. Thus, in western TN, it appears that it takes at least 20 years of forest maturation to support salamander populations, assuming a source population exists to facilitate colonization.

Interestingly, amphibian species diversity and relative abundance of Hylidae were negatively related with overstory canopy closure. Although more amphibian species were detected at older sites with intact forest canopies, the relative abundance of species was less evenly distributed than at younger sites with open canopies. For example, the amphibian community at reference sites was composed of 17 species, but was dominated by southern leopard frogs (*Lithobates sphenocephalus*), marbled salamanders (*Ambysotma opacum*), bird-voiced treefrogs (*Hyla avivoca*) and gray treefrogs (*Hyla versicolor*). Fifteen amphibian species were detected at restoration sites, with relative abundance similar among species. Hylidae was the most common family at restoration sites; the primary species were green treefrog (*Hyla cinerea*), gray treefrog, bird-voiced treefrog and northern cricket frog (*Acris crepitans*). These species are known to use emergent wetlands (Winston 1997), which early successional hardwood bottomlands resemble. Collectively, these results indicate that early successional bottomland restoration sites are used by various anuran species and that amphibian community composition changes with site age.

Relative abundance of Ranidae was positively associated with the percent cover of forbs (i.e. non-grass herbaceous vegetation). The AIC model for Bufonidae also indicated positive association of forbs with this family. Lichtenberg et al. (2006) reported a positive relationship between density of herbaceous vegetation and amphibian species richness. A high percentage of herbaceous vegetation may benefit anurans by providing microhabitat for invertebrate prey (Taigen and Pough 1983), protective cover from desiccation (Dupuis 1995), and cryptic concealment from predators (Warfe and Barmuta 2004). Thus, encouraging the production of

forbs in the understory through wildlife management practices may benefit anurans in hardwood bottomlands.

Birds.—Opposite of amphibian community trends, bird diversity was greatest at older sites with more closed overstory canopies. Further, relative abundance of canopy, branch, and twig nesting species, and relative abundance of branch and canopy feeding species were positively related with site age. In contrast, ground feeding and ground nesting species were negatively related with site age, canopy closure, and midstory stem density. These results support previous studies that indicate bird species richness and diversity tend to be greatest in mature forests (Johnston and Odum 1956, Shugart and James 1973), which is believed to be a result of greater opportunities for niche partitioning (May 1982). Early stages of forest succession tend to be dominated by grassland species (Twedt et al. 2002, Hamel 2003). Buffington et al. (2000) reported that grassland birds are most common in newly replanted hardwood bottomlands, and their abundance is negatively related with canopy closure and height. The negative association of ground nesting and ground feeding guilds with canopy closure and site age likely is an interaction of reduced availability of suitable nesting habitat (Martin 1993), increased competition for food resources with shrub and forest specialist species (Cody 1974), and susceptibility to predators (Glasser 1979, Rodewald and Yahner 2001) due to high predator densities (e.g., snakes) in mature bottomland forests (Moorman et al. 2002). Thus, hardwood bottomland restoration sites provided habitat for various bird species, with composition changing with succession and the greatest species use occurring in mature forests.

I found that vertical vegetation structure was positively related with relative abundance of shrub and ground nesting species and negatively related with air feeding species. Given that

vertical vegetation structure was greatest for younger sites (Chapter II), these results confirm the tendency for shrub and ground nesting species to select hardwood bottomlands in early succession (Twedt et al. 2002). Dense vegetation at early successional sites likely contributed to concealment of birds and nests from predators (Martin 1993). Invertebrate prey densities also tend to be greater in dense vegetation (Curry 1994). The negative relationship of air feeders (e.g., swallows, flycatchers) with vertical vegetation structure at 1 – 1.5 m aboveground is difficult to interpret, but may be associated with the need to forage in open areas (Cody 1981, Coppedge et al. 2008). Swallows (Hirundinidae) were only found at 2 sites, which were 10 and 4 years old and devoid of shrub vegetation. I also found that species richness and abundance of canopy feeders were positively related with vertical cover. In both cases, vertical cover explained less variation in these metrics than site age. Nonetheless, there may be some benefit of vertical vegetation structure in forested systems also (Twedt and Portwood 1997). Swift et al. (1984) found that bird density and diversity were positively correlated with structural heterogeneity in forested riparian zones. Thus, vertical vegetation structure may be an important predictor of habitat quality for birds in early and late successional hardwood bottomlands.

I documented a positive seasonal relationship for bird diversity and relative abundance of ground nesting species. Thus, these community metrics increased with each 2-month seasonal period from March – August. Given that AIC models suggested bird species richness remained relatively constant during sampling, the trend in diversity was driven by a more evenly distributed bird community later in the year. This trend was likely a consequence of differences in species composition and turnover between spring migrants and the breeding community. Migrants generally move in foraging flocks, and rapid changes in bird species composition are

typical as migrants move through a region (Morse 1970, Temple et al. 1997, Hurlbert and Haskell 2003). The positive relationship of ground nesting species with season is likely due to the presence of fledglings in late spring and summer. No other seasonal trends were documented, indicating that hardwood bottomland restoration sites consistently provided habitat for a large number of bird species from March – August 2008.

Model Selection Procedures

Despite the widespread use of AIC in developing ecological models, I found that this procedure typically resulted in more complex models than stepwise selection. Top AIC models as per relative model weights typically had 1 – 3 additional variables, with some candidate models having 6 more variables than stepwise models. A total of 164 candidate models were generated within 2 AIC units of the lowest AIC, which is a common threshold for building candidate lists of AIC models (Guthery et al. 2005). Ninety percent of these candidate models contained habitat variables that were not significant. There also were 63 AIC models that contained no significant variables, which I did not include in the results. Others have noted the tendency for AIC selection to overestimate the number of parameters (Kadane and Lazaar 2004), resulting in models which perform poorly when tested on different data sets (Guthery et al. 2005). Guthery et al. (2005) emphasized the risk of simply accepting trends in top AIC models when very little variation in the dependent variable may be explained. In contrast, 17 stepwise models were created that typically contained 1 – 2 explanatory variables. As per the design of the stepwise algorithm, all retained variables explained significant variation in the community metric. For 15 of 17 models, all variables included in the stepwise model were included in the top AIC model. Thus, stepwise model selection did not result in erroneous inclusion of

unimportant explanatory variables as a result of Type I error from multiple sequential *F*-tests, which is cited as a concern (Anderson et al. 2000). Even though AIC models contained more variables, typically <10% more variation was explained in the dependent variable. Thus, the primary shortcomings of AIC model development were: (1) a large number of candidate models were generated which may confuse interpretation of meaningful ecological patterns, (2) top candidate models were less parsimonious than stepwise models, (3) candidate models contained non-significant variables, and (4) very little additional variation was explained by the more complex AIC models. Additionally, when AIC models are reported, very few investigators include *P*-values, partial R^2, and standardized coefficients for variables (Guthery et al. 2005), which adds to the confusion of variable importance and model performance. A possible shortcoming of stepwise selection is that important variable combinations may be missed in the final models, because all possible combinations are not considered due to its sequential algorithm of adding and removing variables (Kutner et al. 2004).

Based on this comparative analysis, I recommend a change in AIC model reporting standards. First, more informative standards need to be established for generating candidate model lists. My study demonstrated that the 2 AIC-unit standard can result in a large group of candidate models. One option is to interpret the top model based on the lowest AIC as I did for comparisons. However, if inspecting a group of models is desired, I recommend restricting the candidate list to models containing a weight that is at least 50% or 75% of the value of the lowest AIC model. In my study, this would have resulted in 4 or less models to inspect per metric. I also recommend that *P*-values, partial R^2, and standardized coefficients are provided for variables in all final models similar to Tables 3.3 – 3.7. Lastly, I recommend that scientists not

be discouraged from using stepwise selection for model building. This approach did not result in erroneous inclusion of unimportant explanatory variables and all models were parsimonious. Simple models are particularly attractive when they are used for predicting responses, which is commonly done by natural resource practitioners (Beutel et al. 1999).

The models that I provided in Tables 3.3 and 3.4 can be used to predict amphibian and bird metric responses, which could be used to monitor ecological restoration at bottomland sites. In particular, these models could be used to predict bird and amphibian responses for IBI models presented in Chapter II. This approach would eliminate the need to sample bird and amphibian communities for IBI model predictions, which may be a limiting factor for some natural resource agencies if the expertise or resources do not exist to sample these assemblages. This approach of linking habitat and IBI model predictions has never been proposed and would need to be evaluated.

CONCLUSIONS

My results indicate that WRP sites in western Tennessee are providing habitat for at least 14 amphibian and 100 bird species, thus contributing to the biodiversity of the region. Species diversity of amphibians was greatest in early successional bottomlands, and the community was dominated by anurans. Salamanders were only documented at forested reference sites. Bird community composition changed through stages of restoration, with early stages dominated by ground nesting and ground feeding guilds (i.e., mostly grassland birds). Canopy nesting, branch nesting, twig nesting, branch feeding, and canopy feeding guilds dominated late successional and reference sites. The greatest bird species richness and diversity were at the reference sites in the Hatchie River bottomland, which were approximately 50 yrs old. Few seasonal trends were

documented in amphibian and bird community metrics indicating that my bottomland sites provided habitat consistently from March – August 2008. My study provided supporting evidence that WRP bottomland restoration sites provide habitat for 2 major vertebrate groups throughout succession. I recommend that the WRP be renewed in future Farm Bill legislation. Habitat models provided in Tables 3.3 and 3.4 could be used to monitor ecological restoration at bottomland restoration sites, and be used in combination with IBI models in Chapter II to eliminate the need to sample amphibian or bird assemblages.

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APPENDICES

APPENDIX I

TABLES AND FIGURES

Table 2.1. Landowner name, county, first year of restoration, and size of replanted area at 17 Wetlands Reserve Program sites sampled in western Tennessee, March – August 2008.

Site name	County	Restoration year	Size (ha)
Moore	Dyer	1987	67.2
Carroll	Hardin	1995	139
Coffman	Henderson	1997	45.9
Williams	Madison	1998	7.7
Palazola	Hardeman	1998	214.1
Henry	Weakley	1998	18.4
TDOT	Madison	1998	176.9
Bogota WMA (South)	Dyer	1998	175
Fairless	Gibson	2000	15.3
Keiser	Lake	2000	50
Deere	Henderson	2001	9.1
McWilliams	Lake	2001	161.6
Anglin	Decatur	2002	32.2
Bogota WMA (North)	Dyer	2002	40.5
Vandiver	Hardeman	2003	121.4
WTREC	Madison	2004	22.7
Enochs	Crockett	2006	13.4

Table 2.2. Commonly detected bird nesting and feeding guilds in Tennessee hardwood bottomlands, May – August 2008.

Species[a]	Scientific Name	Nesting Guild[b]	Foraging Guild[c]
Acadian flycatcher	*Empidonax virescens*	twig	air
American crow	*Corvus brachyrhynchos*	branch	ground
American goldfinch	*Carduelis tristis*	twig	ground
American redstart	*Setophaga ruticilla*	branch	canopy
American robin	*Turdus migratorius*	branch	ground
bank swallow	*Riparia riparia*	other	air
barn swallow	*Hirundo rustica*	other	air
black and white warbler	*Mniotilta varia*	ground	canopy
blue-gray gnatcatcher	*Polioptila caerulea*	branch	canopy
brown-headed cowbird	*Molothrus ater*	other	ground
blue grosbeak	*Passerina caerulea*	shrub	ground
blue jay	*Cyanocitta cristata*	branch	ground
blackpoll warbler	*Dendroica striata*	branch	canopy
brown thrasher	*Toxostoma rufum*	shrub	ground
blue-winged teal	*Anas discors*	ground	other
blue-winged warbler	*Vermivora pinus*	ground	canopy
Carolina chickadee	*Parus carolinensis*	cavity	canopy
Carolina wren	*Thryothorus ludovicianus*	cavity	ground
chimney swift	*Chaetura pelagica*	cavity	air
cliff swallow	*Hirundo spilodera*	other	air
common grackle	*Quiscalus quiscula*	branch	ground
common snipe	*Gallinago gallinago*	ground	ground
common yellowthroat	*Geothlypis trichas*	ground	canopy
dickcissel	*Spiza americana*	ground	ground
downy woodpecker	*Picoides tridactylus*	cavity	bark
eastern bluebird	*Sialia sialis*	cavity	air
eastern kingbird	*Tyrannus tyrannus*	branch	air
eastern meadowlark	*Sturnella magna*	ground	ground
eastern phoebe	*Sayornis phoebe*	cavity	air
eastern towhee	*Pipilo erythrophthalmus*	ground	ground
eastern wood-pewee	*Contopus virens*	twig	air
fish crow	*Corvus ossifragus*	branch	ground
field sparrow	*Spizella pusilla*	ground	ground
fox sparrow	*Passerella iliaca*	ground	ground
great blue heron	*Ardea herodias*	branch	other
great-crested flycatcher	*Myiarchus crinitus*	cavity	air

Table 2.2 (continued).

Species[a]	*Scientific Name*	Nesting Guild[b]	Foraging Guild[c]
golden-crowned kinglet	*Regulus satrapa*	twig	canopy
gray catbird	*Dumetella carolinensis*	shrub	ground
great egret	*Egretta alba*	branch	other
green heron	*Butorides virescens*	branch	other
hairy woodpecker	*Picoides villosus*	cavity	bark
hermit thrush	*Catharus guttatus*	ground	ground
indigo bunting	*Passerina cyanea*	ground	canopy
killdeer	*Charadrius vociferous*	ground	ground
least bittern	*Ixobrychus exilis*	ground	other
marsh wren	*Cistothorus palustris*	ground	ground
Mississippi kite	*Ictinia mississippiensis*	branch	air
mourning dove	*Zenaida macroura*	branch	ground
Nashville warbler	*Vermivora ruficapilla*	ground	canopy
northern bobwhite	*Colinus virginianus*	ground	ground
northern cardinal	*Cardinalis cardinalis*	ground	ground
northern parula	*Parula americana*	twig	canopy
northern waterthrush	*Seiurus noveboracensis*	ground	other
orchard oriole	*Icterus spurius*	twig	canopy
palm warbler	*Dendroica palmarum*	ground	ground
pileated woodpecker	*Dryocopus pileatus*	cavity	bark
prairie warbler	*Dendroica discolor*	shrub	canopy
prothonotary warbler	*Protonotaria citrea*	cavity	bark
purple martin	*Progne subsis*	cavity	air
red-bellied woodpecker	*Melanerpes carolinus*	cavity	bark
ruby-crowned kinglet	*Regulus calendula*	twig	canopy
red-eyed vireo	*Vireo olivaceus*	shrub	canopy
red-shouldered hawk	*Buteo lineatus*	branch	ground
ruby-throated hummingbird	*Archilochus colubris*	branch	other
red-winged blackbird	*Agelaius phoeniceus*	ground	ground
savanna sparrow	*Passerculus sandwichensis*	ground	ground
song sparrow	*Melospiza melodia*	ground	ground
summer tanager	*Piranga rubra*	branch	canopy
swamp sparrow	*Melospiza georgiana*	shrub	ground
Swainson's thrush	*Catharus ustulatus*	branch	ground
Swainson's warbler	*Limnothlypis swainsonii*	shrub	ground
Tennessee warbler	*Vermivora peregrina*	ground	canopy
tree swallow	*Tachycineta bicolor*	cavity	air
tufted titmouse	*Baeolophus bicolor*	cavity	canopy

Table 2.2 (continued).

Species[a]	*Scientific Name*	Nesting Guild[b]	Foraging Guild[c]
white-breasted nuthatch	*Sitta carolinensis*	cavity	bark
white-eyed vireo	*Vireo griseus*	shrub	canopy
willow flycatcher	*Empidonax traillii*	shrub	air
winter wren	*Troglodytes troglodytes*	ground	ground
wood duck	*Aix sponsa*	cavity	other
wood thrush	*Hylocichla mustelina*	branch	ground
white-throated sparrow	*Zonotrichia albicollis*	ground	ground
yellow-breasted chat	*Icteria virens*	shrub	canopy
yellow-billed cuckoo	*Coccyzus americanus*	shrub	canopy
yellow-bellied sapsucker	*Sphyrapicus varius*	cavity	bark
yellow-crowned night heron	*Nyctanassa violacea*	branch	other
yellow-rumped warbler	*Dendroica coronata*	branch	canopy
yellow-throated vireo	*Vireo flavifrons*	twig	canopy
yellow-throated warbler	*Dendroica dominica*	branch	canopy
yellow warbler	*Dendroica petechia*	branch	canopy

[a]Species detected in a 0.79-ha (50-m radius) plot during a 10-min point count survey.

[b]Twig = species primarily nests on tree twigs, branch = species primarily nests on tree branches, ground = species primarily nests on ground or in low herbaceous vegetation, shrub = species primarily nests in shrubs, vines or brambles, cavity = species primarily nests in tree cavities or crevices, and other = species belongs to a nesting guild which was not commonly detected (DeGraaf and Chadwick 1984).

[c]Air = species primarily forages aerially, ground = species primarily forages on the ground, canopy = species primarily forages in the canopy, and other = species belongs to a foraging guild which was not commonly detected (DeGraaf and Chadwick 1984).

Table 2.3. Relationship between significant vegetation metrics, site age and season[a] in Tennessee hardwood bottomlands, May – August 2008.

Vegetation Metric[b]	Predictor Variable[c]	Estimates		*t*-value	*P*-value	Partial R^2
		Un-standardized	Standardized			
CA	age	0.01	0.46	3.17	0.003	0.21
	season	-0.01	-0.01	-0.10	0.920	0.00
OM	age	0.64	0.41	2.83	0.007	0.17
	season	-3.19	-0.06	-0.42	0.677	0.00
FO	age	-0.49	-0.36	-2.42	0.020	0.13
	season	2.62	0.06	0.39	0.699	0.00
LV	age	-1.13	-0.69	-6.06	<0.001	0.48
	season	-4.44	-0.08	-0.71	0.480	0.01
ML	age	-1.35	-0.71	-6.33	<0.001	0.51
	season	0.44	0.01	0.06	0.952	0.00
MH	age	-0.98	-0.49	0.00	0.001	0.24
	season	-5.95	-0.09	0.53	0.532	0.01
HV	age	-0.67	-0.32	-2.10	0.043	0.10
	season	0.16	0.00	0.01	0.988	0.00
BA	age	2.15	0.80	10.36	<0.001	0.64
OH	age	0.67	0.60	5.84	<0.001	0.36
LO	age	2.47	0.94	22.06	<0.001	0.89
SN	age	0.43	0.77	9.36	<0.001	0.59
OT	age	0.60	0.83	11.66	<0.001	0.69

[a]Season was not included as a predictor for vegetation variables which were only measured once.

[b]CA = % canopy closure, OM = % dead organic matter in a 1-m^2 plot, FO = % cover of forbs in 1-m^2 plot, LV = % vertical cover (0 – 0.5 m high), ML = % vertical cover (0.5 – 1.0 m high), MH = % vertical cover (1.0 – 1.5 m high), HV = % vertical cover (1.5 – 2.0 m high), BA = basal area of all woody plants measured with a 10-basal-area-factor prism, OH = height (m) of nearest overstory tree, LO = number of logs (>11.4-cm dia) in 3.14-ha (100-m radius) plot, SN = number of snags (>11.4 cm DBH) in 3.14-ha plot, and OT = number of overstory trees (>11.4 cm DBH) in 0.04-ha plot.

Table 2.3 (continued).

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[c]Site age = number of years since restoration activities were initiated, and season = 2 (May – June) or = 3 (July – August).

Table 2.4. Relationship between significant amphibian community metrics, site age and season in Tennessee hardwood bottomlands, March – August 2008.

Amphibian Metric[a]	Predictor Variable[b]	Estimates		*t*-value	*P*-value	Partial R^2
		Un-standardized	Standardized			
AM	age	0.03	0.55	4.90	<0.001	0.30
	season	-0.11	4.81	-0.81	0.421	0.01
PL	age	0.01	0.61	5.74	<0.001	0.37
	season	0.01	0.03	0.28	0.781	0.00

[a]AM = abundance of Ambystomatid salamanders, and PL = abundance of Plethodontid salamanders; surveyed using a combination of 3.14-ha searches and cover-boards.

[b]Site age = number of years since restoration activities were initiated, and season = 1 (March – April), = 2 (May – June) or = 3 (July – August).

Table 2.5. Relationship between significant bird community metrics, site age and season in Tennessee hardwood bottomlands, March – August 2008.

Bird Metric[a]	Predictor Variable[b]	Estimates		*t*-value	*P*-value	Partial R^2
		Un-standardized	Standardized			
DI	site age	0.01	0.36	3.09	0.003	0.15
	season	0.21	0.37	3.18	0.002	0.16
RI	site age	0.16	0.51	4.67	<0.001	0.28
	season	1.37	0.21	1.94	0.058	0.06
CN	site age	0.11	0.41	3.35	0.001	0.17
	season	-1.08	-0.20	-1.62	0.111	0.05
BN	site age	0.07	0.66	6.59	<0.001	0.44
	season	-0.09	-0.05	-0.45	0.657	0.00
TN	site age	0.09	0.91	16.64	<0.001	0.83
	season	0.05	0.03	0.49	0.623	0.00
GN	site age	-0.11	-0.51	-4.39	<0.001	0.26
	season	0.78	0.17	1.48	0.144	0.00
BF	site age	0.05	0.87	13.35	<0.001	0.76
	season	0.05	0.05	0.73	0.467	0.01
CF	site age	0.11	0.40	3.34	0.002	0.17
	season	1.09	0.19	1.61	0.112	0.05
GF	site age	-0.06	-0.34	-2.70	0.009	0.12
	season	-0.44	-0.12	-0.94	0.349	0.02

[a]DI = Shannon-Wiener species diversity, RI = species richness, and CN, BN, TN, GN, BF, CF, and GF = abundance of cavity nesting, branch nesting, twig nesting, ground nesting, bark feeding, canopy feeding, and ground feeding bird species, respectively, in a 0.79-ha (50-m radius) plot during a 10-min point count survey.

[b]Site age = number of years since restoration activities were initiated, and season = 1 (March – April), = 2 (May – June) or = 3 (July – August).

Table 2.6. Vegetation metric scoring for index of biotic integrity (IBI) models that predict the state of ecological restoration in hardwood bottomlands, western Tennessee, 2008.

Metric[a]	Field Measurement	IBI Restoration Score
Logs	0	1
	1 - 2	2
	3 - 21	3
	>21	4
Snags[b]	0	1
	1 - 2	2
	>2	3
Overstory trees[b]	0	1
	1 - 5	2
	>5	3
Basal area	0 - 1	1
	2 - 30	2
	31 - 60	3
	>60	4
Mid-level vertical cover	93.9 - 100	1
	80.5 - 93.8	2
	47.6 - 80.4	3
	0 - 47.5	4
Low vertical cover[b]	98.3 - 100	1
	85.1 - 98.2	2
	0 - 85	3

[a] Logs = number of logs (>11.4-cm dia) in 3.14-ha (100-m radius) plot, snags = number of snags (>11.4 cm DBH) in 3.14-ha plot, overstory trees = number of overstory trees (>11.4 cm DBH) in a 0.04-ha plot, basal area = basal area of all woody plants measured with a 10-basal-area-factor prism, mid-level vertical cover = percent vertical cover at 0.5 – 1.0 m aboveground measured using a profile board, and low vertical cover = percent vertical cover at 0 – 0.5 m aboveground measured using a profile board.

Table 2.6 (continued).

[b]Restoration score categories were reduced to 1 – 3 because values were identical at multiple percentiles.

Table 2.7. Amphibian metric scoring for index of biotic integrity (IBI) models that predict the state of ecological restoration in hardwood bottomlands, western Tennessee, 2008.

Metric[a]	Field Measurement	IBI Restoration Score
Ambystomatidae	Absent	0
	Present	1
Plethodontidae	Absent	0
	Present	1

[a]Presence or absence of Ambystomatidae and Plethodontidae detected using 3.14-ha searches and cover boards.

Table 2.8. Bird metric scoring for index of biotic integrity (IBI) models that predict the state of ecological restoration in hardwood bottomlands, western Tennessee, 2008.

Metric[a]	Field Measurement	IBI Restoration Score
Bark feeders[b]	0	1
	0.1 - 0.3	2
	>0.3	3
Branch nesters	0 - 0.3	1
	0.4 - 1.0	2
	1.1 - 2.6	3
	>2.6	4
Twig nesters	0 - 0.1	1
	0.2 - 0.5	2
	0.6 - 1.0	3
	>1.0	4

[a]Abundance of bark feeding, branch nesting, and twig nesting bird species in a 0.79-ha plot detected during a 10-min point count survey.

[b]Restoration score categories were reduced to 1 – 3 because values were identical at multiple percentiles.

Table 3.1. Amphibian species detected at 17 restoration and 4 reference hardwood bottomland sites in western Tennessee, March – August 2008.

Common Name	Scientific Name	Site[a]
American toad	*Bufo americanus*	Anglin
		Bogota1
		Carroll
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Keiser
		WTREC
barking treefrog	*Hyla gratiosa*	Vandiver
American bullfrog	*Lithobates catesbeianus*	Carroll
		Deere
		Enochs
		Hatchie2
		Hatchie3
		Henry
		Keiser
		Palazola
		Vandiver
bird-voiced treefrog	*Hyla avivoca*	Anglin
		Carroll
		Coffman
		Deere
		Enochs
		Hatchie1
		Hatchie2
		Hatchie3
		Moore
		Palazola
		Vandiver
		WTREC
crawfish frog	*Rana areolata*	Fairless
eastern narrow-mouthed toad	*Gastrophryne carolinensis*	Carroll

Table 3.1 (continued).

Common Name	Scientific Name	Site
Fowler's toad	*Bufo fowleri*	Bogota1
		Bogota2
		Carroll
		Coffman
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Keiser
		McWilliams
		Moore
		Palazola
		Vandiver
		Williams
		WTREC
green frog	*Rana clamitans*	Bogota2
		Carroll
		Deere
		Enochs
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Palazola
		Vandiver
		Williams

Table 3.1 (continued).

Common Name	Scientific Name	Site
green treefrog	*Hyla cinerea*	Anglin
		Bogota1
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Keiser
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		WTREC
gray treefrog	*Hyla versicolor*	Anglin
		Bogota1
		Bogota2
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		McWilliams
		Moore
		Palazola
		Vandiver
		WTREC
lesser siren	*Siren intermedia*	Hatchie2
marbled salamander	*Ambystoma opacum*	Hatchie2
		Hatchie3
		Hatchie4
mole salamander	*Ambystoma talpoideum*	Hatchie2

Table 3.1 (continued).

Common Name	Scientific Name	Site
northern cricket frog	*Acris crepitans*	Anglin
		Bogota1
		Bogota2
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Henry
		Keiser
		McWilliams
		Palazola
		TDOT
		Vandiver
		WTREC
spotted dusky salamander	*Desmognathus fuscus*	Hatchie3
		Hatchie4
southeastern chorus frog	*Pseudacris feriarum*	Anglin
		Deere
		Fairless
		Henry
		Keiser
		McWilliams
		TDOT
		Vandiver
		Williams
small-mouthed salamander	*Ambystoma texanum*	Hatchie3
		Hatchie4
southern cricket frog	*Acris gryllus*	Carroll
		Coffman
		Palazola
		Vandiver

Table 3.1 (continued).

Common Name	Scientific Name	Site
southern leopard frog	*Lithobates sphenocephalus*	Anglin
		Bogota1
		Bogota2
		Carroll
		Deere
		Enochs
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Keiser
		McWilliams
		Moore
		Palazola
		Vandiver
		Williams
		WTREC
spring peeper	*Pseudacris crucifer*	Anglin
		Carroll
		Coffman
		Fairless
		Henry
		Vandiver
		Williams
southern two-lined salamander	*Eurycea cirrigera*	Hatchie2
three-lined salamander	*Eurycea guttolineata*	Hatchie2

[a]Anglin = Terry Anglin, Bogota1 = Bogota WMA South, Bogota 2 = Bogota WMA North, Carroll = Jimmy Carroll, Coffman = Danny Coffman, Deere = William Deere, Enochs = Don Enochs, Fairless = Cy Fairless, Hatchie1 = Hatchie NWR Site 1, Hatchie2 = Hatchie NWR Site 2, Hatchie3 = Hatchie NWR Site 3, Hatchie4 = Hatchie NWR Site 4, Henry = Bobby Henry, Keiser = William Keiser, McWilliams = Rebecca McWilliams, Moore = Murray Moore, Palazola = Mike Palazola, TDOT = Tennessee Department of Transportation, Vandiver = Mike Vandiver, Williams = Kenneth Williams, and WTREC = West Tennessee Research and Education Center.

Table 3.2. Bird species detected at hardwood bottomland restoration and reference sites, surveyed using 10-minute, unlimited-radius point counts, western Tennessee, March – August 2008.

Common Name	Scientific Name	Site
Acadian flycatcher	*Empidonax virescens*	Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Moore
		Palazola
		TDOT
American coot	*Fulica americana*	Keiser
		WTREC
American crow	*Corvus brachyrhynchos*	Anglin
		Bogota1
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Keiser
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC

Table 3.2 (continued).

Common Name	Scientific Name	Site
American goldfinch	*Carduelis tristis*	Anglin
		Bogota2
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie4
		Henry
		Keiser
		McWilliams
		Moore
		TDOT
		Vandiver
		Williams
		WTREC
American redstart	*Setophaga ruticilla*	Enochs
		Hatchie1
		Hatchie2
		Hatchie3
		Palazola
		Vandiver
American robin	*Turdus migratorius*	Anglin
		Bogota1
		Carroll
		Coffman
		Deere
		Fairless
		Hatchie4
		McWilliams
		Williams
		WTREC
barred owl	*Strix varia*	Carroll
		Enochs
		Fairless
		Hatchie3
		Hatchie4
		Vandiver
bald eagle	*Haliaeetus leucocephalus*	Anglin
bank swallow	*Riparia riparia*	Bogota1
		Bogota2
Baltimore oriole	*Icterus galbula*	McWilliams

Table 3.2 (continued).

Common Name	Scientific Name	Site
barn swallow	*Hirundo rustica*	Bogota1
		Bogota2
		Keiser
		WTREC
black and white warbler	*Mniotilta varia*	Coffman
belted kingfisher	*Megaceryle alcyon*	Carroll
		WTREC
blue-gray gnatcatcher	*Polioptila caerulea*	Anglin
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC
brown-headed cowbird	*Molothrus ater*	Anglin
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Keiser
		McWilliams
		Moore
		Vandiver
		Williams
		WTREC

Table 3.2 (continued).

Common Name	Scientific Name	Site
blue grosbeak	*Molothrus ater*	Bogota1
		Henry
		Keiser
		McWilliams
		WTREC
blue jay	*Cyanocitta cristata*	Anglin
		Bogota2
		Carroll
		Coffman
		Deere
		Fairless
		Hatchie1
		Hatchie3
		Henry
		Moore
		Palazola
		TDOT
		Williams
		WTREC
blackpoll warbler	*Dendroica striata*	Hatchie1
brown thrasher	*Toxostoma rufum*	Coffman
		Deere
		TDOT
		Vandiver
		Williams
black-throated green warbler	*Dendroica virens*	Hatchie4
blue-winged teal	*Anas discors*	Vandiver
		WTREC
blue-winged warbler	*Vermivora pinus*	Anglin
		Deere
		Hatchie1

Table 3.2 (continued).

Common Name	Scientific Name	Site
Carolina chickadee	*Parus carolinensis*	Anglin
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
Canada goose	*Branta canadensis*	Carroll
		Coffman
		Hatchie4
		Henry
		Keiser
		McWilliams
		TDOT
		Vandiver
		WTREC
Carolina wren	*Thryothorus ludovicianus*	Anglin
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC

Table 3.2 (continued).

Common Name	Scientific Name	Site
chimney swift	*Chaetura pelagica*	Carroll
		Coffman
		Enochs
		Hatchie1
		Hatchie2
		Keiser
		Palazola
		TDOT
		WTREC
		Bogota1
		Bogota2
		Henry
cliff swallow	*Hirundo spilodera*	WTREC
common grackle	*Quiscalus quiscula*	Deere
		Keiser
		Palazola
		Vandiver
common snipe	*Gallinago gallinago*	WTREC
common yellowthroat	*Geothlypis trichas*	Anglin
		Bogota1
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Keiser
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC

Table 3.2 (continued).

Common Name	Scientific Name	Site
dickcissel	*Spiza americana*	Bogota1
		Bogota2
		Enochs
		Keiser
		Keiser
		McWilliams
		Vandiver
		WTREC
downy woodpecker	*Picoides tridactylus*	Anglin
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Moore
		Palazola
		Vandiver
eastern bluebird	*Sialia sialis*	Anglin
		Bogota2
		Coffman
		Fairless
		Hatchie1
		McWilliams
		Palazola
		WTREC
eastern kingbird	*Tyrannus tyrannus*	Enochs
eastern meadowlark	*Sturnella magna*	Anglin
		Bogota1
		Deere
		Fairless
		McWilliams
		Vandiver
		WTREC
eastern phoebe	*Sayornis phoebe*	Carroll
		Coffman
		Moore
		Vandiver
		Williams

Table 3.2 (continued).

Common Name	Scientific Name	Site
eastern towhee	*Pipilo erythrophthalmus*	Anglin
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Henry
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC
eastern wood-pewee	*Contopus virens*	Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Keiser
		Palazola
fish crow	*Corvus ossifragus*	Bogota1
		Deere
		Hatchie1
		Hatchie2
		Hatchie4
		Henry
		Moore
		TDOT
field sparrow	*Spizella pusilla*	Anglin
		Bogota1
		Bogota1
		Bogota2
		Carroll
		Coffman
		Deere
		Fairless
		McWilliams
		Moore
		TDOT
		Vandiver
		Williams
		WTREC

Table 3.2 (continued).

Common Name	Scientific Name	Site
fox sparrow	*Passerella iliaca*	Carroll
		Deere
		Fairless
		Henry
		Williams
great blue heron	*Ardea herodias*	Bogota1
		Carroll
		Enochs
		Hatchie1
		Henry
		Keiser
		McWilliams
		Palazola
		Vandiver
		WTREC
great-crested flycatcher	*Myiarchus crinitus*	Deere
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		McWilliams
		Moore
golden-crowned kinglet	*Regulus satrapa*	Carroll
		Williams
gray catbird	*Regulus satrapa*	Anglin
		Bogota1
		Carroll
		Henry
		Palazola
great egret	*Egretta alba*	Bogota1
		Bogota2
		Enochs
		Henry
		Keiser
		Vandiver
		WTREC
green heron	*Butorides virescens*	Carroll
		McWilliams

Table 3.2 (continued).

Common Name	Scientific Name	Site
hairy woodpecker	*Picoides villosus*	Carroll
		Coffman
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Palazola
hermit thrush	*Catharus guttatus*	Hatchie1
indigo bunting	*Passerina cyanea*	Anglin
		Bogota1
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Keiser
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC
killdeer	*Charadrius vociferous*	Bogota1
		Carroll
		Deere
		Enochs
		Keiser
		Vandiver
		WTREC
least bittern	*Ixobrychus exilis*	Keiser
mallard	*Anas platyrhynchos*	Anglin
		Carroll
		Coffman
		Keiser
		TDOT
		WTREC

Table 3.2 (continued).

Common Name	Scientific Name	Site
marsh wren	*Cistothorus palustris*	Carroll
		Vandiver
		WTREC
Mississippi kite	*Ictinia mississippiensis*	Hatchie2
mourning dove	*Zenaida macroura*	Anglin
		Bogota1
		Bogota2
		Carroll
		Enochs
		Fairless
		Hatchie3
		Henry
		Keiser
		McWilliams
		Moore
		Palazola
		Vandiver
Nashville warbler	*Vermivora ruficapilla*	Williams
northern bobwhite	*Colinus virginianus*	Anglin
		Bogota1
		Bogota2
		Enochs
		Keiser
		Vandiver
northern cardinal	*Cardinalis cardinalis*	Anglin
		Bogota1
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Keiser
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC

Table 3.2 (continued).

Common Name	Scientific Name	Site
northern flicker	*Colaptes auratus*	Anglin
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie4
		Henry
		Keiser
		McWilliams
		Moore
		TDOT
		Vandiver
		Williams
northern mockingbird	*Mimus polyglottos*	WTREC
northern parula	*Parula americana*	Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Moore
		Palazola
		Vandiver
		Williams
		WTREC
northern waterthrush	*Seiurus noveboracensis*	Hatchie3
		Palazola
		TDOT
orchard oriole	*Icterus spurius*	Anglin
		Carroll
		Hatchie1
		Henry
		Keiser
		Keiser
		McWilliams
		Moore
palm warbler	*Dendroica palmarum*	Moore
		Vandiver
		WTREC

Table 3.2 (continued).

Common Name	Scientific Name	Site
pied-billed grebe	*Podilymbus podiceps*	Anglin
		Carroll
		Vandiver
pileated woodpecker	*Dryocopus Pileatus*	Anglin
		Bogota1
		Bogota2
		Coffman
		Enochs
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Moore
		Palazola
		Vandiver
		WTREC
prairie warbler	*Dendroica discolor*	Anglin
		Hatchie4
		Vandiver
prothonotary warbler	*Protonotaria citrea*	Carroll
		Coffman
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		McWilliams
		Moore
		Palazola
		Vandiver
purple martin	*Progne subsis*	Keiser
rose-breasted grosbeak	*Pheucticus ludovicianus*	Hatchie4

Table 3.2 (continued).

Common Name	Scientific Name	Site
red-bellied woodpecker	*Melanerpes carolinus*	Anglin
		Bogota1
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		WTREC
ruby-crowned kinglet	*Regulus calendula*	Carroll
		Hatchie4
		Williams
red-eyed vireo	*Vireo olivaceus*	Carroll
		Coffman
		Deere
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Palazola
		WTREC
red-headed woodpecker	*Melanerpes carolinus*	Hatchie4

Table 3.2 (continued).

Common Name	Scientific Name	Site
red-shouldered hawk	*Buteo lineatus*	Anglin
		Bogota1
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC
red-tailed hawk	*Buteo jamaicensis*	Bogota2
		TDOT
ruby-throated hummingbird	*Archilochus colubris*	Bogota2
		Hatchie1
		Hatchie3
		Henry
		Palazola
		Vandiver
		WTREC

Table 3.2 (continued).

Common Name	Scientific Name	Site
red-winged blackbird	*Agelaius phoeniceus*	Anglin
		Bogota1
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Henry
		Keiser
		Keiser
		McWilliams
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC
savanna sparrow	*Passerculus sandwichensis*	WTREC
sora	*Porzana carolina*	Enochs
		Henry
		Vandiver
		WTREC
song sparrow	*Melospiza melodia*	Carroll
		Coffman
		Vandiver
		WTREC
summer tanager	*Piranga rubra*	Anglin
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		WTREC
swamp sparrow	*Melospiza georgiana*	Anglin
		Carroll
		Deere
		Fairless
		Vandiver
Swainson's thrush	*Catharus ustulatus*	Hatchie1
		Hatchie3
		Hatchie4
Swainson's warbler	*Limnothlypis swainsonii*	Carroll
		Coffman
		Williams
Tennessee warbler	*Vermivora peregrina*	Hatchie3
		Hatchie4

Table 3.2 (continued).

Common Name	Scientific Name	Site
tree swallow	*Tachycineta bicolor*	Bogota1
		Bogota2
		Enochs
		WTREC
tufted titmouse	*Baeolophus bicolor*	Anglin
		Bogota1
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC
turkey vulture	*Cathartes aura*	Coffman
		Deere
		Enochs
		WTREC
warbling vireo	*Vireo gilvus*	McWilliams
white-breasted nuthatch	*Sitta carolinensis*	Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Moore
		Palazola
		Vandiver

Table 3.2 (continued).

Common Name	Scientific Name	Site
white-eyed vireo	*Vireo griseus*	Anglin
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC
willow flycatcher	*Empidonax traillii*	Palazola
		Vandiver
		Anglin
		Moore
		Vandiver
		Williams
winter wren	*Troglodytes troglodytes*	Hatchie1
wood duck	*Aix sponsa*	Carroll
		Coffman
		Enochs
		Hatchie1
wood thrush	*Hylocichla mustelina*	Carroll
		Coffman
		Fairless
		Hatchie3
		Hatchie4
		Henry
		Palazola
		TDOT
		Williams

Table 3.2 (continued).

Common Name	Scientific Name	Site
white-throated sparrow	*Zonotrichia albicollis*	Anglin
		Deere
		Hatchie1
		Moore
		TDOT
		Vandiver
		Williams
		WTREC
yellow-breasted chat	*Icteria virens*	Anglin
		Bogota1
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Henry
		McWilliams
		Moore
		Palazola
		TDOT
		Vandiver
		Williams
		WTREC
yellow-billed cuckoo	*Coccyzus americanus*	Anglin
		Bogota1
		Bogota2
		Carroll
		Coffman
		Deere
		Enochs
		Fairless
		Hatchie1
		Hatchie2
		Hatchie3
		Hatchie4
		Henry
		Keiser
		McWilliams
		Moore
		Palazola
		Vandiver
		Williams
		WTREC

Table 3.2 (continued).

Common Name	Scientific Name	Site
yellow-bellied sapsucker	*Sphyrapicus varius*	Hatchie3
		Hatchie4
yellow-crowned night heron	*Nyctanassa violacea*	Deere
		Hatchie1
		Hatchie2
		Hatchie3
yellow-rumped warbler	*Dendroica coronata*	Carroll
		Coffman
		Deere
		Hatchie4
		Vandiver
yellow-throated vireo	*Vireo flavifrons*	Hatchie1
		Hatchie2
		Hatchie4
yellow-throated warbler	*Dendroica dominica*	Hatchie1
		Hatchie2
		Hatchie4
yellow warbler	*Dendroica petechia*	Bogota2
		Enochs
		McWilliams

[a]Anglin = Terry Anglin, Bogota1 = Bogota WMA South, Bogota 2 = Bogota WMA North, Carroll = Jimmy Carroll, Coffman = Danny Coffman, Deere = William Deere, Enochs = Don Enochs, Fairless = Cy Fairless, Hatchie1 = Hatchie NWR Site 1, Hatchie2 = Hatchie NWR Site 2, Hatchie3 = Hatchie NWR Site 3, Hatchie4 = Hatchie NWR Site 4, Henry = Bobby Henry, Keiser = William Keiser, McWilliams = Rebecca McWilliams, Moore = Murray Moore, Palazola = Mike Palazola, TDOT = Tennessee Department of Transportation, Vandiver = Mike Vandiver, Williams = Kenneth Williams, and WTREC = West Tennessee Research and Education Center.

Table 3.3. Habitat models[a] developed using stepwise parameter selection that explained significant variation in amphibian community metrics in Tennessee hardwood bottomlands, March – August 2008.

Amphibian Metric[b]	Variable[c]	Estimates		*P*-value	Partial R^2
		Un-standardized	Standardized		
DI	canopy	-0.28	-0.29	0.039	0.08
BU	PO_4	3.57	0.51	<0.001	0.26
RA	forb	0.68	0.38	0.005	0.14
HY	canopy	-3.64	-0.36	0.008	0.13
AM	age	0.03	0.55	<0.001	0.30
PL	age	0.01	0.61	<0.001	0.38

[a]Models developed using stepwise selection with entry and stay significance levels at $\alpha = 0.05$.

[b]DI = species diversity, and BU, RA, HY, AM, and PL = relative abundance of Bufonidae, Ranidae, Hylidae, Ambystomatidae, and Plethodontidae species, respectively; surveyed using a combination of 3.14-ha searches, treefrog tubes and coverboards (Chapter II).

[c]PO_4 = phosphate concentration (ppm) measured once every 2 months, March – August 2008, forb = percent cover of forbs in a 1-m^2 plot, canopy = percent canopy closure, and age = number of years since restoration activities were initiated.

[d]VIF = variance inflation factor; VIF >10 suggests multicollinearity (Belsley et al. 1980).

Table 3.4. Habitat models[a] developed using stepwise parameter selection that explained significant variation in bird community metrics in Tennessee hardwood bottomlands, March – August 2008.

		Estimates					
Bird Metric[b]	Variable[c]	Un-standardized	Standardized	*P*-value	Partial R^2	VIF[d]	$R^2_{Adjusted}$
DI	canopy	0.38	0.39	0.002	0.17	1.02	0.26
	season	0.16	0.31	0.013	0.11	1.02	
RI	age	0.20	0.70	<0.001	0.41	1.21	0.38
	medhigh	0.05	0.35	0.005	0.14	1.21	
CN	age	0.11	0.39	0.004	0.15	1.00	0.15
BN	age	0.06	0.68	<0.001	0.47	1.00	0.47
TN	age	0.08	0.91	<0.001	0.84	1.00	0.84
GN	medhigh	0.06	0.60	<0.001	0.39	1.16	0.49
	midstem	0.00	-0.26	0.015	0.12	1.10	
	canopy	-4.23	-0.51	<0.001	0.33	1.10	
	season	1.00	0.22	0.033	0.09	1.04	
SN	medhigh	0.02	0.42	0.002	0.18	1.00	0.18
AF	medhigh	-0.05	-0.36	0.008	0.13	1.00	0.13
BF	age	0.05	0.88	<0.001	0.78	1.00	0.78
CF	age	0.16	0.61	<0.001	0.32	1.21	0.32
	medhigh	0.06	0.45	0.001	0.20	1.21	
GF	age	-0.07	-0.47	<0.001	0.22	1.05	0.21
	midstem	0.00	-0.28	0.031	0.09	1.05	

[a]Models developed using stepwise selection with entry and stay significance levels at $\alpha = 0.05$.

[b]DI = species diversity, RI = species richness, and CN, BN, TN, GN, SN, AF, BF, CF, and GF = relative abundance of cavity nesting, branch nesting, twig nesting, ground nesting, shrub nesting, air feeding, bark feeding, canopy feeding, and ground feeding bird species, respectively, in a 0.79-ha (50-m radius) plot during a 10-min point count survey.

Table 3.4 (continued).

[c]Canopy = Percent canopy closure, season = 1 (March – April), = 2 (May – June) or = 3 (July – August), age = number of years since restoration activities were initiated, medhigh = percent vertical cover of vegetation (1.0 – 1.5 m) measured using a profile board, and midstem = number of midstory trees (<11.4 cm DBH and >1.4 m tall) in a 100-m^2 plot.

[d]VIF = variance inflation factor; VIF >10 suggests multicollinearity (Belsley et al. 1980).

Table 3.5. Habitat models developed using vegetation variables and Akaike's Information Criteria (AIC) for amphibian community metrics in Tennessee hardwood bottomlands, March – August 2008.

Amphibian Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
DI	1	age	-99.87	0.00	0.20	0.01	0.26	0.078	0.06	1.28	0.10
		canopy				-0.39	-0.41	0.007	0.13	1.28	
	2	age	-99.29	0.58	0.15	0.01	0.41	0.039	0.08	2.18	0.11
		medhigh				0.00	0.20	0.254	0.03	1.83	
		canopy				-0.51	-0.53	0.005	0.15	1.93	
	3	age	-98.88	0.99	0.12	0.01	0.28	0.062	0.07	1.30	0.10
		canopy				-0.36	-0.38	0.017	0.11	1.36	
		deadOM				0.00	-0.13	0.337	0.02	1.14	
	4	canopy	-98.55	1.32	0.10	-0.27	-0.29	0.035	0.08	1.00	0.08
	5	age	-98.29	1.58	0.09	0.01	0.26	0.084	0.06	1.28	0.09
		canopy				-0.38	-0.40	0.010	0.12	1.31	
		season				-0.04	-0.08	0.534	0.01	1.02	
	6	age	-98.17	1.71	0.09	0.01	0.27	0.073	0.06	1.29	0.09
		canopy				-0.36	-0.37	0.027	0.09	1.58	
		forb				0.00	0.08	0.603	0.01	1.37	
	7	age	-98.16	1.71	0.09	0.01	0.42	0.035	0.09	2.18	0.11
		medhigh				0.00	0.19	0.284	0.02	1.84	
		canopy				-0.47	-0.49	0.011	0.13	2.05	
		deadOM				0.00	-0.12	0.378	0.02	1.15	
	8	age	-98.10	1.78	0.08	0.01	0.24	0.129	0.05	1.43	0.09
		medhigh				0.00	-0.06	0.650	0.00	1.14	
		canopy				-0.37	-0.39	0.014	0.11	1.39	
	9	age	-98.02	1.85	0.08	0.01	0.29	0.061	0.07	1.30	
		canopy				-0.32	-0.34	0.036	0.09	1.45	
		deadOM				0.00	-0.19	0.213	0.03	1.30	
		season				-0.07	-0.14	0.310	0.02	1.16	

Table 3.5 (continued).

Amphibian Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
RI	1	age	91.34	0.00	0.17	0.09	0.62	0.002	0.18	2.22	0.15
		medhigh				0.03	0.36	0.041	0.08	1.85	
		canopy				-1.96	-0.35	0.067	0.07	2.15	
		forb				0.03	0.29	0.061	0.07	1.38	
	2	age	92.05	0.71	0.12	0.09	0.64	0.002	0.19	2.24	0.16
		medhigh				0.03	0.39	0.031	0.09	1.88	
		canopy				-1.72	-0.30	0.114	0.05	2.24	
		forb				0.04	0.35	0.033	0.09	1.64	
		season				-0.46	-0.15	0.287	0.02	1.22	
	3	age	92.61	1.27	0.09	0.09	0.62	0.002	0.18	2.22	0.15
		medhigh				0.02	0.35	0.052	0.08	1.87	
		canopy				-1.84	-0.32	0.090	0.06	2.19	
		deadOM				-0.01	-0.12	0.423	0.01	1.27	
		forb				0.03	0.25	0.123	0.05	1.53	
	4	age	92.63	1.29	0.09	0.09	0.64	0.001	0.20	2.24	0.16
		medhigh				0.03	0.37	0.038	0.09	1.90	
		canopy				-1.48	-0.26	0.180	0.04	2.33	
		deadOM				-0.01	-0.16	0.269	0.03	1.36	
		forb				0.04	0.32	0.060	0.07	1.71	
		season				-0.59	-0.19	0.192	0.04	1.30	
	5	age	92.71	1.38	0.09	0.07	0.50	0.003	0.17	1.61	0.15
		medhigh				0.02	0.27	0.082	0.06	1.47	
		deadOM				-0.02	-0.26	0.074	0.06	1.27	
		forb				0.04	0.35	0.030	0.09	1.53	
		season				-0.78	-0.25	0.080	0.06	1.21	
	6	age	92.86	1.53	0.08	0.04	0.29	0.040	0.08	1.11	0.08
		forb				0.03	0.28	0.048	0.07	1.11	

Table 3.5 (continued).

Amphibian Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
RI	7	age	92.88	1.55	0.08	0.07	0.46	0.007	0.14	1.57	0.11
		medhigh				0.02	0.27	0.088	0.06	1.47	
		forb				0.05	0.42	0.008	0.13	1.42	
		season				-0.62	-0.20	0.162	0.04	1.17	
	8	age	93.07	1.74	0.07	0.06	0.40	0.014	0.11	1.48	0.09
		medhigh				0.02	0.21	0.168	0.04	1.37	
		forb				0.04	0.35	0.020	0.10	1.25	
	9	age	93.26	1.92	0.07	0.08	0.57	0.005	0.15	2.18	0.11
		medhigh				0.02	0.33	0.069	0.06	1.83	
		canopy				-2.60	-0.46	0.014	0.11	1.93	
	10	age	93.31	1.97	0.07	0.08	0.58	0.004	0.16	2.18	0.12
		medhigh				0.02	0.31	0.083	0.06	1.84	
		canopy				-2.26	-0.40	0.035	0.09	2.05	
		deadOM				-0.02	-0.18	0.186	0.04	1.15	
	11	age	93.33	1.99	0.06	0.09	0.62	0.003	0.17	2.36	0.14
		medhigh				0.03	0.36	0.043	0.08	1.85	
		midstem				0.00	0.01	0.932	0.00	1.17	
		canopy				-1.98	-0.35	0.071	0.07	2.19	
		forb				0.03	0.29	0.065	0.07	1.42	
BU	1	forb	75.31	0.00	0.32	0.03	0.30	0.027	0.09	1.00	0.09
	2	medhigh	76.46	1.16	0.18	-0.01	-0.12	0.385	0.01	1.03	0.07
		forb				0.03	0.28	0.041	0.08	1.03	
	3	forb	77.05	1.74	0.13	0.03	0.31	0.025	0.09	1.07	0.06
		season				-0.18	-0.07	0.621	0.00	1.07	
	4	age	77.07	1.76	0.13	0.01	0.06	0.645	0.00	1.11	0.06
		forb				0.01	0.32	0.026	0.09	1.11	
	5	deadOM	77.11	1.81	0.13	0.00	0.05	0.728	0.00	1.18	0.06
		forb				0.03	0.32	0.032	0.09	1.18	
	6	midstem	77.27	1.96	0.12	0.00	-0.03	0.831	0.00	1.03	0.05
		forb				0.03	0.29	0.034	0.08	1.03	

Table 3.5 (continued).

Amphibian Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
HY	1	canopy	150.75	0.00	0.14	-3.63	-0.37	0.006	0.14	1.00	0.14
	2	midstem	151.40	0.65	0.10	0.00	-0.15	0.261	0.02	1.02	0.12
		canopy				-3.43	-0.35	0.010	0.02	1.02	
	3	canopy	151.66	0.91	0.09	-3.43	-0.35	0.010	0.12	1.02	0.12
		season				-0.71	-0.13	0.312	0.02	1.02	
	4	canopy	151.76	1.01	0.08	-4.37	-0.44	0.005	0.15	1.35	0.12
		forb				-0.03	-0.15	0.335	0.02	1.35	
	5	canopy	151.81	1.05	0.08	-3.23	-0.33	0.021	0.10	1.12	0.11
		deadOM				-0.02	-0.12	0.384	0.01	1.12	
	6	midstem	152.04	1.28	0.07	0.00	-0.17	0.208	0.03	0.03	0.13
		canopy				-4.27	-0.43	0.006	0.14	0.14	
		forb				-0.03	-0.17	0.263	0.02	0.02	
	7	midstem	152.05	1.29	0.07	0.00	-0.16	0.224	0.03	1.03	0.13
		canopy				-3.20	-0.32	0.017	0.11	1.05	
		season				-0.79	-0.15	0.265	0.02	1.03	
	8	canopy	152.11	1.36	0.07	-4.08	-0.41	0.009	0.13	1.39	0.13
		deadOM				-0.03	-0.18	0.219	0.03	1.24	
		forb				-0.04	-0.21	0.195	0.03	1.50	
	9	medhigh	152.23	1.47	0.07	0.01	0.10	0.483	0.01	1.08	0.11
		canopy				-3.88	-0.39	0.005	0.14	1.08	
	10	medhigh	152.27	1.51	0.06	0.02	0.14	0.308	0.02	1.15	0.12
		midstem				0.00	-0.18	0.180	0.04	1.09	
		canopy				-3.76	-0.38	0.006	0.14	1.08	
	11	midstem	152.39	1.63	0.06	0.00	-0.16	0.235	0.03	1.04	0.13
		canopy				-4.01	-0.41	0.010	0.13	1.39	
		deadOM				-0.02	-0.17	0.247	0.03	1.25	
		forb				-0.05	-0.23	0.158	0.04	1.51	

Table 3.5 (continued).

Amphibian Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
HY	12	medhigh	152.57	1.82	0.06	0.02	0.16	0.250	0.03	1.16	0.13
		midstem				0.00	-0.20	0.141	0.04	1.10	
		canopy				-3.55	-0.36	0.010	0.13	1.10	
		season				-0.88	-0.16	0.217	0.03	1.04	
	13	age	152.74	1.98	0.05	0.00	-0.02	0.897	0.00	1.28	0.10
		canopy				-3.54	-0.36	0.019	0.10	1.28	
RA	1	forb	384.97	0.00	0.26	0.67	0.38	0.004	0.14	1.00	0.14
	2	medhigh	386.02	1.05	0.15	0.13	0.12	0.339	0.02	1.03	0.13
		forb				0.71	0.40	0.003	0.16	1.03	
	3	forb	386.12	1.14	0.15	0.73	0.41	0.003	0.16	1.07	0.13
		season				-5.66	-0.12	0.366	0.02	1.07	
	4	canopy	386.53	1.56	0.12	8.44	0.10	0.520	0.01	1.35	0.12
		forb				0.76	0.43	0.006	0.14	1.35	
	5	deadOM	386.58	1.61	0.12	-0.11	-0.09	0.538	0.01	1.18	0.12
		forb				0.61	0.35	0.016	0.11	1.18	
	6	medhigh	386.79	1.81	0.11	0.16	0.15	0.264	0.02	1.05	0.13
		forb				0.78	0.44	0.002	0.17	1.11	
		season				-6.81	-0.14	0.282	0.02	1.10	
	7	midstem	386.95	1.97	0.10	0.00	-0.02	0.867	0.00	1.03	0.11
		forb				0.67	0.38	0.006	0.14	1.03	
AM	1	age	-24.88	0.00	0.18	0.03	0.46	<0.001	0.25	1.07	0.38
		deadOM				0.01	0.33	0.005	0.14	1.07	
	2	age	-24.86	0.02	0.18	0.03	0.50	<0.001	0.27	1.14	0.38
		deadOM				0.01	0.38	0.002	0.17	1.22	
		forb				0.01	0.15	0.203	0.03	1.25	
	3	age	-24.12	0.76	0.13	0.03	0.52	<0.001	0.26	1.30	0.38
		canopy				-0.31	-0.14	0.287	0.02	1.36	
		deadOM				0.01	0.36	0.003	0.16	1.14	

Table 3.5 (continued).

Amphibian Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
AM	4	age	-23.26	1.62	0.08	0.03	0.52	<0.001	0.27	1.31	0.38
		canopy				-0.19	-0.08	0.549	0.01	1.60	
		deadOM				0.01	0.40	0.002	0.18	1.26	
		forb				0.01	0.14	0.311	0.02	1.50	
	5	age	-23.14	1.74	0.08	0.03	0.45	<0.001	0.22	1.16	0.37
		midstem				0.00	-0.06	0.615	0.01	1.10	
		deadOM				0.01	0.34	0.005	0.15	1.13	
	6	age	-23.04	1.84	0.07	0.03	0.50	<0.001	0.27	1.17	0.37
		deadOM				0.01	0.37	0.004	0.15	1.27	
		forb				0.01	0.16	0.186	0.03	1.30	
		season				-0.06	-0.05	0.661	0.00	1.13	
	7	age	-23.03	1.85	0.07	0.03	0.52	<0.001	0.24	1.50	0.37
		medhigh				0.00	0.05	0.669	0.00	1.38	
		deadOM				0.01	0.38	0.002	0.17	1.22	
		forb				0.01	0.17	0.183	0.04	1.41	
	8	age	-22.91	1.97	0.07	0.03	0.49	<0.001	0.24	1.25	0.37
		midstem				0.00	-0.03	0.796	0.00	1.15	
		deadOM				0.01	0.38	0.003	0.17	1.24	
		forb				0.01	0.15	0.236	0.03	1.30	
	9	age	-22.90	1.98	0.07	0.03	0.46	<0.001	0.25	1.09	0.36
		deadOM				0.01	0.32	0.009	0.13	1.17	
		season				-0.02	-0.02	0.861	0.00	1.09	
	10	age	-22.88	2.00	0.07	0.03	0.46	0.001	0.21	1.31	0.36
		medhigh				0.00	0.00	0.981	0.00	1.22	
		deadOM				0.01	0.33	0.006	0.14	1.08	
PL	1	age	-156.30	0.00	0.13	0.01	0.67	<0.001	0.40	1.11	0.38
		forb				0.00	0.17	0.147	0.04	1.11	
	2	age	-156.12	0.17	0.12	0.01	0.61	<0.001	0.38	1.00	0.36

Table 3.5 (continued).

Amphibian Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
PL	3	age	-156.10	0.20	0.12	0.01	0.75	<0.001	0.40	1.48	0.39
		medhigh				0.00	0.16	0.196	0.03	1.37	
		forb				0.00	0.22	0.072	0.06	1.25	
	4	age	-155.76	0.53	0.10	0.01	0.83	<0.001	0.35	2.18	0.38
		medhigh				0.00	0.23	0.116	0.05	1.83	
		canopy				-0.17	-0.26	0.093	0.06	1.93	
	5	age	-155.70	0.60	0.10	0.01	0.86	<0.001	0.37	2.22	0.39
		medhigh				0.00	0.25	0.087	0.06	1.85	
		canopy				-0.13	-0.19	0.231	0.03	2.15	
		forb				0.00	0.17	0.187	0.04	1.38	
	6	age	-155.07	1.23	0.07	0.01	0.67	<0.001	0.36	1.28	0.36
		canopy				-0.08	-0.12	0.348	0.02	1.28	
	7	age	-154.82	1.47	0.06	0.01	0.64	<0.001	0.38	1.07	0.36
		deadOM				0.00	-0.09	0.444	0.01	1.07	
	8	age	-154.69	1.61	0.06	0.01	0.65	<0.001	0.36	1.22	0.36
		medhigh				0.00	0.09	0.476	0.01	1.22	
	9	age	-154.60	1.70	0.06	0.01	0.68	<0.001	0.40	1.21	0.37
		midstem				0.00	0.06	0.593	0.01	1.12	
		forb				0.00	0.18	0.128	0.04	1.18	
	10	age	-154.44	1.85	0.05	0.01	0.77	<0.001	0.40	1.57	0.38
		medhigh				0.00	0.18	0.167	0.04	1.47	
		forb				0.00	0.24	0.063	0.07	1.42	
		season				-0.02	-0.06	0.577	0.01	1.17	
	11	age	-154.44	1.86	0.05	0.01	0.68	<0.001	0.38	1.29	0.37
		canopy				-0.03	-0.05	0.718	0.00	1.58	
		forb				0.00	0.14	0.263	0.03	1.37	
	12	age	-154.40	1.89	0.05	0.01	0.67	<0.001	0.40	1.14	0.37
		deadOM				0.00	-0.04	0.767	0.00	1.22	
		forb				0.00	0.15	0.210	0.03	1.25	

Table 3.5 (continued).

Amphibian Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
PL	13	age	-154.34	1.96	0.05	0.01	0.67	<0.001	0.40	1.12	0.37
		forb				0.00	0.17	0.152	0.04	1.20	
		season				-0.01	-0.02	0.847	0.00	1.08	

[a]DI = species diversity, RI = species richness, and BU, RA, HY, AM, and PL = relative abundance of Bufonidae, Ranidae, Hylidae, Ambystomatidae, and Plethodontidae species, respectively; surveyed using a combination of 3.14-ha searches, treefrog tubes and coverboards (Chapter II).

[b]Age = number of years since restoration activities were initiated, canopy = percent canopy closure, medhigh = percent vertical cover (1.0 – 2.0 m), measured using a profile board, deadOM = percent cover of dead organic matter in 1-m^2 plot, season = 1 (March – April), = 2 (May – June) or = 3 (July – August), forb = percent cover of forbs in 1-m^2 plot, and midstem = number of midstory trees (<11.4 cm DBH and >1.4 m tall) in 0.01-ha plot.

[c]VIF = variance inflation factor; VIF >10 suggests multicollinearity (Belsley et al. 1980).

Table 3.6. Habitat models developed using water quality variables and Akaike's Information Criteria (AIC) for Bufonidae[a] in Tennessee hardwood bottomlands, March – August 2008.

Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R2	VIF[c]	Adjusted R^2
					Un-standardized	Standardized				
1	PO_4	68.18	0.00	0.29	2.86	0.45	0.001	0.20	1.00	0.20
2	PO_4	68.98	0.80	0.19	3.07	0.49	<0.001	0.22	1.07	0.19
	season				0.35	0.14	0.289	0.02	1.07	
3	PO_4	69.62	1.44	0.14	2.93	0.47	0.001	0.21	1.02	0.18
	NO_3				-0.06	-0.09	0.467	0.01	1.02	
4	PO4	69.63	1.44	0.14	2.90	0.46	0.001	0.21	1.01	0.18
	sal				-2.85	-0.09	0.469	0.01	1.01	
5	PO_4	69.79	1.60	0.13	3.20	0.51	<0.001	0.24	1.09	0.19
	sal				-4.26	-0.13	0.295	0.02	1.08	
	season				0.45	0.17	0.194	0.03	1.15	
6	PO_4	70.12	1.94	0.11	2.83	0.45	0.001	0.20	1.02	0.18
	turb				0.00	-0.03	0.811	0.00	1.02	

[a]Surveyed using a combination of 5-min call surveys, 3.14-ha searches and coverboards; no other amphibian families or metrics presented, because no water quality variables explained significant variation.

[b]PO_4= water PO_4 (ppm), season = 1 (March – April), = 2 (May – June) or = 3 (July – August), NO_3 = water NO_3 (ppm), sal = water salinity (ppm), and turb = water turbidity (Formazin Turbidity Units).

[c]VIF = variance inflation factor; VIF >10 suggests multicollinearity (Belsley et al. 1980).

Table 3.7. Habitat models developed using Akaike's Information Criteria (AIC) for bird species diversity and richness in Tennessee hardwood bottomlands, March – August 2008.

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
DI	1	age	-125.03	0.00	0.22	0.02	0.64	<0.001	0.38	1.35	0.47
		medhigh				0.01	0.54	<0.001	0.32	1.26	
		deadOM				0.00	-0.18	0.106	0.05	1.18	
		season				0.12	0.22	0.039	0.08	1.12	
	2	age	-124.88	0.15	0.20	0.02	0.66	<0.001	0.36	1.57	0.46
		medhigh				0.01	0.59	<0.001	0.32	1.47	
		forb				0.00	0.16	0.198	0.03	1.42	
		season				0.12	0.22	0.043	0.08	1.17	
	3	age	-124.83	0.20	0.20	0.01	0.59	<0.001	0.59	1.23	0.45
		medhigh				0.01	0.52	<0.001	0.52	1.24	
		season				0.14	0.27	0.010	0.27	1.02	
	4	age	-124.17	0.86	0.14	0.02	0.69	<0.001	0.38	1.61	0.47
		medhigh				0.01	0.59	<0.001	0.33	1.47	
		deadOM				0.00	-0.15	0.185	0.04	1.27	
		forb				0.00	0.11	0.365	0.02	1.53	
		season				0.10	0.20	0.081	0.06	1.21	
	5	age	-123.17	1.86	0.09	0.02	0.65	<0.001	0.38	1.39	0.46
		medhigh				0.01	0.54	<0.001	0.31	1.31	
		midstem				0.00	0.03	0.757	0.00	1.14	
		deadOM				0.00	-0.18	0.103	0.05	1.23	
		season				0.12	0.22	0.040	0.08	1.12	
	6	age	-123.06	1.97	0.08	0.02	0.63	<0.001	0.27	2.19	0.45
		medhigh				0.01	0.52	<0.001	0.23	1.85	
		canopy				0.02	0.02	0.868	0.00	2.11	
		deadOM				0.00	-0.16	0.167	0.04	1.30	
		season				0.12	0.23	0.041	0.08	1.17	

Table 3.7 (continued).

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
DI	7	age	-123.03	2.00	0.08	0.02	0.67	<0.001	0.35	1.63	0.45
		medhigh				0.01	0.58	<0.001	0.31	1.50	
		midstem				0.00	0.03	0.812	0.00	1.14	
		forb				0.00	0.16	0.195	0.03	1.47	
		season				0.12	0.23	0.045	0.08	1.47	
RI	1	age	140.08	0.00	0.37	0.22	0.78	<0.001	0.48	1.31	0.46
		medhigh				0.05	0.38	0.001	0.19	1.22	
		deadOM				-0.05	-0.29	0.007	0.13	1.08	
	2	age	141.49	1.40	0.18	0.22	0.77	<0.001	0.46	1.35	0.45
		medhigh				0.06	0.40	0.001	0.20	1.27	
		midstem				0.00	-0.08	0.449	0.01	1.14	
		deadOM				-0.05	-0.28	0.013	0.12	1.13	
	3	age	141.60	1.52	0.17	0.23	0.81	<0.001	0.46	1.50	0.45
		medhigh				0.06	0.40	0.001	0.19	1.38	
		deadOM				-0.04	-0.27	0.019	0.10	1.22	
		forb				0.02	0.07	0.550	0.01	1.41	
	4	age	142.05	1.96	0.14	0.22	0.77	<0.001	0.34	2.18	0.44
		medhigh				0.05	0.36	0.013	0.12	1.84	
		canopy				0.30	0.03	0.855	0.00	2.05	
		deadOM				-0.05	-0.29	0.013	0.12	1.15	
	5	age	142.08	1.99	0.14	0.22	0.79	<0.001	0.47	1.35	0.44
		medhigh				0.05	0.38	0.002	0.18	1.26	
		deadOM				-0.05	-0.30	0.010	0.13	1.18	
		season				-0.07	-0.01	0.911	0.00	1.12	

Table 3.7 (continued).

[a]DI = species diversity and RI = species richness in a 0.79-ha plot during a 10-min point count survey.

[b]Age = number of years since restoration activities were initiated, medhigh = percent vertical cover (1.0 – 1.5 m), measured using a profile board, deadOM = percent cover of dead organic matter in 1-m^2 plot, season = 1 (March – April), = 2 (May – June) or = 3 (July – August), forb = percent cover of forbs in 1-m^2 plot, midstem = number of midstory trees (<11.4 cm DBH and >1.4 m tall) in 0.01-ha plot, and canopy = percent canopy closure.

[c]VIF = variance inflation factor; VIF >10 suggests multicollinearity (Belsley et al. 1980).

Table 3.8. Habitat models developed using Akaike's Information Criteria (AIC) for bird nesting guilds in Tennessee hardwood bottomlands, March – August 2008.

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
CN	1	age	154.03	0.00	0.31	0.13	0.47	0.001	0.22	1.09	0.22
		deadOM				-0.04	-0.26	0.050	0.07	1.17	
		season				-1.68	-0.29	0.025	0.09	1.09	
	2	age	154.20	0.17	0.29	0.11	0.39	0.008	0.13	1.35	0.23
		medhigh				-0.02	-0.19	0.171	0.04	1.26	
		deadOM				-0.04	-0.24	0.069	0.06	1.18	
		season				-1.51	-0.26	0.045	0.08	1.12	
	3	age	155.49	1.46	0.15	0.14	0.51	0.001	0.22	1.30	0.21
		canopy				-1.09	-0.10	0.487	0.01	1.45	
		deadOM				-0.04	-0.25	0.082	0.06	1.30	
		season				-1.60	-0.28	0.041	0.08	1.16	
	4	age	155.70	1.67	0.14	0.12	0.45	0.001	0.19	1.17	0.20
		midstem				0.00	-0.07	0.598	0.01	1.10	
		deadOM				-0.04	-0.25	0.072	0.06	1.22	
		season				-1.68	-0.29	0.026	0.09	1.09	
	5	age	156.01	1.98	0.12	0.13	0.48	0.001	0.21	1.17	0.20
		deadOM				-0.04	-0.25	0.072	0.06	1.27	
		forb				0.01	0.03	0.811	0.00	1.30	
		season				-1.72	-0.30	0.026	0.09	1.13	
GN	1	age	101.18	0.00	0.26	-0.05	-0.23	0.109	0.05	2.30	0.54
		medhigh				0.05	0.44	0.001	0.20	1.86	
		midstem				0.00	-0.27	0.009	0.14	1.17	
		canopy				-2.25	-0.27	0.053	0.08	2.16	
		deadOM				-0.03	-0.23	0.038	0.09	1.32	
		season				0.68	0.15	0.141	0.05	1.17	

Table 3.8 (continued).

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
GN	2	age	101.69	0.51	0.20	-0.05	-0.22	0.124	0.05	2.30	0.53
		medhigh				0.05	0.45	0.001	0.20	1.85	
		midstem				0.00	-0.28	0.008	0.14	1.17	
		canopy				-1.96	-0.24	0.090	0.06	2.10	
		deadOM				-0.03	-0.28	0.009	0.14	1.18	
	3	medhigh	102.15	0.98	0.16	0.06	0.56	<0.001	0.38	1.19	0.53
		midstem				0.00	-0.24	0.022	0.11	1.11	
		canopy				-3.41	-0.41	<0.001	0.23	1.31	
		deadOM				-0.03	-0.24	0.029	0.10	1.31	
		season				0.66	0.15	0.161	0.04	1.17	
	4	medhigh	102.38	1.20	0.14	0.06	0.57	<0.001	0.38	1.18	0.52
		midstem				0.00	-0.25	0.018	0.11	1.11	
		canopy				-3.10	-0.37	0.001	0.20	1.23	
		deadOM				-0.04	-0.29	0.006	0.14	1.17	
	5	age	102.62	1.45	0.13	-0.05	-0.25	0.093	0.06	2.38	0.54
		medhigh				0.04	0.42	0.002	0.19	1.90	
		midstem				0.00	-0.28	0.008	0.14	1.19	
		canopy				-2.49	-0.30	0.042	0.09	2.37	
		deadOM				-0.03	-0.24	0.032	0.10	1.37	
		forb				-0.01	-0.08	0.495	0.01	1.73	
		season				0.78	0.17	0.110	0.05	1.30	
	6	age	102.96	1.79	0.11	-0.08	-0.38	0.001	0.20	1.35	0.52
		medhigh				0.03	0.32	0.004	0.15	1.27	
		midstem				0.00	-0.31	0.004	0.16	1.14	
		deadOM				-0.04	-0.32	0.003	0.17	1.13	
SN	1	medhigh	48.87	0.00	0.10	0.02	0.35	0.009	0.13	1.10	0.21
		canopy				0.93	0.23	0.093	0.06	1.23	
		deadOM				-0.02	-0.27	0.047	0.08	1.15	

Table 3.8 (continued).

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
SN	2	age	49.10	0.23	0.09	0.02	0.24	0.089	0.06	1.31	0.23
		medhigh				0.03	0.52	<0.001	0.23	1.22	
		deadOM				-0.02	-0.28	0.030	0.09	1.08	
	3	medhigh	49.31	0.44	0.08	0.02	0.41	0.002	0.17	1.01	0.19
		season				0.44	0.20	0.118	0.05	1.01	
	4	medhigh	49.67	0.81	0.07	0.02	0.36	0.005	0.15	1.07	0.24
		deadOM				-0.02	-0.26	0.052	0.07	1.24	
		forb				-0.02	-0.23	0.097	0.05	1.28	
		season				0.43	0.19	0.140	0.04	1.13	
	5	medhigh	49.84	0.97	0.06	0.02	0.35	0.010	0.13	1.10	0.21
		canopy				0.79	0.20	0.161	0.04	1.31	
		deadOM				-0.01	-0.22	0.118	0.05	1.29	
		season				0.28	0.13	0.336	0.02	1.16	
	6	age	49.85	0.98	0.06	0.02	0.21	0.129	0.05	1.35	0.23
		medhigh				0.03	0.49	0.001	0.21	1.26	
		deadOM				-0.01	-0.24	0.068	0.07	1.18	
		season				0.26	0.11	0.374	0.02	1.12	
	7	medhigh	49.94	1.07	0.06	0.02	0.42	0.001	0.19	1.00	0.20
		deadOM				-0.01	-0.22	0.076	0.06	1.00	
	8	medhigh	50.02	1.15	0.05	0.02	0.40	0.002	0.18	1.01	0.21
		deadOM				-0.01	-0.18	0.153	0.04	1.07	
		season				0.33	0.15	0.244	0.03	1.09	
	9	age	50.27	1.40	0.05	0.01	0.14	0.321	0.02	1.23	0.19
		medhigh				0.02	0.47	0.001	0.19	1.24	
		season				0.41	0.18	0.145	0.04	1.02	
	10	medhigh	50.28	1.42	0.05	0.02	0.43	0.001	0.19	1.00	0.19
	11	age	50.29	1.42	0.05	0.01	0.13	0.470	0.01	2.18	0.20
		medhigh				0.02	0.43	0.013	0.12	1.84	
		canopy				0.60	0.15	0.394	0.01	2.05	
		deadOM				-0.02	-0.27	0.044	0.08	1.15	

Table 3.8 (continued).

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
SN	12	medhigh	50.40	1.53	0.05	0.02	0.38	0.004	0.15	1.05	0.19
		forb				-0.01	-0.13	0.318	0.02	1.11	
		season				0.52	0.23	0.077	0.06	1.10	
	13	medhigh	50.44	1.57	0.04	0.02	0.38	0.003	0.16	1.04	0.22
		deadOM				-0.02	-0.30	0.029	0.09	1.20	
		forb				-0.02	-0.19	0.164	0.04	1.23	
	14	medhigh	50.53	1.66	0.04	0.02	0.35	0.010	0.13	1.10	0.20
		canopy				0.79	0.20	0.190	0.03	1.47	
		deadOM				-0.02	-0.29	0.041	0.08	1.27	
		forb				-0.01	-0.08	0.579	0.01	1.50	
	15	medhigh	50.56	1.69	0.04	0.02	0.37	0.006	0.14	1.08	0.19
		canopy				0.43	0.11	0.408	0.01	1.09	
		season				0.43	0.20	0.121	0.05	1.03	
	16	medhigh	50.58	1.71	0.04	0.02	0.37	0.008	0.13	1.18	0.20
		midstem				0.00	-0.07	0.609	0.01	1.11	
		canopy				0.93	0.23	0.095	0.06	1.23	
		deadOM				-0.02	-0.26	0.059	0.07	1.17	
	17	age	50.61	1.74	0.04	0.02	0.19	0.196	0.03	1.50	0.23
		medhigh				0.02	0.47	0.001	0.19	1.38	
		deadOM				-0.02	-0.32	0.021	0.10	1.22	
		forb				-0.01	-0.12	0.391	0.01	1.41	
	18	age	50.76	1.89	0.04	0.02	0.14	0.348	0.02	1.61	0.24
		medhigh				0.02	0.43	0.005	0.15	1.47	
		deadOM				-0.02	-0.28	0.040	0.08	1.27	
		forb				-0.01	-0.17	0.250	0.03	1.53	
		season				0.35	0.16	0.241	0.03	1.21	
BN	1	age	14.57	0.00	0.13	0.08	0.84	<0.001	0.53	1.35	0.50
		medhigh				0.01	0.22	0.050	0.07	1.26	
		deadOM				-0.02	-0.29	0.009	0.13	1.18	
		season				-0.31	-0.15	0.136	0.04	1.12	

Table 3.8 (continued).

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
BN	2	age	14.61	0.04	0.12	0.08	0.81	<0.001	0.51	1.31	0.49
		medhigh				0.01	0.19	0.086	0.06	1.22	
		deadOM				-0.01	-0.24	0.022	0.10	1.08	
	3	age	14.99	0.42	0.10	0.08	0.89	<0.001	0.52	1.61	0.50
		medhigh				0.01	0.26	0.030	0.09	1.47	
		deadOM				-0.01	-0.26	0.021	0.10	1.27	
		forb				0.01	0.12	0.325	0.02	1.53	
		season				-0.37	-0.18	0.089	0.06	1.21	
	4	age	15.27	0.70	0.09	0.07	0.73	<0.001	0.49	1.07	0.47
		deadOM				-0.01	-0.23	0.031	0.09	1.07	
	5	age	15.96	1.38	0.06	0.08	0.83	<0.001	0.49	1.50	0.48
		medhigh				0.01	0.21	0.076	0.06	1.38	
		deadOM				-0.01	-0.22	0.047	0.08	1.22	
		forb				0.00	0.06	0.602	0.01	1.41	
	6	age	15.96	1.39	0.06	0.06	0.68	<0.001	0.42	1.30	0.48
		canopy				0.46	0.13	0.273	0.02	1.36	
		deadOM				-0.01	-0.22	0.041	0.08	1.14	
	7	age	16.00	1.43	0.06	0.06	0.68	<0.001	0.43	1.30	0.49
		canopy				0.60	0.17	0.166	0.04	1.45	
		deadOM				-0.01	-0.27	0.018	0.11	1.30	
		season				-0.28	-0.14	0.185	0.04	1.16	
	8	age	16.07	1.50	0.06	0.08	0.83	<0.001	0.41	2.24	0.51
		medhigh				0.01	0.19	0.151	0.04	1.90	
		canopy				0.48	0.13	0.373	0.02	2.33	
		deadOM				-0.01	-0.23	0.043	0.08	1.36	
		forb				0.01	0.18	0.164	0.04	1.71	
		season				-0.39	-0.20	0.076	0.07	1.30	
	9	age	16.14	1.56	0.06	0.07	0.74	<0.001	0.50	1.09	0.47
		deadOM				-0.01	-0.26	0.017	0.11	1.17	
		season				-0.24	-0.12	0.254	0.03	1.09	

Table 3.8 (continued).

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
BN	10	age	16.32	1.74	0.05	0.07	0.80	<0.001	0.39	2.19	0.50
		medhigh				0.01	0.16	0.223	0.03	1.85	
		canopy				0.25	0.07	0.635	0.00	2.11	
		deadOM				-0.01	-0.27	0.021	0.11	1.30	
		season				-0.30	-0.15	0.162	0.04	1.17	
	11	age	16.45	1.88	0.05	0.08	0.83	<0.001	0.52	1.39	0.50
		medhigh				0.01	0.22	0.048	0.08	1.31	
		midstem				0.00	-0.04	0.692	0.00	1.14	
		deadOM				-0.02	-0.28	0.013	0.12	1.23	
		season				-0.31	-0.16	0.137	0.04	1.12	
	12	age	16.46	1.89	0.05	0.06	0.69	<0.001	0.44	1.31	0.50
		canopy				0.85	0.23	0.080	0.06	1.81	
		deadOM				-0.01	-0.25	0.034	0.09	1.35	
		forb				0.01	0.15	0.244	0.03	1.66	
		season				-0.36	-0.18	0.244	0.05	1.29	
	13	age	16.52	1.95	0.05	0.08	0.80	<0.001	0.50	1.35	0.48
		medhigh				0.01	0.20	0.082	0.06	1.27	
		midstem				0.00	-0.04	0.723	0.00	1.14	
		deadOM				-0.01	-0.23	0.031	0.09	1.13	
	14	age	16.54	1.97	0.05	0.07	0.79	<0.001	0.37	2.18	0.49
		medhigh				0.01	0.15	0.259	0.03	1.84	
		canopy				0.13	0.03	0.807	0.00	2.05	
		deadOM				-0.01	-0.21	0.050	0.08	1.15	
TN	1	age	-53.90	0.00	0.33	0.09	0.97	<0.001	0.83	1.50	0.86
		medhigh				0.00	0.11	0.076	0.06	1.38	
		deadOM				0.01	0.17	0.004	0.15	1.22	
		forb				0.01	0.16	0.009	0.13	1.41	
	2	age	-52.48	1.42	0.16	0.08	0.91	<0.001	0.84	1.14	0.85
		deadOM				0.01	0.16	0.006	0.14	1.22	
		forb				0.01	0.13	0.033	0.09	1.25	

Table 3.8 (continued).

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
TN	3	age	-52.09	1.81	0.13	0.09	0.96	<0.001	0.82	1.57	0.86
		medhigh				0.01	0.11	0.072	0.06	1.40	
		midstem				0.00	-0.02	0.678	0.00	1.17	
		deadOM				0.01	0.17	0.004	0.16	1.25	
		forb				0.01	0.16	0.012	0.12	1.44	
	4	age	-52.05	1.85	0.13	0.08	0.89	<0.001	0.82	1.31	0.86
		canopy				0.29	0.08	0.235	0.03	1.60	
		deadOM				0.01	0.16	0.010	0.13	1.26	
		forb				0.01	0.16	0.017	0.11	1.50	
	5	age	-52.03	1.87	0.13	0.09	0.95	<0.001	0.76	2.22	0.86
		medhigh				0.00	0.09	0.187	0.04	1.87	
		canopy				0.09	0.03	0.737	0.00	2.19	
		deadOM				0.01	0.16	0.007	0.14	1.27	
		forb				0.01	0.17	0.011	0.13	1.53	
	6	age	-51.92	1.99	0.12	0.09	0.97	<0.001	0.82	1.61	0.86
		medhigh				0.00	0.11	0.084	0.06	1.47	
		deadOM				0.01	0.17	0.005	0.15	1.27	
		forb				0.01	0.17	0.012	0.12	1.53	
		season				-0.01	-0.01	0.908	0.00	1.21	

[a]CN, GN, SN, BN, and TN = relative abundance of cavity nesting, ground nesting, shrub nesting, branch nesting, and twig nesting bird species, respectively, in a 0.79-ha plot during a 10-min point count survey.

Table 3.8 (continued).

[b]Age = number of years since restoration activities were initiated, medhigh = percent vertical cover (1.0 – 1.5 m), measured using a profile board, deadOM = percent cover of dead organic matter in 1-m^2 plot, season = 1 (March – April), = 2 (May – June) or = 3 (July – August), forb = percent cover of forbs in 1-m^2 plot, midstem = number of midstory trees (<11.4 cm DBH and >1.4 m tall) in 0.01-ha plot, and canopy = percent canopy closure.

[c]VIF = variance inflation factor; VIF >10 suggests multicollinearity (Belsley et al. 1980).

Table 3.9. Habitat models developed using Akaike's Information Criteria (AIC) for bird feeding guilds in Tennessee hardwood bottomlands, March – August 2008.

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
AF	1	medhigh	160.62	0.00	0.19	-0.05	-0.36	0.007	0.13	1.00	0.13
	2	medhigh	161.07	0.44	0.15	-0.05	-0.37	0.006	0.14	1.00	0.12
		deadOM				-0.02	-0.15	0.241	0.03	1.00	
	3	medhigh	161.07	0.44	0.15	-0.05	-0.39	0.004	0.15	1.04	0.12
		deadOM				-0.03	-0.21	0.140	0.04	1.20	
		forb				-0.03	-0.14	0.315	0.02	1.23	
	4	medhigh	161.94	1.32	0.10	-0.05	-0.35	0.008	0.13	1.01	0.12
		deadOM				-0.03	-0.19	0.167	0.04	1.07	
		season				-0.78	-0.13	0.323	0.02	1.09	
	5	medhigh	162.18	1.55	0.09	-0.05	-0.35	0.010	0.12	1.01	0.10
		season				-0.50	-0.08	0.516	0.01	1.01	
	6	medhigh	162.33	1.71	0.08	-0.05	-0.34	0.016	0.11	1.08	0.10
		canopy				-0.77	-0.07	0.600	0.01	1.08	
	7	medhigh	162.42	1.79	0.08	-0.05	-0.37	0.007	0.13	1.03	0.10
		forb				-0.01	-0.06	0.664	0.00	1.03	
	8	medhigh	162.45	1.82	0.08	-0.05	-0.34	0.013	0.11	1.08	0.10
		midstem				0.00	-0.05	0.691	0.11	1.08	
	9	age	162.55	1.92	0.07	-0.01	-0.04	0.784	0.00	1.22	0.10
		medhigh				-0.05	-0.37	0.011	0.12	1.22	
BF	1	age	-94.42	0.00	0.31	0.06	1.10	<0.001	0.76	2.22	0.81
		medhigh				0.01	0.23	0.007	0.14	1.85	
		canopy				-0.35	-0.16	0.067	0.07	2.15	
		forb				0.01	0.13	0.075	0.06	1.38	

Table 3.9 (continued).

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
BF	2	age	-93.15	1.28	0.17	0.06	1.10	<0.001	0.76	2.22	0.81
		medhigh				0.01	0.24	0.006	0.15	1.87	
		canopy				-0.37	-0.17	0.055	0.07	2.19	
		deadOM				0.00	0.05	0.425	0.01	1.27	
		forb				0.01	0.15	0.054	0.08	1.53	
	3	age	-92.88	1.54	0.15	0.06	1.08	<0.001	0.74	2.18	0.80
		medhigh				0.01	0.22	0.012	0.12	1.83	
		canopy				-0.46	-0.22	0.015	0.11	1.93	
	4	age	-92.68	1.74	0.13	0.05	1.00	<0.001	0.77	1.48	0.79
		medhigh				0.00	0.16	0.031	0.09	1.37	
		forb				0.01	0.16	0.022	0.10	1.25	
	5	age	-92.59	1.83	0.13	0.06	1.10	<0.001	0.76	2.24	0.81
		medhigh				0.01	0.24	0.007	0.14	1.88	
		canopy				-0.34	-0.16	0.089	0.06	2.24	
		forb				0.01	0.14	0.076	0.06	1.64	
		season				-0.03	-0.03	0.701	0.00	1.22	
	6	age	-92.47	1.95	0.12	0.06	1.09	<0.001	0.74	2.36	0.81
		medhigh				0.01	0.23	0.007	0.14	1.85	
		midstem				0.00	-0.01	0.828	0.00	1.17	
		canopy				-0.35	-0.16	0.077	0.06	2.19	
		forb				0.01	0.13	0.087	0.06	1.42	
CF	1	age	135.38	0.00	0.35	0.19	0.70	<0.001	0.41	1.31	0.42
		medhigh				0.06	0.49	<0.001	0.26	1.22	
		deadOM				-0.05	-0.35	0.002	0.17	1.08	
	2	age	136.42	1.04	0.21	0.20	0.73	<0.001	0.40	1.50	0.41
		medhigh				0.07	0.52	<0.001	0.26	1.38	
		deadOM				-0.05	-0.32	0.007	0.14	1.22	
		forb				0.02	0.09	0.480	0.01	1.41	

Table 3.9 (continued).

Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	Bird Metric[a]
						Un-standardized	Standardized				
CF	3	age	136.66	1.28	0.18	0.18	0.68	<0.001	0.39	1.35	0.42
		medhigh				0.07	0.51	<0.001	0.27	1.27	
		midstem				0.00	-0.10	0.388	0.01	1.14	
		deadOM				-0.05	-0.33	0.004	0.15	1.13	
	4	age	137.22	1.85	0.14	0.18	0.67	<0.001	0.27	2.18	0.40
		medhigh				0.06	0.45	0.003	0.16	1.84	
		canopy				0.59	0.06	0.710	0.00	2.05	
		deadOM				-0.05	-0.33	0.005	0.15	1.15	
	5	age	137.36	1.99	0.13	0.19	0.70	<0.001	0.40	1.35	0.41
		medhigh				0.06	0.49	<0.001	0.26	1.26	
		deadOM				-0.05	-0.35	0.003	0.16	1.18	
		season				-0.02	0.00	0.976	0.00	1.12	
GF	1	medhigh	89.86	0.00	0.19	0.03	0.42	0.002	0.19	1.18	0.31
		midstem				0.00	-0.24	0.053	0.08	1.12	
		canopy				-3.13	-0.51	0.001	0.22	1.47	
		deadOM				-0.02	-0.18	0.160	0.04	1.29	
		forb				-0.03	-0.25	0.078	0.06	1.51	
	2	medhigh	90.11	0.24	0.17	0.03	0.45	0.001	0.21	1.15	0.29
		midstem				0.00	-0.26	0.039	0.08	1.10	
		canopy				-3.35	-0.55	<0.001	0.24	1.42	
		forb				-0.02	-0.19	0.161	0.04	1.38	
	3	medhigh	90.29	0.43	0.15	0.03	0.44	0.001	0.20	1.15	0.28
		midstem				0.00	-0.24	0.058	0.07	1.09	
		canopy				-2.76	-0.45	0.001	0.22	1.08	
	4	age	90.58	0.71	0.13	-0.03	-0.19	0.292	0.02	2.36	0.31
		medhigh				0.02	0.31	0.050	0.08	1.88	
		midstem				0.00	-0.27	0.034	0.09	1.19	
		canopy				-2.49	-0.41	0.021	0.11	2.22	
		deadOM				-0.02	-0.18	0.171	0.04	1.29	
		forb				-0.03	-0.28	0.058	0.07	1.55	

Table 3.9 (continued).

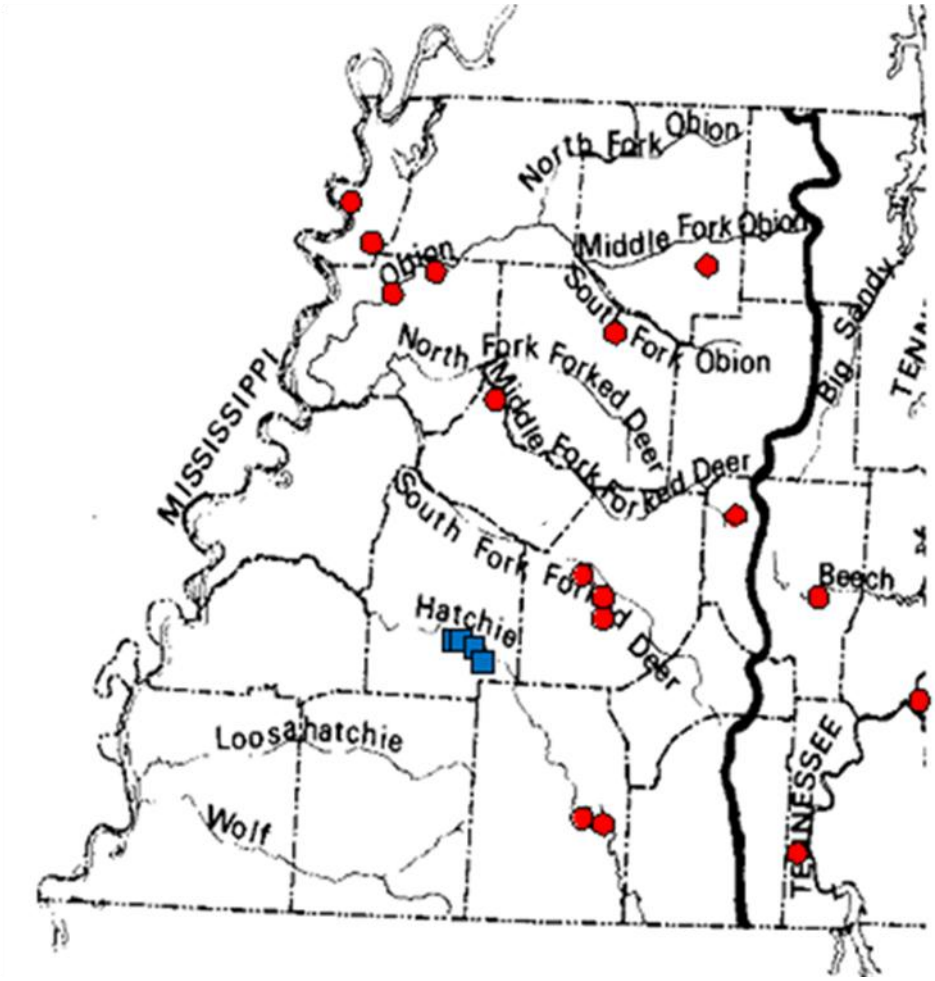
Bird Metric[a]	Candidate Model	Variable[b]	AIC	ΔAIC	w_i	Estimates		*P*-value	Partial R^2	VIF[c]	$R^2_{Adjusted}$
						Un-standardized	Standardized				
GF	5	age	90.75	0.89	0.12	-0.03	-0.20	0.275	0.02	2.36	0.30
		medhigh				0.03	0.34	0.035	0.09	1.85	
		midstem				0.00	-0.29	0.024	0.10	1.17	
		canopy				-2.67	-0.44	0.014	0.12	2.19	
		forb				-0.03	-0.22	0.117	0.05	1.42	
	6	medhigh	91.39	1.53	0.09	0.03	0.42	0.002	0.19	1.18	0.28
		midstem				0.00	-0.22	0.079	0.06	1.11	
		canopy				-2.51	-0.41	0.003	0.17	1.23	
		deadOM				-0.01	-0.11	0.369	0.02	1.17	
	7	age	91.55	1.68	0.08	-0.02	-0.15	0.413	0.01	2.29	0.27
		medhigh				0.03	0.36	0.026	0.10	1.84	
		midstem				0.00	-0.26	0.044	0.08	1.14	
		canopy				-2.20	-0.36	0.036	0.09	2.01	
	8	medhigh	91.85	1.98	0.07	0.03	0.42	0.002	0.19	1.19	0.29
		midstem				0.00	-0.24	0.055	0.08	1.12	
		canopy				-3.09	-0.50	0.002	0.19	1.68	
		deadOM				-0.02	-0.19	0.168	0.04	1.37	
		forb				-0.03	-0.25	0.104	0.06	1.67	
		season				-0.05	-0.02	0.903	0.00	1.29	

[a]AF, BF, CF, and GF = relative abundance of air feeding, bark feeding, canopy feeding, and ground feeding bird species, respectively, in a 0.79-ha plot during a 10-min point count survey.

Table 3.9 (continued).

[b]Age = number of years since restoration activities were initiated, medhigh = percent vertical cover (1.0 – 1.5 m), measured using a profile board, deadOM = percent cover of dead organic matter in 1-m^2 plot, season = 1 (March – April), = 2 (May – June) or = 3 (July – August), forb = percent cover of forbs in 1-m^2 plot, midstem = number of midstory trees (<11.4 cm DBH and >1.4 m tall) in 0.01-ha plot, and canopy = percent canopy closure.

[c]VIF = variance inflation factor; VIF >10 suggests multicollinearity (Belsley et al. 1980).



Restoration sites

Reference sites

Figure 2.1. Seventeen bottomland restoration and 4 bottomland reference sites sampled in western Tennessee, March – August 2008.

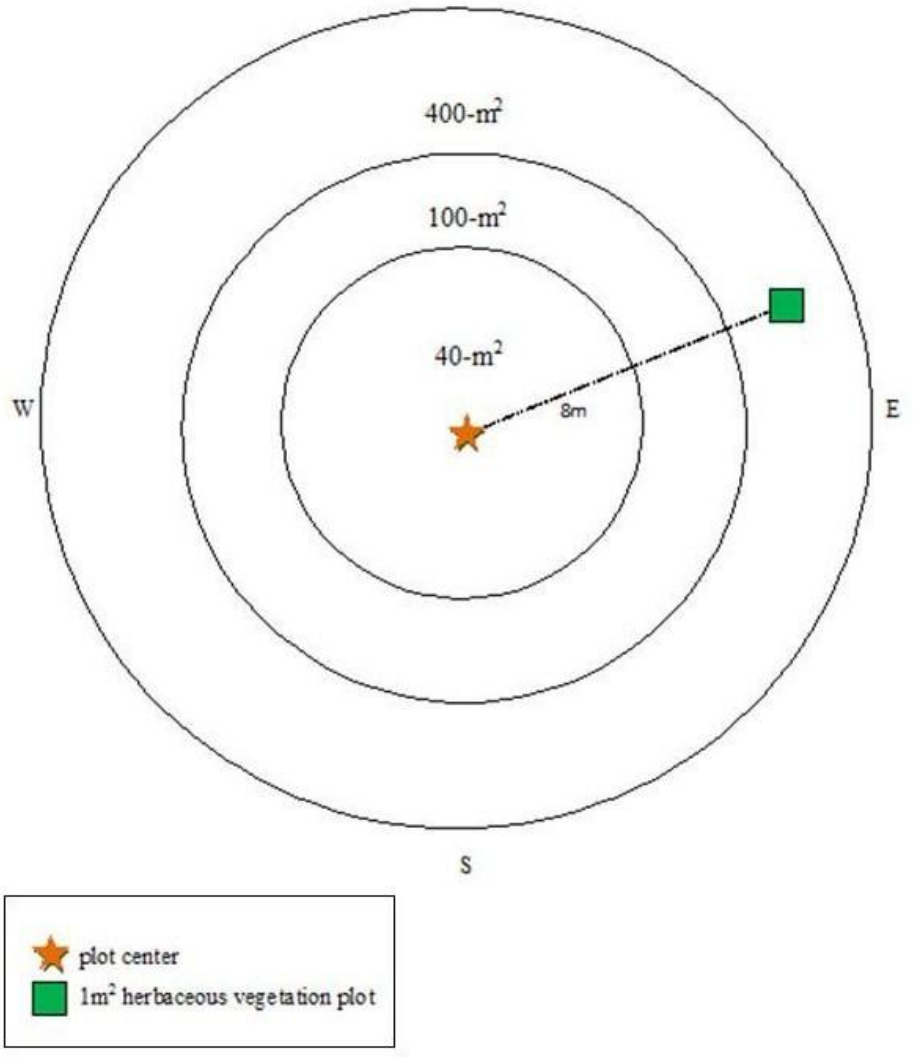


Figure 2.2. Schematic of plot placement for sampling herbaceous vegetation and concentric understory (40-m^2), midstory (100-m^2) and overstory (400-m^2) sampling plots, Tennessee, 2008.

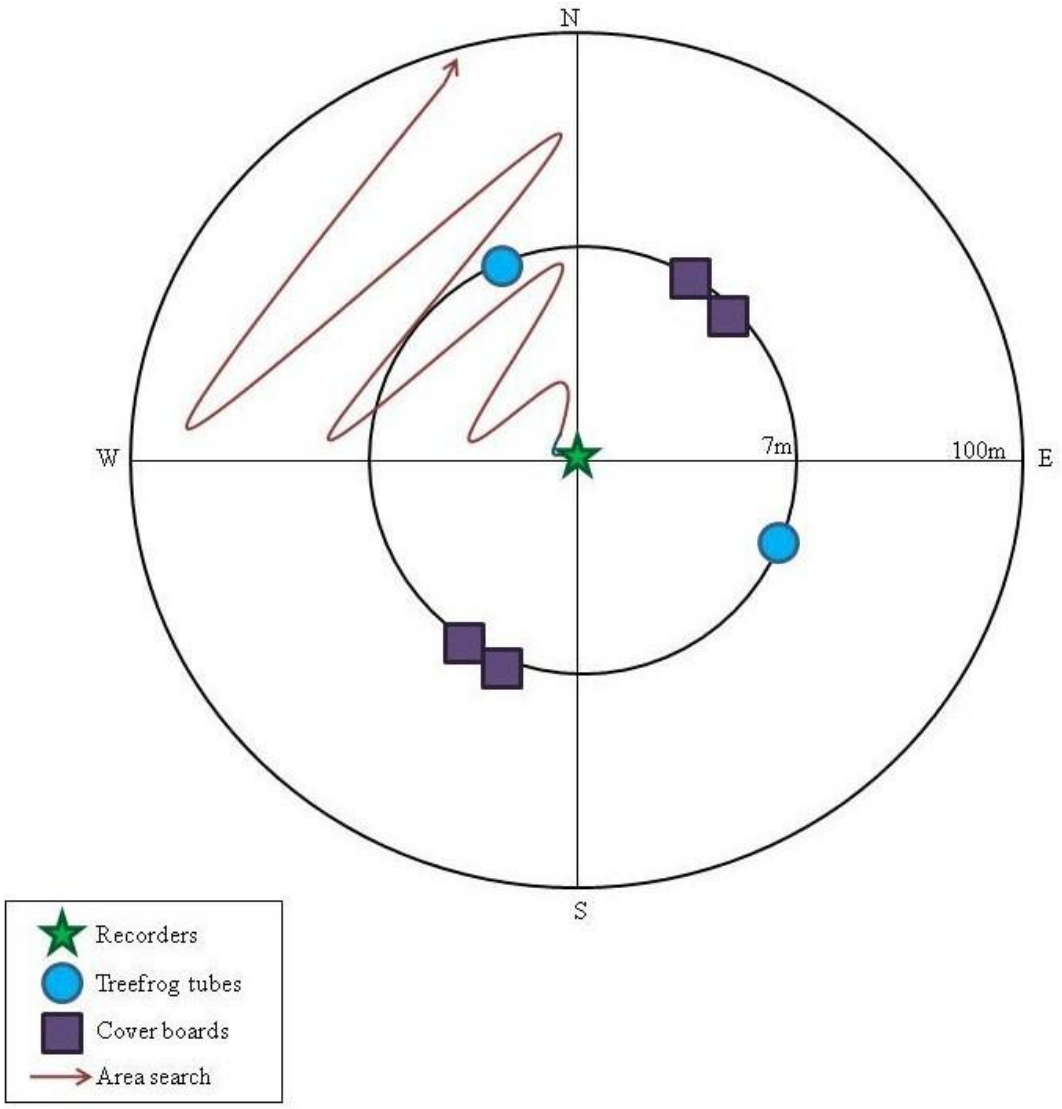


Figure 2.3. Schematic for location of call recorders, treefrog tubes, coverboards, and area searches at bottomland restoration and reference sampling plots, Tennessee, 2008.

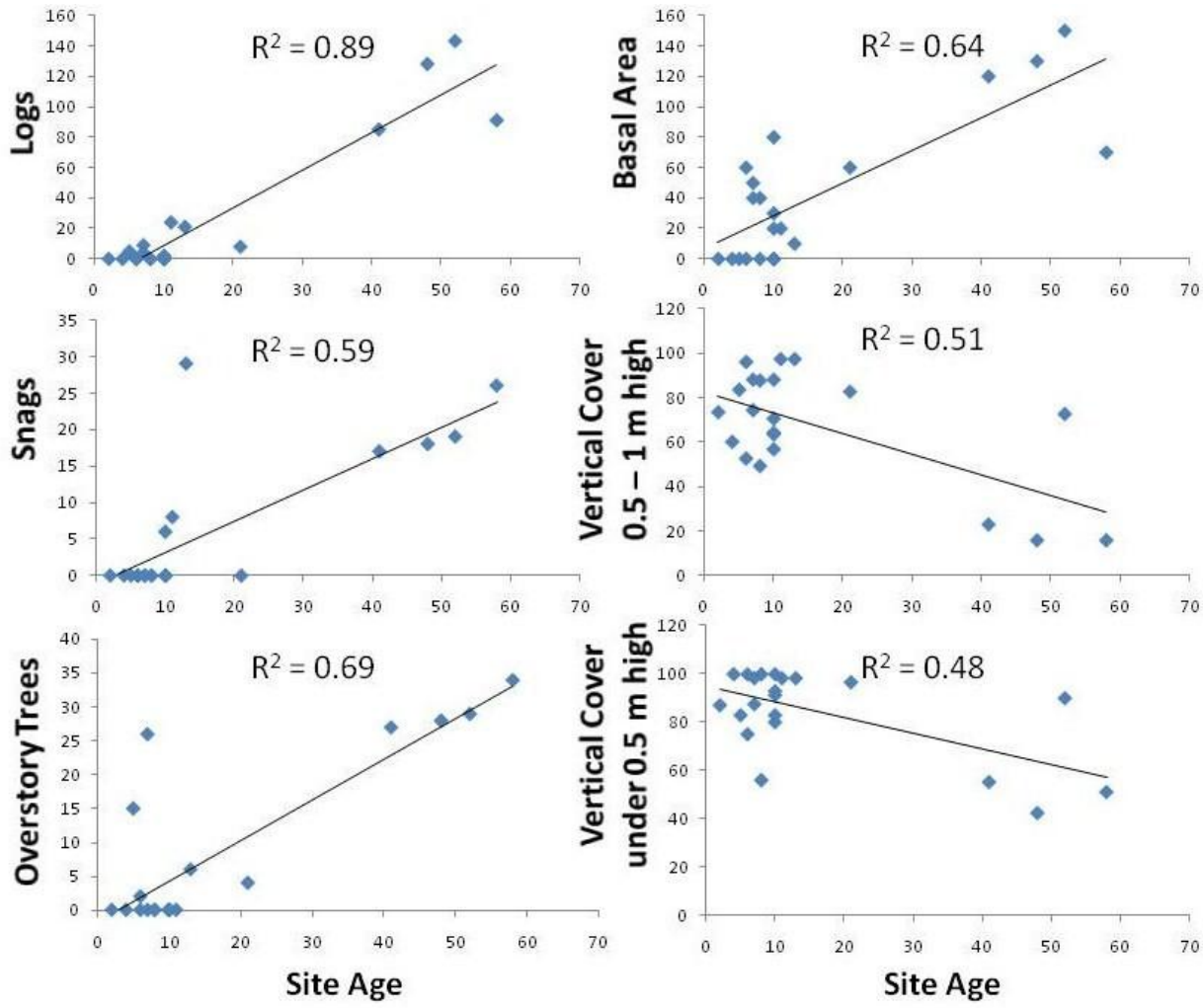


Figure 2.4. Relationship between site age and vegetation metrics for index of biotic integrity (IBI) models at bottomland restoration and reference sampling plots, Tennessee, 2008. Site age = number of years since restoration activities were initiated, logs = number of logs (>11.4-cm dia) in 3.14-ha (100-m radius) plot, snags = number of snags (>11.4 cm DBH) in 3.14-ha plot, overstory trees = number of overstory trees (>11.4 cm DBH) in 0.04-ha plot, basal area = basal area of all woody plants measured with a 10-basal-area-factor prism, and vertical cover 0.5 – 1 m high and vertical cover under 0.5 m high = % vertical cover (0.5 – 1 m and 0 – 0.5 m above ground level, respectively) measured using a profile board.

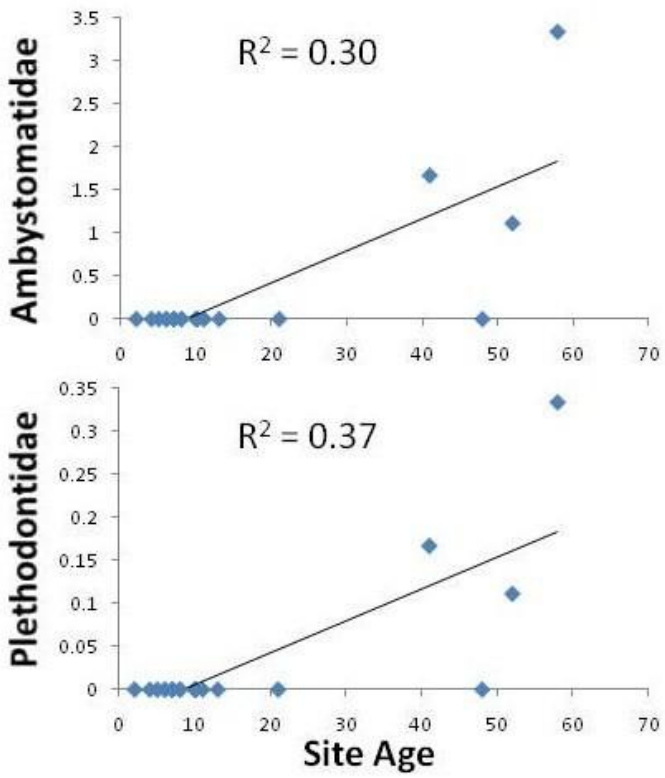


Figure 2.5. Relationship between site age and amphibian metrics for index of biotic integrity (IBI) models at bottomland restoration and reference sampling plots, Tennessee, 2008. Site age = number of years since restoration activities were initiated, and Ambystomatidae and Plethodontidae = relative abundance of Ambystomatidae, and Plethodontidae species, respectively; surveyed using a combination of 3.14-ha searches and coverboards.

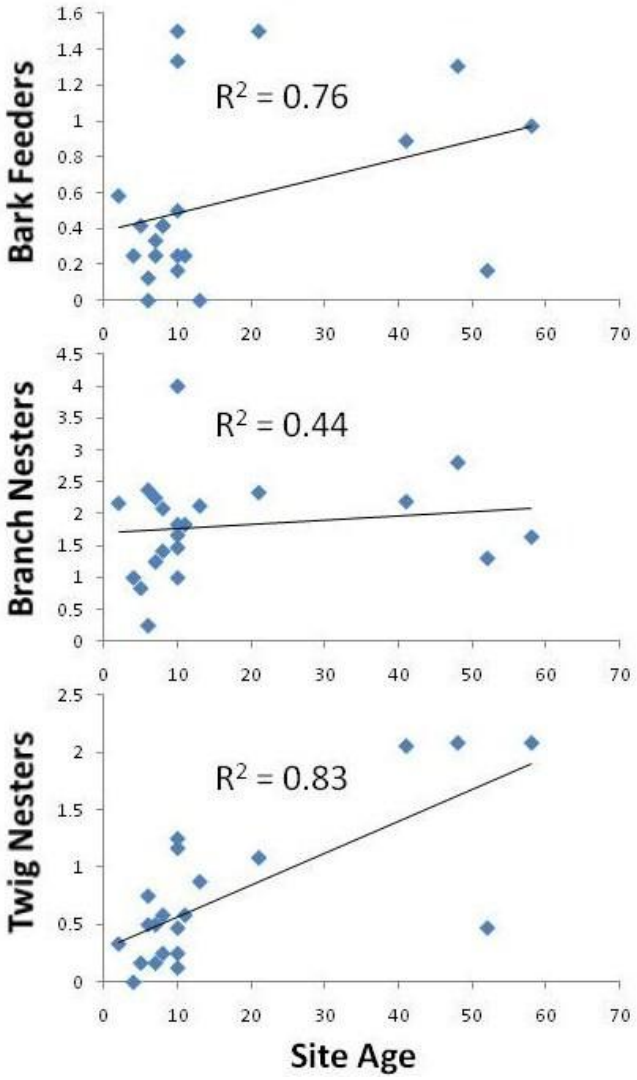


Figure 2.6. Relationship between site age and bird metrics for index of biotic integrity (IBI) models at bottomland restoration and reference sampling plots, Tennessee, 2008. Site age = number of years since restoration activities were initiated, and bark feeders, branch nesters and twig nesters = relative abundance of bark feeding, branch nesting and twig nesting bird species, respectively, in a 0.79-ha plot during a 10-min point count survey.

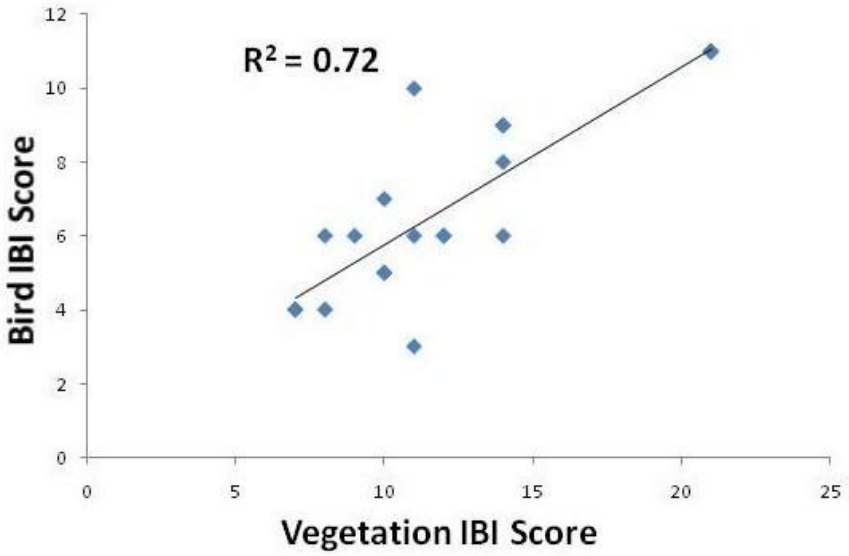


Figure 2.7. Relationship between index of biotic integrity (IBI) scores for bird and vegetation metrics at bottomland restoration and reference sampling plots, Tennessee, 2008.

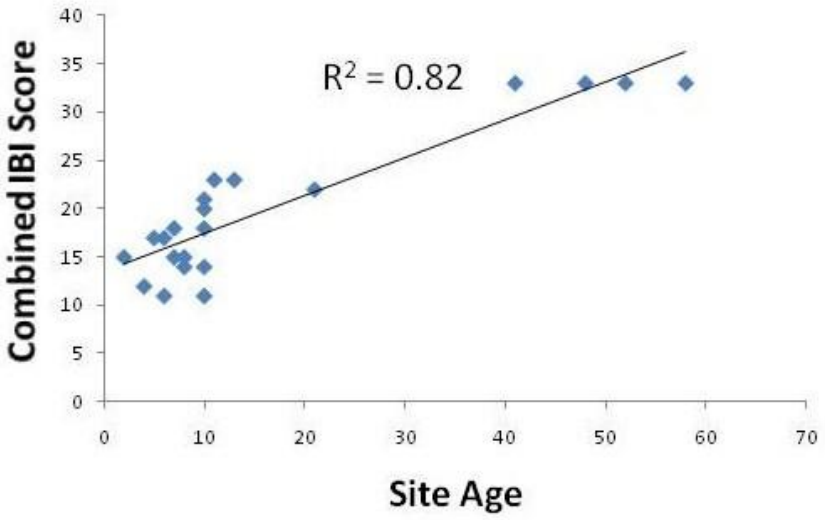


Figure 2.8. Relationship between site age and combined index of biotic integrity (IBI) scores for vegetation, amphibians and birds at bottomland restoration and reference sampling plots, Tennessee, 2008. Site age = number of years since restoration activities were initiated.

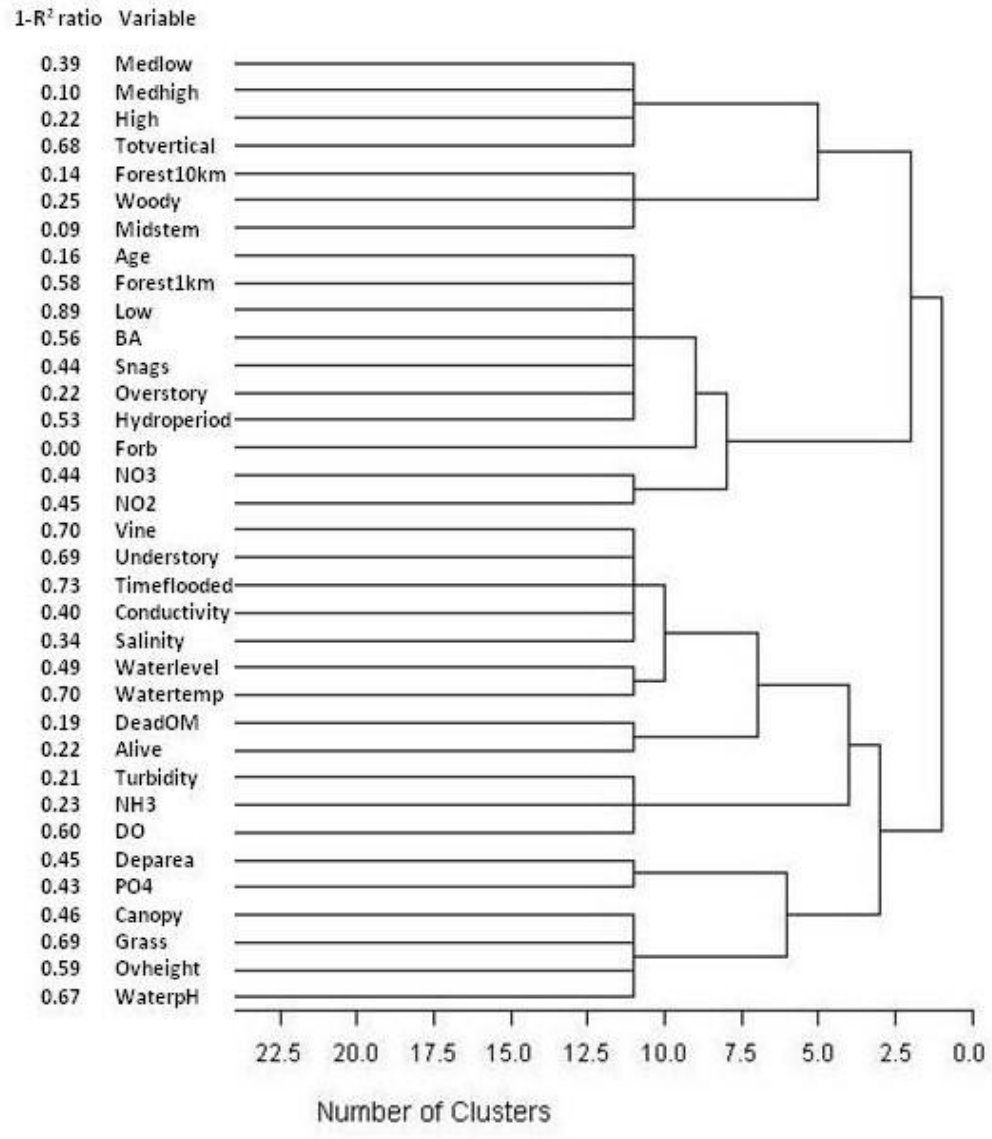


Figure 3.1. Results of cluster analysis on 35 vegetation and biotic variables, Tennessee, 2008. Medlow, medhigh, high and totvertical = percent vertical cover of vegetation at 0.5 – 1.0, 1.0 – 1.5 and 0 – 2 m aboveground, respectively, measured using a profile board, forest10km = percent forested land within10-km radius of site center, woody = percent cover of woody plants in 1-m^2 plot, midstem = number of midstory trees (<11.4 cm DBH and >1.4 m tall) in 0.01-ha plot, age = number of years since restoration activities were initiated, forest1km = percent forested land within 1-km radius of site center,

Figure 3.1 (continued).

low = percent vertical cover of vegetation at 0.0 – 0.5 m aboveground, BA = basal area of overstory trees measured using a 10-BAF prism, snags = number of snags (>11.4 cm DBH) in 3.14-ha plot, overstory = number of overstory trees (>11.4 cm DBH) in 0.04-ha plot, hydroperiod = mean length (days) of flood events from 4/2007 – 7/2009, forb = percent cover of forbs in 1-m^2 plot, NO_3 = water NO_3 (ppm), NO_2 = water NO_2 (ppm), vine = percent cover of vines in 1-m^2 plot, understory = number of understory trees (<1.4 m tall) in 0.004-ha plot, timeflooded = percent of time water was aboveground, conductivity = water conductivity (µS/cm), salinity = water salinity (ppm), waterlevel = water depth (in), watertemp = water temperature (°C), deadOM = percent cover of dead organic matter in 1-m^2 plot, alive = percent cover live vegetation in 1-m^2 plot, turbidity = water turbidity (Formazin Turbidity Units), NH_3 = water NH_3 (ppm), DO = water dissolved oxygen (ppm), deparea = total area (m^2) of depressions capable of holding water in 3.14-ha plot, PO_4 = water PO_4 (ppm), canopy = percent canopy closure, grass = percent cover of grass in 1-m^2 plot, ovheight = height of the nearest overstory tree to plot center (m), and waterpH = water pH.

VITA

Beth Summers was born in Green Bay, Wisconsin to Dorothy and Jeff Summers. She attended Henry S. Baird Elementary and continued to Edison Middle School and Preble High School. She majored in Wildlife Ecology and received a Bachelor of Science in International Agriculture and Natural Resources from the University of Wisconsin, Madison. She spent a semester abroad in Sydney, Australia, where she worked with the Australian National Parks and Wildlife Service. She continued her work as a wildlife research technician for Point Reyes Bird Observatory, SWCA Environmental Consultants, Clemson University, UW Madison, Chapman University and the Joseph W. Jones Ecological Research Center. She accepted a graduate research assistantship at the University of Tennessee, Knoxville, where she received her Master of Science in Wildlife and Fisheries Science in August 2010.