SPECIES-HABITAT RELATIONSHIPS FOR THE BREEDING BIRDS OF A LONGLEAF PINE ECOSYSTEM

by

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ABSTRACT

At the Fort Bragg Military Installation, an army base in North Carolina, the habitat associations for the breeding bird species and the effects of the current prescribed fire program on the avifauna are virtually unknown. Fort Bragg encompasses one of the largest, fire-dependent longleaf pine systems existing today and is a mosaic of forested habitats. I used bird count data collected during 1994-1997 at 50-m fixed radius point count stations to examine bird species-habitat relationships in relation to fire treatment (i.e., fire intense longleaf pine woodlands versus fire suppressed mixed pine-hardwood and hardwood forests) and a riparian-upland habitat gradient, and at multiple spatial scales (i.e., the microhabitat and landscape). I used two-way factorial analyses to test for the effects of fire treatment and the riparian-upland habitat gradient on total bird abundance, species richness, and species relative abundance. To examine species-habitat associations at multiple spatial scales, I measured vegetation characteristics at a 50-m radius microhabitat scale, and I quantified landscape structural attributes at a 300-m to 1500-m radius landscape scale using a GIS database and the spatial analysis program FRAGSTATS. I then used logistic regression to determine which microhabitat and landscape variables were associated with the probability of occurrence for each species and which spatial scale was of greater relative importance to a species' occurrence. Finally, I tested logistic regression (LR) models and multiple linear regression (MLR) models, specific to the microhabitat scale, with independent data to evaluate their usefulness at predicting the occurrence and relative abundance for several breeding bird species.

Total bird abundance did not vary across fire treatment and species richness may be only slightly greater in fire suppressed habitats, even though this habitat offered greater structural complexity than the park-like longleaf pine, fire intense habitats. Both total bird abundance and species richness were highest within the riparian habitat of streamhead pocosins, which offered distinctive vegetative characteristics otherwise lacking in this landscape. The fire treatment and riparian-upland habitat gradient also were greatly associated with the relative abundance of many species. Four bird species assemblages were defined based on the relative abundance patterns across fire treatments and the riparian-upland gradient: longleaf pine, fire suppressed, drain (i.e., riparian habitat), and generalist assemblages. Continued longleaf pine restoration using growing season prescribed fire likely will cause a decline in species of the fire suppressed assemblage in mixed pine-hardwood and hardwood forests, including many Neotropical migrant songbirds, but will greatly benefit members of the longleaf pine assemblage, such as the Red-cockaded Woodpecker, Brown-headed Nuthatch, Prairie Warbler, and Bachman's Sparrow.

Breeding bird distributions in this fire-influenced, forest-dominated system were associated with attributes at both microhabitat and landscape spatial scales, though microhabitat attributes generally were of greater importance for the occurrence of most species. Microhabitat variation associated with the fire management gradient (intensely burned habitat versus fire suppressed habitat) and the riparian-upland gradient were the most frequent predictors in the species-habitat models. These results are similar to other studies documenting that microhabitat features were more influential than landscape features for birds in a naturally patchy or forest-dominated landscape.

The microhabitat LR (probability of occurrence) models performed best in presence/absence classification when tested with the same data used for model development (cross-validation tests), and the LR and MLR (relative abundance) models performed better for an independent two-year data set compared to an independent one-year data set (validation tests). Although most MLR models were not significantly biased when tested with an independent two-year data set, these models had relatively low precision, suggesting they can be used to predict species relative abundance across a large area but they may not be sensitive to changes in abundance at individual count stations. These model validation results suggest that modeling species occurrence, rather than both occurrence and relative abundance, would have been sufficient to describe general species-habitat associations and to produce reliable, predictive models sensitive to changes in microhabitat structure and composition.

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CHAPTER 1

BIRD-HABITAT RELATIONSHIPS IN A LONGLEAF PINE ECOSYSTEM

INTRODUCTION

Since 1966, the Breeding Bird Survey (BBS) administered by the U.S. Fish and Wildlife Service and Canadian Wildlife Service has documented avian population trends across most of the U.S. and southern Canada (Robbins et al. 1993). Growing evidence from BBS data suggests decreasing population trends for many resident and migratory species (James et al. 1992; Sauer and Droege 1992; Robbins et al. 1993; Peterjohn et al. 1995). Concern for the future persistence for many avian species is justified because of the extensive threats to populations across their breeding, migratory, and wintering habitats, such as habitat loss, nest predation, and brood parasitism (Askins 1993). Habitat fragmentation and destruction are often cited as the most serious threats contributing to many species' declines (Whitcomb et al. 1981; Wilcove et al. 1986; Askins et al. 1992; Sherry and Holmes 1993; Robinson and Wilcove 1994). Many threats to birds are related to changes in land use patterns; hence, biologists seek to understand how habitat changes and loss will affect avian communities.

It is often assumed that there is a relationship between a species' distribution or abundance and the associated habitat characteristics. Although this correlative relationship between observed patterns may be misleading (Wiens 1989), Rotenberry (1981) concludes that quantitative measurement of the habitat is essential to comprehending "patterns of life history, adaptation, and evolution of any species." For a land manager, species-habitat associations are important in developing management plans for targeted species and predicting the effects of land use or single species management on non-target species.

At the Fort Bragg Military Installation, an army base located in North Carolina, the habitat associations for bird species within the predominant habitat types are virtually unknown. The Fort Bragg area represents one of the largest remnant longleaf pine (*Pinus palustris* Miller) systems existing today and natural resource managers on the base use prescribed burns during the growing season to manage for this fire-adapted system. There are a few bird species that are strongly associated with longleaf pine, such as the federally endangered Red-cockaded Woodpecker (*Picoides borealis*) and the threatened Bachman's Sparrow (*Aimophila aestivalis*) (Ware et al. 1993). In 1989, the U.S. Fish and Wildlife Service mandated a growing season burning policy for Fort Bragg mimicking the natural fire regimen of longleaf pine to protect habitat for the Red-cockaded Woodpecker (Cantrell et al. 1995). Since optimum fire frequency for longleaf pine has been estimated at one to three years (Ware et al. 1993), one third of the approximately 40,000-forested hectares on the base is burned every year resulting in a three-year burn rotation.

Due to the lack of information about the importance of longleaf pine and associated habitats to birds generally, and the unknown effects of burning on the avifauna, a five year study was initiated in 1994 with the following goals:

(1) determine the abundance and habitat associations of breeding and wintering species in the predominant habitats on Fort Bragg,
(2) determine the effect of fire on species abundance, richness and productivity of breeding birds, especially in longleaf pine,
(3) develop species-habitat models to predict bird abundance, and
(4) test the predictive capabilities of habitat predictors of species abundance in selected habitats (Collazo and Walters 1994).

THE LONGLEAF PINE ECOSYSTEM

The longleaf pine forest once dominated the Atlantic coastal plain from Virginia south to Florida and the Gulf coastal plain from Florida west to Texas, and extended into the piedmont of the southeastern United States and the mountains of north Alabama and northwest Georgia (Stout and Marion 1993; Ware et al. 1993; Landers et al. 1995). Before European settlement, this forest covered over 92 million acres (Frost 1993) but current estimates of remnant areas total less than 3 million acres (Landers et al. 1995). This forest was arguably one of the largest ecosystems in North America and probably dominated the southeastern United States for the last 5000 years (Watts 1980; Landers et al. 1995). Since European settlement, it has shrunk to less than 3% of its historical range (Ware et al. 1993). The longleaf pine ecosystem is a mosaic of forests, woodlands, and savannas, and its diverse ground cover ranks this ecosystem as one of the most specious plant communities in the temperate zone (Peet and Allard 1993). With modern-day extensive habitat loss and degradation, 187 vascular plant taxa and several vertebrate species (e.g., Red-cockaded Woodpecker, Bachman's Sparrow, Henslow's Sparrow *Ammodramus henslowii*, Gopher Tortoise *Gopherus polyphemus*, Indigo Snake *Drymarchon corais couperi*, and Southeastern Fox Squirrel *Sciurus niger*) have become increasingly rare, threatened or endangered (Walker 1993; Engstrom et al. 1996).

Longleaf pine forests began declining in the 1600's due to conversion to agricultural and developed lands, seedling consumption by hogs and cattle, logging, the naval store industry (i.e., production of tar, pitch, rosin and turpentine), fire suppression, and conversion to southern pine plantations (Ware et al. 1993). Beginning in the 1920's, fire suppression became the general policy of government agencies, further impacting much of the remaining longleaf pine forests. Only recently has fire been recognized as a natural disturbance important in maintaining natural systems, and therefore been incorporated more often into management plans (White and Pickett 1985; Frost et al. 1986). Without extensive growing season fires every few years, longleaf pine may be outcompeted by hardwood species, such that longleaf forests succeed to hardwood communities. Even where longleaf pine remains dominant in the canopy, lack of fire results in the development of a hardwood midstory. The dynamics of fire can therefore greatly influence habitat structure, and habitat structure is generally known to be an important factor in the distribution of birds and species diversity (e.g., Rotenberry and

Wiens 1980).

Fire historically played a major role in maintaining the open, park-like longleaf pine ecosystem. Before European settlement, lightning strikes during the growing season were the main progenitors of fire, with a one to three year estimated frequency in pyroclimax regions and five to ten years in partially fire-protected areas (Ware et al. 1993). Native Americans were another source of fire in the Southeast, employing fire in hunting and agricultural practices, and this probably contributed to maintaining the park-like landscapes (Hammett 1992; Ware et al. 1993). In addition, the longleaf pine is fire-dependent for regeneration and may aid in maintaining itself by converting lightning strikes quickly into ground fires (Platt et al. 1988). For example, resin-soaked longleaf snags provide ignition sources and may burn for days or weeks, increasing the chances of starting a wildfire, and the longleaf pine needles are shed more frequently than many other pines, adding to the fuel load (Platt et al. 1988). The fire-adapted bunch grasses associated with the longleaf pine ecosystem also add dead biomass to the fuel load and aid in quickly spreading ground fires.

The importance of fire to the maintenance of the longleaf pine ecosystem is increasingly accepted and understood. Prescribed burning is now the main ecological management tool for the conservation and restoration of longleaf pine ecosystems. Still, continued work on understanding the processes supporting this ecosystem and factors threatening it is needed. For example, many remaining longleaf pine forests may be aging without sufficient replacement (Landers et al. 1995; Brockway and Lewis 1997), possibly caused by shorter rotation timber practices (Jackson 1988).

AVIAN COMMUNITIES IN A LONGLEAF PINE ECOSYSTEM

Many studies have documented how fire events influence avian communities by changing vegetative structure or composition (e.g., Raphael et al. 1987; Herkert 1994; Stribling and Barron 1995; Van't Hul et al. 1997; Woinarski and Recher 1997). Single fire events may immediately affect the reproduction and distribution of some bird species but may not always cause long-term changes. Fire history (i.e., periodic natural fire disturbances or suppression of them) can affect the long-term composition and dynamics of bird communities through changes in available foraging, nesting, and cover habitat. Only a few individuals have studied the effects of fire management on the avifauna in a longleaf pine ecosystem (e.g., Engstrom et al. 1996; Krieger 1997) even though prescribed burning is now commonly used for the management and restoration of this ecosystem.

Since fire suppression was a common practice in the last century and contributed to the decline of longleaf pine forests, the current avifauna of the Southeast, including Fort Bragg, may be remarkably different than before European settlement (Jackson 1988). The current three-year burning policy at Fort Bragg may cause longleaf pine forests to become more abundant and fire suppressed habitats (e.g., mixed pine-hardwood stands) to decline; thus these vegetative changes may result in changes in the avifauna.

An understanding of the current species-habitat relationships for the birds indicative of longleaf pine and fire suppression habitats is necessary to predict long-term changes in avian community patterns due to fire management. Hence, research was initiated in 1994 to study species-habitat relationships and the abundance and productivity of breeding bird species in fire-maintained longleaf pine stands and fire suppressed mixed pine-hardwood or hardwood dominated stands. Krieger (1997) presents the results of an initial two-year study on species abundance and breeding productivity in fire maintained and suppressed habitats at Fort Bragg. In addition, the study design allowed for comparison of bird abundance patterns along a riparian-upland gradient. Vegetation characterizing streamhead pocosins (i.e., drains) is different in structure and floristics from the surrounding habitat and was hypothesized to be an important component determining species composition and abundance.

In this work, I expand on Krieger's research on species-habitat relationships in these two fire treatments and along the riparian-upland gradient (herein referred to as location effects). In Chapter 2, I use two independent data sets, the first spanning four years (1994-97) and the second one spanning one year (1996), to examine the effects of fire treatment and location on bird species relative abundance, species richness, and total bird abundance. I also delineate species assemblage groups based on these results. In Chapter 2, I examine bird-habitat associations at the microhabitat scale, i.e., within the home range area of an individual bird. Though this level of habitat association is important, the distribution and abundance of many species may also be influenced at macrohabitat levels such as the landscape, as shown by many avian studies (Lynch and Whigham 1984; Freemark and Merriam 1986; Loyn 1987; Rolstad 1991; Pearson 1993; Andren 1994; McGarigal and McComb 1995). Hence in Chapter 3, I examine whether a microhabitat or landscape scale is most associated with the distributions of the breeding bird species. In Chapter 4, I test the predictive ability of species-habitat models specific to the microhabitat scale to evaluate their usefulness in guiding land management decisions.

The results of this study hopefully will provide (1) an improved understanding of the breeding bird-habitat relationships of the longleaf pine forests at Fort Bragg, (2) information on how fire may impact the bird community by changing forest structure and floristic composition, and (3) guidance for Fort Bragg personnel in determining how management actions may alter bird communities for this longleaf pine ecosystem and its associated avifauna.

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CHAPTER 2

ASSOCIATIONS OF BREEDING BIRDS WITH FIRE-INFLUENCED AND RIPARIAN-UPLAND HABITATS IN A LONGLEAF PINE ECOSYSTEM

INTRODUCTION

The pyroclimax longleaf pine (*Pinus palustris* Miller) ecosystem once dominated much of the southeastern United States and included a mosaic of longleaf pine savannas and woodlands, mixed pine and hardwood forests, and bottomland hardwood forests (Croker 1979; Ware et al. 1993; Landers et al. 1995; Brockway and Lewis 1997). This mosaic shifted both temporally and spatially due to soil moisture gradients and frequency of fire (Frost et al. 1986). Native vegetation types were relatively undisturbed until European settlement. Degradation of this ecosystem was mainly caused by open range hogs and cattle, settlement clearings, naval stores and timber production, fire suppression policies, and after World War II, conversion to other southern pine plantations (slash pine *Pinus elliottii* Engelm. and loblolly pine *Pinus taeda* L.) (Croker 1979; Frost 1993; Landers et al. 1995). These factors quickly led to the decline of the longleaf pine, with remaining stands composing less than 3% of the original acreage (Frost 1993; Ware et al. 1993).

Beginning in the 1930's, a few biologists (e.g., Herman H. Chapman and Herbert L. Stoddard) began recommending the planned use of fire as a forestry management tool for the regeneration of longleaf pine and its associated communities (Croker 1979). Without regular fires, understory plant species richness and ground cover biomass decreases, a hardwood midstory develops, and the longleaf pine is unable to regenerate and compete with the more aggressive southern pine and hardwood species (Brockway and Lewis 1997). Only recently has fire been recognized as a natural disturbance important in maintaining natural systems. Thus active prescribed fire programs have been incorporated more often into management plans (White and Pickett 1985; Frost et al. 1986).

Although the longleaf pine ecosystem and its inhabitants have become increasingly threatened, few studies have been conducted on the avian community associated with the longleaf pine habitats or the influence of fire thereon (Engstrom 1993). However, Engstrom et al. (1984) studied the effects of 15 years of fire exclusion on the vegetation and birds in an oldfield loblolly and shortleaf pine stand in Florida. They reported the disappearance of open habitat bird species (e.g., Bachman's Sparrow and Blue Grosbeak; Scientific names of birds in Appendix I) after only five years of fire exclusion and as a subcanopy developed, species associated with mesic woods appeared (e.g., Yellow-billed Cuckoo, Wood Thrush, and Red-eyed Vireo). Repenning and Labisky (1985) conducted a study of the effects of timber management on avian communities in Florida and found that breeding bird density and species richness were higher in longleaf pine stands than in 1 to 40 year old slash pine plantations. Hirth et al.

(1991) documented seasonal avian community dynamics of a Florida longleaf stand to establish reference data for longleaf avifauna. Yet the communities observed may not have been representative of the fire-maintained longleaf ecosystem since a hardwood midstory existed from 17 years of fire suppression. Engstrom et al. (1996) studied the effects of dormant versus lightning (i.e. growing) season prescribed fires on the avifauna of longleaf pine forests in Florida. They reported preliminary evidence that growing season fire does not reduce survival or productivity of breeding bird species, including the ground-nesting Bachman's Sparrow. Recently, Engstrom (*in prep*) studied the avian community of an old-growth longleaf pine forest, the Wade Tract in Georgia, and found breeding bird species richness was as high or higher than in southeastern hardwood forests that had much greater tree species richness and foliage height diversity. However, since many extant longleaf pine forests are second- or third-growth, not old-growth, and pine forests are typically thought to have lower bird species richness than hardwood forests, it is unknown whether breeding bird species richness in most longleaf pine forests could be greater than in vertically diverse, fire suppressed, mixed pine-hardwood stands.

Engstrom et al. (1996) constitutes the only known published work (but see Krieger 1997) regarding fire influence on the longleaf pine avian community, even though studies of other ecosystems have previously documented that fire events or suppression can have various effects on species abundance, composition, and richness (Theberge 1976; Johnson and Landers 1982; Stanton 1986; Raphael et al. 1987; Fitzgerald and Tanner 1992; Herkert 1994; Stribling and Barron 1995). Within recent years, prescribed burning has become a common conservation tool for the longleaf pine, especially with federal mandates to protect and enhance critical habitat for the endangered Red-cockaded Woodpecker (U.S. Fish and Wildlife Service 2000). Because of the unknown effects of these management practices on non-target species, researchers throughout the Southeast are focusing on the influence of fire on faunal (e.g., Brennan et al. 1995; Engstrom et al. 1996) and floral communities (e.g., Brockway and Lewis 1997).

In addition to the effects of fire, the influence of a riparian-upland gradient on the longleaf pine avian assemblages is unknown. For systems where riparian areas offer distinctive vegetation structure, species richness, species relative abundance, and total bird abundance are often higher, and the bird assemblages often different, in riparian compared to upland habitats (Stauffer and Best 1980; Szaro 1980; Emmerich and Vohs 1982; Doyle 1990; Thurmond et al. 1995). This riparian effect does not always occur where less contrast between riparian and upland habitats exists (McGarigal and McComb 1992; Murray and Stauffer 1995). For open longleaf pine forests, riparian areas often provide distinct habitats and as such, may influence avian species distribution and abundance.

The objective of this study was to determine the influence of fire treatment and the riparian-upland gradient on breeding bird assemblages within the Fort Bragg Military Installation in North Carolina, one of the largest remnant longleaf pine ecosystems existing today. Natural resource managers have regularly used growing season prescribed burns since 1989 without information on how this management practice may affect the associated bird species. Hence in 1994, a study began to assess the breeding

bird assemblages in two fire treatments, fire intense and fire suppressed, at three distances from riparian zones of streamhead pocosins (i.e., drains), 0 m, 75 m, and ≥150 m. The fire intense treatment is represented by areas historically burned and possibly mechanically thinned. Structurally, it is an open savanna or woodland lacking a midstory component but with a diverse understory and herbaceous cover. Fire suppressed areas are those areas historically lacking growing season fires, and they are typified by having a well-developed midstory of mixed pine and hardwood species, and sometimes a hardwood component in the overstory. Riparian vegetation of drains provides vertical structural and floristic diversity within the structurally simplistic longleaf pine stands.

One unique aspect of this project is that all analyses are performed for two independent data sets with the same comparative study design. Although independent studies are desirable because it is often unknown how much spatio-temporal variation affects the results of a single study, the opportunity to conduct them rarely exists because of limited funding and time. For this study, I analyzed two independent data sets, enabling me to describe consistent patterns. I compared species richness, total bird abundance, bird species abundance, and vegetational characteristics for both data sets by fire treatment and for three riparian-upland locations. Based on the observed bird abundance patterns, I delineated species assemblages that are associated with certain habitat types. In addition, I examined whether observer differences and annual variation may have affected the estimated bird metrics.

STUDY AREA DESCRIPTION

The Fort Bragg Military Installation is located in the Sandhills physiographic region of North Carolina and encompasses 63,143 hectares, with approximately 40,000 hectares forested (Cantrell et al. 1995). The Sandhills is characterized by flat-topped sandy ridges formed by ocean deposits, and broad flat valleys that were created by deposition of sand, clay, and gravel from waterways flowing from the piedmont. Many natural resource activities, such as wildlife and endangered species management, hunting and fishing, prescribed burning, timber harvesting, and pine straw raking, are coordinated with military use of the land on Fort Bragg. By the establishment of Fort Bragg in 1917, most of the longleaf pine had been cut and now mostly second- and third-growth stands exist on the base. Current timber management guidelines on Fort Bragg call for harvest rotations of 120 years for longleaf pine and 100 years for other pines (Cantrell et al. 1995; Carter et al. 1995). Dormant season burns were conducted by the Natural Resources Branch in the forested area on a 5-year rotation prior to 1989 and wildfires periodically occurred during all seasons (Cantrell et al. 1995). Since 1989, Fort Bragg has adopted a three-year growing season rotation for prescribed burns to enhance and conserve this longleaf pine ecosystem.

Due to varying fire frequency, timber history, and soil types, Fort Bragg is a heterogeneous landscape of upland pine, successional communities of mixed pine-hardwood and hardwood stands, and seeps and streamhead pocosins (i.e., drains). Unique features interspersed in the forest area are parachute drop zones (i.e., early

successional fields), artillery-impact areas, wildlife food plots, and fire-breaks approximately every two-tenths of a mile running east to west.

Most fire intense sites are classified as longleaf pine/scrub oak sandhills or xeric sandhill scrub (Schafale and Weakley 1990) or as fall-line xeric and subxeric longleaf pine woodlands (Peet and Allard 1993). These sites currently experience periodic growing season burns. Longleaf pine dominates the canopy, and there is virtually no vertical structural diversity. The ground layer is highly diverse and dominated by wiregrass (*Aristida stricta* Michaux) and a patchy shrub layer of scrub oaks (e.g., post oak *Quercus stellata* Wang., turkey oak *Q. laevis* Walter, blackjack oak *Q. marilandica* Muenchh., and bluejack oak *Q. incana* Bartram), huckleberry (*Gaylussacia spp.*), poison oak (*Rhus toxicodendron* L.), persimmon (*Diospyros virginiana* L.) and sassafras (*Sassafras albidum* Nees).

Fire suppressed sites have lacked periodic growing season fires, though dormant season burns may have occurred. These sites can be described as xeric sandhill scrub, dry oak-hickory forest, and bottomland hardwood communities (Schafale and Weakley 1990). Their canopies are dominated by longleaf pine and/or loblolly pine and hardwoods, and these sites have a hardwood midstory, low wiregrass abundance, and low ground cover diversity. Common species in addition to those found in fire intense sites are black oak (*Q. velutina* Lam.), southern red oak (*Q. falcata* Michaux), hickory (*Carya spp.*) and sweetgum (*Liquidambar styraciflua* L.).

The streamhead pocosin community (Schafale and Weakley 1990) along drains is a feature common to both fire intense and suppressed stands. Its associated vegetation is generally more speciose and dense than the nearby upland habitats. The tree species mentioned above are often augmented by blackgum (*Nyssa sylvatica* Marshall), water tupelo (*Nyssa aquatica* L.), red maple (*Acer rubrum* L.), and pond pine (*Pinus serotina* Michaux). The understory and midstory are diverse with the following species relatively common: American holly (*Ilex opaca* Aiton), gallberry (*Ilex glaba* Gray), sweetbay (*Magnolia virginiana* L.), sweetleaf (*Symplocos tinctoria* L'Her.), waxmyrtle (*Myrica cerifera* L.), bayberry (*Myrica heterophylla* Raf.), redbay (*Persea borbonia* Sprengel), staggerbush (*Lyonia mariana* D. Don), poison sumac (*Rhus vernix* L.), and titi (*Cyrilla racemiflora* L.).

STUDY SITE SELECTION

The breeding bird assemblages were sampled by 50-m fixed-radius point counts at permanent stations (Hutto et al. 1986). All count stations were positioned in areas classified as either fire intense or fire suppressed, and at one of three distances (herein termed location) from a drain: drain (0 m), intermediate (75 m), and upland (≥150 m). All count stations were ≥200 m apart for sampling independence, and were ≥200 m from the following edges to reduce possible edge effects: forest community ecotones, paved roads, parachute drop zones, and fields. For the first data set, Krieger (1997) selected 65 points for count stations in 1994 based on fire history, timber stocking levels, military

activity, and presence of drains. Fire history was determined from 1978 onward with documentation provided by the Fort Bragg Natural Resources Office, and the latter three criteria and current vegetation conditions were determined by field inspections.

In 1996, I established 156 additional count stations for the second data set. In selecting potential sampling sites by fire treatment and location, every effort was made to choose habitat types similar to what was sampled by Krieger (1997). However, fire suppressed sites selected by Krieger (1997) represented a limited subset of the full gradient of fire suppressed habitat types. To have a sufficient sampling pool for fire suppressed sites, I expanded the habitat gradient included within the fire suppressed treatment. Although this decision introduced more habitat variation, all fire suppressed sites still were characterized by a well-developed pine-hardwood midstory, extensive canopy closure, and low ground flora diversity.

I selected potential study sites for this second data set (n=156) with the aid of a GIS database of structural wildlife habitat classifications based on dominant over- and mid-story tree species and basal areas. This GIS was developed by Fort Bragg personnel using Forest Inventory Stand data and it has a 10 acre (4.05 hectare) minimum resolution (Schultz and Howell, pers. comm.). I verified the GIS-generated map by visiting potential sites in March and April of 1996. Field inspections were also necessary to assess military activity and vegetation conditions, and to verify presence of drains. Drains were excluded from this study if shrubby vegetation had been removed by a recent fire.

FIELD METHODS

Vegetation Sampling

I collected vegetation structure and floristics data from four subplots at each count station based on the sampling protocol of BBIRD (Martin 1994). The first subplot was centered on the count station and the second subplot was 30 m away at a random azimuth. The third and fourth subplots were 120 degrees in opposite directions from the previous azimuth and 30 m from the first subplot center. Each subplot consisted of nested 5-m and 11.3-m radius plots. Within the 5-m radius plots, I measured shrubs, saplings, litter depth and ground cover characteristics. Saplings were defined as any tree species having a diameter of less than 8 cm for the main stem (or trunk), and tree species were defined as large woody plants having one (or a few) supporting trunk and potentially reaching heights greater than 20 feet (Petrides 1986). Shrubs were distinguished from trees (and saplings) as those woody plants that generally will be smaller than a tree and will consist of a number of small stems originating from or near the ground (Petrides 1986). I quantified shrub and sapling species ≥50 cm above ground by counting number of stems, and I counted stems separately if they branched at <10 cm above the ground. I delineated two shrub diameter size classes, <2.5 cm and >2.5 cm, measured at 10 cm above the ground, and two sapling diameter size classes, <2.5 cm and 2.5-8 cm. I measured organic litter depth at twelve points, spaced 2 m apart, along two

10-m long transects that intersected and were centered within each 5-m radius plot. I defined ground cover as all stems ≤50 cm tall and quantified the following variables: % green cover, % grass cover, % shrub cover, % forb cover, % fern cover, % leaf litter, % downed logs, % bare ground and % water. I also estimated canopy cover (%) and height (m), aspect, and slope for each subplot. Within each 11.3-m radius plot, I tallied the number of trees >8 cm diameter at breast height (dbh) by species and three size classes: >8-23, >23-38, and >38 cm dbh. Breast height for measuring tree diameter was 1.4 m. Also, I counted the number of snags >12 cm dbh and taller than 1.4 m.

Bird Counts

During the breeding seasons of 1994 through 1997, I used a 50-m fixed-radius point count method to census the avifauna at each permanent count station (Hutto et al. 1986). I marked trees at 25 m and 50 m from each point count center to aid in distance estimation. I conducted counts from April 19th to June 6th in 1994 and from the beginning of May to mid-June in 1995 through 1997. I recorded the birds detected within the 50-m count circle by sight and sound for 10 minutes during 0545 to 1000 in the morning. I excluded observations recorded as fly-overs (i.e., birds flying over the canopy and not stopping within the 50-m radius). I conducted three such counts at each station in 1994, 1995 and 1997 and two surveys in 1996 to allow more stations to be sampled in 1996. For each survey, I varied the observer, order, and time of counts to minimize systematic detection biases. In addition, I trained observers in bird identification skills and distance estimation for three to four weeks prior to the first survey in 1996 and 1997.

ANALYTICAL METHODS

Two independent data sets containing bird count and vegetation data were subjected to statistical analyses. The vegetation data for the first data set were collected in 1994 and the bird data were collected over a 4 year period, 1994-1997; hence, this data set will be referred to as 4-YR. The second data set will be referred to as 1-YR since the vegetation and bird data represent only one breeding season, 1996. I only used bird observations within a 50-m radius of each count station for all analyses. Unless otherwise noted, I performed all analyses with the statistical package SAS (SAS Institute 1996). Since most of the bird count and vegetation data failed to meet the assumptions of normality and homogeneity of variances, I used non-parametric statistical tests for the analyses described below. I used the general linear models (GLM) procedure on ranked values for factorial analyses since most data were unbalanced (i.e., unequal sample sizes) and were not from a normal distribution (Zar 1999). I then employed Bonferroni multiple comparison procedures (MCPs) when necessary to control the experiment-wise error rate. I used an alpha level of 0.05 to determine statistical significance. Before any multivariate analyses were conducted, one outlier from the 1-YR data set was removed.

Vegetation

Since many variables (>200) could have been generated with the numerous vegetation features measured (e.g., shrub, sapling, and tree data were recorded by species and diameter size class), I reduced this data set to 29 variables representing both structural and floristic attributes of the ground cover, under-, mid-, and overstory. I used nine variables, litter depth and cover percentages for the categories green, grass, shrub, forb, fern, downed logs, leaf litter, and bare ground, to characterize ground cover attributes. I retained most ground cover variables because the diverse ground cover is a well-known trait of the longleaf pine ecosystem, and Engstrom (1993) estimated that 36% of the characteristic bird species forage on or near the ground. I also retained the variables percent slope, canopy cover, canopy height, and number of snags ≥12 cm dbh. To characterize the under-, mid-, and overstory structure, I pooled the shrub, sapling, and tree species data into these seven composite variables: number of shrubs <2.5 cm, number of shrubs >2.5 cm, number of saplings <2.5 cm, number of saplings >2.5-8 cm, number of trees 8-23 cm dbh, number of trees >23-38 cm dbh, and number of trees >38 cm dbh. To reflect major floristic differences in the mid- and overstory species composition, I combined the tree and sapling species data into six additional composite variables: number of longleaf pine saplings, number of other pine saplings, number of other species saplings, number of longleaf pine trees, number of other pine trees, and number of other species trees. I then created three species richness variables: shrub, sapling, and tree species richness.

To identify fire treatment and location effects on vegetation, I used a two-way factorial GLM procedure on ranked values for each of the 29 variables. I conducted multivariate analysis of variance (MANOVA) tests, using GLM procedures, to detect if the vegetation characteristics differed between the 4-YR and 1-YR data sets for each fire treatment and location combination. I also tested each variable in a one-way factorial GLM procedure to determine if individual variables differed across data sets.

For both the 4-YR and 1-YR data sets, I used PC-ORD (McCune and Mefford 1997) to perform a centered and standardized principal components analysis (PCA) using a correlation matrix (Gauch 1982) to summarize vegetation patterns based on the vegetation variables examined. Before these analyses, I tested each vegetation variable set for multicollinearity using Pearson's correlation coefficients between all variables. Correlations of ≥0.8 resulted in one variable from a pair being dropped so that each variable set was reduced to 26 vegetation variables. When possible, the harder variable to interpret or measure in the field was dropped. This resulted in the variables % shrub cover, other species (non-pine) saplings, and other species trees being dropped from the 4-YR data set and the variables % shrub cover, shrubs <2.5 cm, and other species saplings being dropped from the 1-YR data set.

Species Richness and Total Bird Abundance

I used all breeding bird observations counted within the 50-m radius point counts for these analyses. For each data set, I defined total bird abundance and species richness

as the number of individuals or species, respectively, observed per count station averaged across surveys and years. To test for differences in species richness and total bird abundance, I used three-way factorial tests with year, fire treatment, and location for the 4-YR data set and two-way factorial tests with fire treatment and location for the 1-YR data set. All factorial tests were performed by a GLM procedure on ranked values and Bonferroni MCPs were performed for location categories when a significant effect was found.

Relative Species Abundance

I tested for fire treatment and location effects for 32 species with ≥20 detections in the 4-YR data set, and for 31 species with ≥10 detections in the 1-YR data set, thereby testing 34 different species. To test for fire treatment and location effects, I used two-way factorial GLM procedures on ranked values of relative abundance, defined for each species as the number of individuals observed per count station averaged across surveys and years.

Ordination of Bird Species Assemblages

For both the 4-YR and 1-YR data sets, I used canonical correspondence analysis (CCA) to describe the bird community composition and its relationship with the vegetation variables using the software package PC-ORD (McCune and Mefford 1997). CCA is a direct gradient analysis that extracts ordination axes of community variation. These ordination axes are restricted by being linear combinations of environmental variables, such that community variation is directly related to the environmental variation (Ter Braak 1986). In other words, ordination of the bird species matrix is performed by reciprocal averaging and this ordination is constrained by multiple linear regression on the vegetation variables.

Tests for multicollinearity in the vegetation variable set (see above) reduced the number of vegetation variables from 29 to 26 for each CCA. The variable set for the 4-YR and 1-YR CCA varied by one unique variable. For the CCA, axis scores were centered and standardized to unit variance and species scores were optimized for axis scaling. For each CCA, I included 31 bird species common to both the 4-YR and 1-YR data sets in sufficient numbers.

Since CCA can find relationships that do not exist biologically, I performed reciprocal averaging (RA) and detrended correspondence analysis (DCA) on the bird species matrix before I accepted the CCA ordination. These latter two techniques are pure ordination methods (i.e., ordination based only on community data and not restrained by environmental variables). The ordination of these two methods supported the findings of the CCA, so the RA and DCA results are not reported.

Annual and Observer Variation

For the 4-YR data set, I tested if the relative abundance index of 32 species varied annually with a Kruskal-Wallis procedure. For species with a significant year effect, Bonferroni MCPs were performed. Additionally, I tested whether relative abundance for seven species varied annually with location and treatment by using a 3-way factorial test with the GLM procedure on ranked values. Only the most commonly observed species were included in this analysis since testing species with a small number of detections might produce spurious results.

For testing observer variation, I compared observers within each year from 1994 to 1997 for two bird metrics, species richness and total bird abundance, since no observer conducted count surveys for all of these years. Species richness was defined as the number of species observed per count station per observer and total bird abundance was the number of individuals observed per count station per observer. For each year, differences in species richness and total birds between observers were tested with three-way factorial tests by a GLM procedure on ranked values to examine if observer effects and interactions of observer with treatment and location existed. When a significant observer effect was found, Bonferroni MCPs were performed.

RESULTS

Vegetation Characteristics

Appendix II lists the woody plant, fern, and select herbaceous species recorded for the vegetation sampled at the point count stations.

Fourteen vegetation variables for the 4-YR data set and 21 for the 1-YR data set had a significant fire treatment effect (Figure 1). In general, fire intense areas had a more open canopy, greater green cover on the ground with a larger percentage of grass, denser understory, a more open midstory, a more longleaf pine-dominated overstory, lower shrub, sapling, and tree species richness, and fewer snags than the fire suppressed areas. When compared to the fire intense treatment, suppressed areas had greater canopy closure, less percentage green cover on the ground, more large saplings and trees 8-23 cm dbh, a larger number of tree species other than longleaf, and higher woody plant species richness and number of snags.

Location effects were abundant with 20 significant variables in the 4-YR data and 25 in the 1-YR data (Figure 1). Significant differences were found for most of these variables with Bonferroni MCPs (Table 1) and most of these differences indicated a drain versus upland distinction. From the drain to upland habitats, the percentage of grass cover, bare ground, and the number of longleaf pine trees increased, and the following variables decreased: slope, canopy cover and height, litter depth, percentages of green, shrub, and fern cover, the number of shrubs and other pine and hardwood species, and shrub, sapling, and tree species richness.

Additionally, there were six variables with a significant treatment by location interaction effect in the 4-YR data set: slope, litter depth, shrubs <2.5 cm, saplings >2.5 cm, other pine species trees, and shrub species richness (Figure 1). In the 1-YR data set, fourteen variables exhibited significant interaction effects: slope, canopy cover, litter depth, shrub cover, leaf litter, shrubs <2.5 cm, shrubs 2.5-8 cm, trees 8-23 cm dbh, other pine species saplings, other pine species trees, other species trees, shrub species richness, sapling species richness, and tree species richness (Figure 1). Shrub cover (1-YR data), shrubs <2.5 cm, other pine species saplings (1-YR data), and shrub species richness were highest in fire intense drains. The number of shrubs 2.5-8 cm (1-YR data), other species trees (1-YR data), and tree species richness (1-YR data) were greatest in fire suppressed drains. The number of saplings 2.5-8 cm (4-YR data) was lowest in fire intense uplands. For canopy cover (1-YR data), litter depth, leaf litter (1-YR data), trees 8-23 cm dbh (1-YR data), other pine species trees, and sapling species richness (1-YR data), location effects were evident only in one treatment, namely the fire intense treatment. In the case of slope, a location effect was more evident in the fire suppressed treatment.

MANOVA revealed no significant differences using Wilk's Lambda test statistic between the vegetational characteristics of the two data sets for any treatment/location combination (Table 2). Although no overall differences were found, several variables significantly varied between data sets when compared with univariate one-way factorial tests (Table 2). The fire intense drain locations had the largest number of variables (11) that differed, and the fire suppressed upland location was the only category with no significant differences. Within each fire treatment, the drain locations had the most variables that differed and the upland had the least. Percentage of forbs in the ground layer was the only variable which differed for every category, except suppressed uplands.

Figures 2 and 3 show the ordination of the first two principal component axes derived from the PCA for the 4-YR and 1-YR data sets, respectively, and the position of the count stations within the vegetation structure space. Appendices III and IV contain the eigenvalues, variance accounted for by each PCA axis, and the eigenvectors of ordination scores per axis for each vegetation variable for the PCAs of both data sets. In both cases, the first principal component separates open pine forests from closed and speciose mixed pine-hardwood forests, reflecting primarily the drain to upland location gradient and to a lesser extent fire treatment effects. The second principal component further separates fire intense and fire suppressed sites for both the 4-YR and 1-YR data sets. The end result is a distinct separation of each fire treatment along a diagonal pattern somewhat correlated with the location gradient (Figures 2 and 3).

Species Richness and Total Bird Abundance

For the 4-YR data set, species richness and total bird abundance varied among years ($p=0.0009$ and $p=0.0001$ respectively) with 1995 having larger values according to Bonferroni MCPs (Figure 4A). There was no fire treatment effect on species richness and total bird abundance (Figure 4B), and no interactions between year, treatment, and/or

location. A location effect was detected for both of these metrics (p=0.0001) with drains having a larger value than the other locations (Figure 4C).

In the 1-YR data set, species richness (p=0.0357) varied between treatments with higher richness in fire suppressed areas (Figure 4B). Total bird abundance was not different between treatments. A location effect was detected for total bird abundance (p=0.0001) with drains having a larger value than the other locations (Figure 4C). For species richness, a location effect also existed (p=0.0001), and drains again had the largest value but richness decreased significantly at each step along the gradient from drain to intermediate to upland locations (Figure 4C). No interaction effect between treatment and location existed.

Relative Species Abundance

Ninety-one bird species were detected for unbounded point counts (i.e., no distance limitation) during the surveys from 1994-1997, with 79 of these species considered breeding season residents (Appendix I). The relative abundance values by fire treatment and by location for all species detected within a 50-m count radius are listed in Appendices V and VI respectively for both data sets. Mean values of relative abundance for the 4-YR data set were the average number of individuals observed per count station averaged across surveys and then years, and for the 1-YR data set was the average number of individuals observed per count station averaged across surveys.

For the 4-YR data set, 19 species had a significant fire treatment effect (Figure 5). The Mourning Dove, Red-cockaded Woodpecker, Red-headed Woodpecker, Eastern Wood Pewee, Brown-headed Nuthatch, Eastern Bluebird, White-eyed Vireo, Common Yellowthroat, Pine Warbler, Prairie Warbler, Bachman's Sparrow, and Chipping Sparrow were more abundant in fire intense areas. The Acadian Flycatcher, Tufted Titmouse, Blue-gray Gnatcatcher, Red-eyed Vireo, Black-and-white Warbler, Ovenbird and Northern Cardinal were more abundant in fire suppressed areas.

Nineteen species had a significant location effect for the 4-YR data with the majority (14 species) most abundant in drain locations (Figure 5). These species were the Great Crested Flycatcher, Acadian Flycatcher, Tufted Titmouse, Carolina Wren, Blue-gray Gnatcatcher, Red-eyed Vireo, White-eyed Vireo, Black-and-white Warbler, Common Yellowthroat, Hooded Warbler, Ovenbird, Yellow-throated Warbler, Northern Cardinal, and Eastern Towhee. The Red-cockaded Woodpecker, Brown-headed Nuthatch, Pine Warbler, and Chipping Sparrow were most abundant at the upland locations, and their relative abundance indices generally increased with increased distance from the drains. Only the Brown-headed Cowbird was most abundant at the intermediate locations.

Interactions between fire treatment and location occurred for five species in the 4-YR data set (Figure 5). In two cases, the location ordering of relative abundance values changed between fire treatments (Brown-headed Cowbird and Red-cockaded

Woodpecker). In the other cases, the location effect was much stronger in one treatment than the other (Common Yellowthroat, Carolina Wren and Eastern Towhee).

Eleven species exhibited a significant fire treatment effect in the 1-YR data set (Figure 5). Species more common in the fire intense treatment were the Red-cockaded Woodpecker, Brown-headed Nuthatch, Pine Warbler, Prairie Warbler, and Bachman's Sparrow. Species more abundant in fire suppressed areas were the Acadian Flycatcher, Wood Thrush, Red-eyed Vireo, Yellow-throated Vireo, Black-and-white Warbler, and Ovenbird.

In addition, 15 species had significant location effects in the 1-YR data set (Figure 5), 11 of which were more common in drains. These species were Tufted Titmouse, Carolina Wren, Wood Thrush, Blue-gray Gnatcatcher, White-eyed Vireo, Yellow-throated Vireo, Black-and-white Warbler, Common Yellowthroat, Hooded Warbler, Northern Cardinal, and Eastern Towhee. The Pine Warbler and Yellow-throated Warbler were most abundant at intermediate locations and the Red-cockaded Woodpecker and Chipping Sparrow were most abundant at upland locations.

For the 1-YR data, there were five species with a significant fire treatment by location interaction (Figure 5). In two cases, relative abundance values differed between treatments by orders of magnitude and the location effect was stronger in one treatment than the other (Red-cockaded Woodpecker and Wood Thrush), and in the other cases, the order of abundance among locations changed between treatments (Carolina Chickadee, Tufted Titmouse, and Black-and-white Warbler).

The data sets varied somewhat by species for significant fire treatment and/or location effects, but the species relative abundance patterns between the two data sets were similar (Tables 3 and 4). Only two out of 21 species, the Blue-gray Gnatcatcher and White-eyed Vireo, had opposite treatment effects in the two data sets (Table 3). Of 21 species with significant location effects, only three, the Great Crested Flycatcher, Pine Warbler, and Yellow-throated Warbler, were most abundant for different locations in the two data sets (Table 4).

Based on examining species relative abundance values across fire treatments and locations and the results of the statistical analyses for treatment and location effects, I classified many species into one of three bird assemblages (longleaf pine, fire suppressed, and drain assemblages) because three patterns of relative abundance were evident. A fourth group of species was defined as generalists. These species assemblages are listed in Table 5. For species that were more abundant in the fire intense sites, I defined these species as members of the longleaf pine assemblage. Seven species, Red-cockaded Woodpecker, Red-headed Woodpecker, Eastern Wood Pewee, Brown-headed Nuthatch, Pine Warbler, Chipping Sparrow and Bachman's Sparrow, are included in this assemblage. Several of these species were most common at fire intense uplands. The Prairie Warbler also was more common in fire intense areas, but tended to be more common in drains rather than uplands.

Seven species (Acadian Flycatcher, Red-eyed Vireo, Wood Thrush, Yellow-throated Vireo, Black-and-white Warbler, Ovenbird, and Tufted Titmouse) were more abundant in fire suppressed sites. Generally, these species are confined to drains in fire intense areas, but spread to other locations and become more abundant in fire suppressed areas. The Blue-gray Gnatcatcher also fits this description somewhat, but it occurs fairly commonly outside of drains even in fire intense areas.

Species reaching their highest abundance in drains and having a distribution virtually limited to drains, regardless of fire treatment, were classified into one assemblage termed the drain assemblage. These species are the Carolina Wren, White-eyed Vireo, Common Yellowthroat, Hooded Warbler, Northern Cardinal, and Eastern Towhee. Some of these species were most abundant in fire intense drains.

Several species were ubiquitous throughout the study area and their relative abundance values were not significantly impacted by fire treatment or location. These species are defined as generalists, and they are the Northern Flicker, Red-bellied Woodpecker, Blue Jay, Carolina Chickadee, and Summer Tanager. The Great Crested Flycatcher can be considered a generalist for similar reasons, even though a drain association was detected in the 4-YR data.

Several uncommon species (Mourning Dove, Eastern Bluebird, Yellow-throated Warbler, Brown-headed Cowbird, American Goldfinch, and Indigo Bunting) were not classified into any bird assemblage because no clear patterns could be ascertained with the insufficient number of observations obtained.

Ordination of Bird Species Assemblages (CCA)

For the 31 breeding bird species included in the CCA for both the 4-YR and 1-YR data sets, Figures 6 and 7 show their ordination along the first two axes. Appendices VII and VIII list the summary statistics for each ordination axis and the correlations of the axes with the species and vegetation variables. The four bird species assemblages described earlier (longleaf pine, fire suppressed, drain, and generalists) were largely supported by these analyses (Figures 6 and 7).

These CCAs directly link the previous results for vegetation and bird distribution patterns. The ordination results for the 4-YR and 1-YR data set are not identical, yet similar patterns can be described. The first axis separates the longleaf pine bird species assemblage from the other bird assemblages. The second axis separates the fire suppressed and drain assemblages from one another, and in the 1-YR data set, provides some separation within the longleaf pine species assemblage. The longleaf pine assemblage (Red-cockaded Woodpecker, Red-headed Woodpecker, Eastern Wood Pewee, Brown-headed Nuthatch, Pine Warbler, Prairie Warbler, Chipping Sparrow and Bachman's Sparrow) is positively associated with grass cover and the number of longleaf pine trees. The Prairie Warbler also shows an association with greater percent green cover in the ground layer. The fire suppressed bird species assemblage (Acadian

Flycatcher, Red-eyed Vireo, Wood Thrush, Yellow-throated Vireo, Black-and-white Warbler, Ovenbird, and Tufted Titmouse) is positively associated with tree species richness, canopy cover, and the number of other pine trees, other species of trees (i.e., non-pine), and trees 8-23 cm dbh. Two of the species classified in the fire suppressed assemblage, the Blue-gray Gnatcatcher and Tufted Titmouse, are grouped closer to the generalists than the other fire suppressed species. Species in the drain assemblage (Carolina Wren, White-eyed Vireo, Common Yellowthroat, Hooded Warbler, Northern Cardinal, and Eastern Towhee) are closely associated with shrub and sapling species richness, % green cover and fern cover, the number of shrubs <2.5 cm, and litter depth.

Location of a species near the center of the biplot indicates that its relative abundance may not be highly related to either ordination axes (i.e., generalists). Inspection of the correlation coefficients between species and ordination axes (Appendices VII and VIII) is necessary to ascertain whether these species are generalists or whether their relationship to each axis causes them to be positioned near the biplot center. For both data sets, the Mourning Dove, Northern Flicker, Red-bellied Woodpecker, Summer Tanager, Blue Jay, and Carolina Chickadee have relatively low correlations with the first two axes. For the 4-YR data set, the Great Crested Flycatcher shows some degree of correlation with the first axis. The Blue-gray Gnatcatcher shows a strong correlation in the 4-YR data set with the first axis and a milder correlation with this axis and the second axis in the 1-YR data set.

Annual and Observer Variation

For the 4-YR data set, nine species (Mourning Dove, Blue Jay, Brown-headed Nuthatch, Blue-gray Gnatcatcher, Red-eyed Vireo, White-eyed Vireo, Pine Warbler, Brown-headed Cowbird, and American Goldfinch) varied annually in relative abundance when tested for a year effect (Figure 8). For example, the Blue Jay and White-eyed Vireo had higher relative abundances in 1994 than 1996. Interestingly, the relative abundance of the Brown-headed Nuthatch had a notable increasing trend and the American Goldfinch declined in relative abundance. No significant interactions of year with treatment and/or location were found for the seven species tested (Table 6).

Each year revealed a significant observer effect for both species richness and total bird abundance (Table 7). Additionally, an observer by location effect existed for each year and an observer by treatment effect was detected for 1996, indicating that detectability of birds and/or distance estimation for birds seen or heard may have varied across habitats.

DISCUSSION

Vegetation Characteristics

Of the 29 vegetation variables, 22 and 28 variables had a fire treatment and/or location effect for the 4-YR and 1-YR data sets, respectively. Differences between fire treatment habitats are not surprising since study sites were chosen based on past management and the assumption that the management history would be reflected in the current vegetation structure and plant species composition. The vegetation variables varied in the predictable fashion, reflecting open, park-like longleaf pine habitats in the fire intense uplands and structurally and floristically (i.e., woody plants) more diverse vegetation characterizing the drain and fire suppressed habitats. Regardless of the fire treatment, drain habitats provided the most diverse and dense vegetation. Furthermore, drains interspersed in open longleaf habitat provided the densest shrub layer with the highest shrub species richness, most likely influenced by fire frequency and a more open canopy.

Based on the principal components analyses, the main pattern of vegetation variation followed a gradient from open pine to closed and speciose mixed pine-hardwood forests. By studying the positions of the count stations in two-dimensional vegetation structure ordination space (Figures 2 and 3), it appears that the upland to drain location classification accounts for a higher amount of vegetation variation than the fire treatment classification. The second major pattern of vegetation variation is influenced by the fire treatment since fire suppression leads to the establishment of a midstory and the loss of an understory and/or ground cover component. These findings are not surprising due to the study design.

Since the vegetational characteristics did not vary significantly between the 4-YR and 1-YR data sets according to the multivariate analysis of variance tests (MANOVA), it appears that the habitat gradient sampled for each data set is similar. One arguable exception is several vegetation variables for the fire intense drains varied significantly across data sets according to the univariate tests. Thus differences in bird abundances in drains between the data sets could be influenced by vegetation attributes intrinsic to one data set.

The vegetation communities characteristic of the fire treatment areas and along the riparian-upland gradient are associated with changes in avian species richness, relative total bird and species abundance, and breeding bird assemblages.

Species Richness and Total Bird Abundance

Higher bird species richness and total bird abundance are often associated with complex vegetation structure and greater floristic diversity (Stauffer and Best 1980; Szaro 1980; Emmerich and Vohs 1982; Thurmond et al. 1995). In accordance, total bird abundance and species richness were highest in the complex drain habitats. These results are similar to other avian studies where riparian habitats offer distinctive vegetational characteristics otherwise lacking in the landscape. For the Great Plains, Tubbs (1980) reported that 45% of the breeding bird species were restricted to or extensively used the riparian habitats, which were estimated to encompass only 1-3% of the total area. Szaro

(1980) summarized many studies from the arid Southwest and reported that the riparian habitats supported high bird populations accounting for 50-77% of the region's breeding bird species. In contrast, studies by McGarigal and McComb (1992) in the Oregon Coast Range and Murray and Stauffer (1995) in central Appalachian forests did not show the same pattern of higher total bird abundance and species richness in riparian habitats where the streamside vegetation was less distinct from upland habitats. In this study, the riparian vegetation (i.e., drains) offered a diverse plant composition and structure that contrasted with the adjacent, less complex upland habitats. Since drains were characterized by higher avian richness and abundance, the existence of drains in this longleaf pine ecosystem may add to the avian biodiversity and enable higher bird abundance and species richness by providing additional niches, and perhaps foraging and nesting resources for species found in the uplands.

Although fire suppressed habitats had complex vertical structure (i.e., a developed midstory) compared to the fire intense longleaf pine habitats, the suppressed habitats did not have significantly greater total bird abundance. Species richness may be slightly higher in suppressed habitats but the pattern was not completely consistent. Engstrom (*in prep*) found that the breeding bird species richness in the Wade Tract, an old-growth longleaf pine stand in Georgia, was comparable to the richness in the vertically diverse southern hardwood forests, and was higher than the richness for other regional longleaf pine stands. The fire intense longleaf stands of Fort Bragg do not have as high species richness as the Wade Tract, but these two areas differ in two important ways. The forested area of Fort Bragg are second- or third-growth and have xeric to mesic soil types, whereas the Wade Tract is an old-growth stand with mesic soils supporting a rich ground cover. At Fort Bragg, in mesic longleaf stands with a diverse ground cover and a patchy distribution of understory scrub oaks, an abundance of bird individuals and species can be observed, especially when seeps and drains are present. As these stands mature, these areas might have the potential to support a bird community comparable to that on the Wade Tract. Succession of these areas to mixed-pine hardwood stands through fire suppression, on the other hand, does not appear to increase bird richness much, despite the resulting increase in structural diversity of habitat.

Breeding Bird Species Assemblages

Of the 34 species tested for relative abundance differences by fire treatment and location, only four species (Northern Flicker, Red-bellied Woodpecker, Blue Jay, and Summer Tanager) exhibited no significant effects. In comparing the two data sets for both univariate and multivariate analyses, similar patterns were observed for almost all breeding bird species with few exceptions. These results suggest a strong effect of fire treatment and location relative to drains on the distribution and relative abundance of breeding bird species. Furthermore, similar treatment and location effects for groups of species suggest the existence of three breeding bird species assemblages and a fourth group of generalists.

Five of the species included in the open longleaf pine assemblage (Red-cockaded Woodpecker, Brown-headed Nuthatch, Pine Warbler, Prairie Warbler, and Bachman's Sparrow) are considered endemics of, or are primarily associated with the open pine forests of the Southeast (Jackson 1988). The Red-cockaded Woodpecker and the Brown-headed Nuthatch, both permanent residents, bark foragers, and cavity nesters, are most abundant in open pine dominated uplands (Conner and Dickson 1997) and benefit from the suppression of a hardwood midstory (Cantrell et al. 1995; Wilson et al. 1995; U.S. Fish and Wildlife Service 2000). The fire intense longleaf pine woodlands of Fort Bragg provide these habitat characteristics for these two species.

The frequency of fire and the time since the last burn are potentially relevant to ground and shrub nesting species in the open longleaf pine system, such as the Bachman's Sparrow and the Prairie Warbler, since fire maintains a diverse ground layer and also influences the occurrence of a shrub layer. A diverse ground layer dominated by bunch grasses is associated with the fire-maintained, open pinelands and this attribute is linked to the occurrence of the Bachman's Sparrow, which nests and forages on the ground (Jackson 1988; Dunning and Watts 1990). Fire suppression allows the invasion of a hardwood midstory and reduces the ground cover vegetation, thus negatively affecting Bachman's Sparrow populations (Dunning 1993). The Prairie Warbler in this open pine system commonly nested in the understory layer of scrub oaks that regenerated after growing season fires (Krieger 1997). In Arkansas (Wilson et al. 1995) and Florida pine stands (Engstrom et al. 1984), this warbler had higher abundances three years after the last fire when the understory layer was well-developed. In addition, Nolan (1978) observed that its density in pine stands peaked a few years after fire events with the development of a shrub layer and then declined when hardwoods reached into the midstory or when fire again removed the shrub layer. Both the Bachman's Sparrow and the Prairie Warbler likely have distributions that shift both spatially and temporally with the frequency and timing of growing season burns.

The Pine Warbler, a canopy nester preferring pines generally and mature pines over younger pine stands (Ehrlich et al. 1988; Jackson 1988), was the most abundant species in this study area and it reached its greatest abundance at the non-riparian locations of longleaf pine stands. In a study of habitat use in Appalachian riparian forests, Murray and Stauffer (1995) also found a negative association with streams for this species. A possible problem with results for the Pine Warbler is that a certain variation of this species' trilling song could be difficult sometimes to distinguish from the Chipping Sparrow. Yet, the abundance pattern for both species might have been correctly detected since the maximum relative abundance for the sparrow was in fire intense longleaf stands at intermediate and upland locations, similar to the pattern for the Pine Warbler. Although occasional misidentification was possible and thus abundance values are suspect, it is still nevertheless clear that both species were least abundant in the lowland drains and prefer upland longleaf areas.

The two other species in the open longleaf pine assemblage, the Eastern Wood Pewee and Red-headed Woodpecker, are not normally thought of as associated with pine. I include these species in this assemblage because their numbers are by far greater in the

fire intense sites. The Red-headed Woodpecker, like other longleaf associates, was most common at upland locations, but the Eastern Wood Pewee was equally common at all locations. When comparing shortleaf pine-grassland restoration areas to unmanaged mixed pine-hardwood stands, Wilson et al. (1995) found the pewee preferred pine stands recently thinned or burned with a partial open canopy and the woodpecker preferred an open, park-like structure. Additionally, Dickson and Segelquist (1979) reported these two species having their highest territorial male densities in older loblolly-shortleaf pine stands (stand ages 26 to 65 years) when compared to similar aged pine-hardwood stands.

At Fort Bragg, the fire suppressed bird assemblage (Acadian Flycatcher, Red-eyed Vireo, Wood Thrush, Yellow-throated Vireo, Black-and-white Warbler, Ovenbird, and Tufted Titmouse) was most associated with greater tree species richness, canopy closure, the number of non-longleaf trees, and small diameter trees indicative of a midstory component. In other forested systems, the species of this assemblage are typically associated with mixed pine-hardwood or hardwood stands, which have greater vertical structural complexity and canopy closure than open longleaf pine stands. Conner and Dickson (1997) describe an association of the Red-eyed Vireo, Black-and-white Warbler, and Tufted Titmouse with deciduous foliage in the mid- and overstory, a defining characteristic of the fire suppressed habitats in this study. Additionally, Engstrom et al. (1984) found that the Wood Thrush, Red-eyed Vireo, and Acadian Flycatcher appeared in a 15-year fire exclusion study area when a sapling subcanopy developed. Furthermore, the removal of a hardwood midstory and subsequent burning in a shortleaf-loblolly pine area resulted in lower densities of the Ovenbird and Black-and-white Warbler (Wilson et al. 1995).

Most of these suppression associated species are able to exist at varying abundance levels in the fire intense drain zones, but typically at lower abundances than in suppressed habitats. One notable exception may be the Wood Thrush, a forest interior species, which was almost nonexistent at every location in fire intense stands. Brennan et al. (1995) also reported Wood Thrush observations only in unmanaged pine-hardwood sites and never in managed Red-cockaded Woodpecker sites in Mississippi. The presence of other species with very low abundance in fire intense drains, namely the Ovenbird, Yellow-throated Vireo, Acadian Flycatcher, and Black-and-white Warbler, may well depend on the existence of fire suppressed sites. These species would surely decline greatly, and might disappear completely, if mixed pine-hardwood and hardwood stands were eliminated from this ecosystem. Red-eyed Vireos and Tufted Titmice, on the other hand, likely would maintain a presence within drains in burned areas. Thus fire suppression allows these two species to spread from drains and become more abundant, but probably is not necessary to their continued presence in the system.

Blue-gray Gnatcatchers presumably would remain relatively common even in the absence of fire suppression. The gnatcatcher was considered a mature hardwoods generalist by Murray and Stauffer (1995), and Smith (1977) reported a relatively large niche width and a ubiquitous distribution across a forest moisture gradient, but with higher occurrences in moist forests. In this study, conflicting fire treatment patterns negate definitively classifying this species. It was more common in fire suppressed sites

in the 4-YR data but was more abundant in fire intense sites in the 1-YR data. The result for the 1-YR data is similar to the gnatcatcher's significant association with open pine sites managed for Red-cockaded Woodpeckers versus unmanaged stands at Noxubee National Wildlife Refuge (Brennan et al. 1995).

The six species of the drain assemblage (Carolina Wren, White-eyed Vireo, Common Yellowthroat, Hooded Warbler, Northern Cardinal, and Eastern Towhee) are associated with dense green cover with a large shrub component and high shrub and sapling species richness, and all of these species nest on the ground or in the shrub layer (Ehrlich et al. 1988). In other studies, the Common Yellowthroat, Eastern Towhee, White-eyed Vireo, Northern Cardinal, and Carolina Wren were also associated with shrubby patches and a dense understory (Engstrom et al. 1984; Wilson et al. 1995; Conner and Dickson 1997). The Hooded Warbler has been described as an eastern deciduous forest bird associated with older forest age classes (Conner and Dickson 1997) and the development of a sapling subcanopy (Engstrom et al. 1984). Yet in this study, its distribution is almost exclusively limited to the drains suggesting an association with mesic habitats, thereby supporting the results of Smith (1977), who termed this species an obligatory moist forest species. Presence of species in this assemblage is likely dependent upon the existence of shrubby drain vegetation. Fire appears to promote the type of vegetation these species prefer, and this type of vegetation does not develop outside of drains even in the absence of fire.

The generalist bird species assemblage included the Northern Flicker, Red-bellied Woodpecker, Blue Jay, Carolina Chickadee, Summer Tanager, and Great Crested Flycatcher. None of these species, except for the Great Crested Flycatcher in the 4-YR data set, exhibited fire treatment or location effects, although the Carolina Chickadee had an interaction effect for the 1-YR data set. Presumably, the resources required by each of these species are not greatly influenced by fire treatment or location, and therefore may be uniformly distributed or at least not limiting across the study area. The Blue Jay, Summer Tanager, and Great Crested Flycatcher, all canopy species, may be minimally affected by vegetation changes as long as overstory pine and/or hardwood trees exist for foraging and/or nesting requirements (Engstrom et al. 1984). For the four cavity nesters (Northern Flicker, Red-bellied Woodpecker, Carolina Chickadee, Great Crested Flycatcher), the distribution of suitable cavities may be a more important habitat component than structural and floristic differences in vegetation due to fire treatment and/or location effects, unless cavity availability is impacted by these factors. Most species in this assemblage may be more aptly named forest generalists since they require a minimum amount of forested area to be present. For example, McIntyre (1995) found that the Red-bellied Woodpecker, Carolina Chickadee, and Summer Tanager decreased in abundance with decreasing forest patch size.

Some of the species not placed in a particular assemblage, namely the Brown-headed Cowbird, American Goldfinch, and Indigo Bunting, probably could not be classified because the study design did not adequately sample the range of their habitats. The Indigo Bunting, for instance, is associated with disturbed habitats such as canopy

gaps and other edges, and the American Goldfinch and Brown-headed Cowbird are invasive species associated with large clearings (Jackson 1988).

Annual and Observer Variation

Although annual variation in relative abundance was found for nine species, five of these species still had a detectable, overriding fire treatment or location effect, further indicating the strength of fire management and the riparian-upland gradient on avian communities. There is little in the data to indicate why these species varied annually, whether due to temporal habitat variation, demographic or environmental stochasticity, observer detection biases, or some other factor. An exception may be the apparent observer effect on variation in species richness and total bird abundance. Observers were not tested for bird identification abilities simultaneously at the same location each year but instead, observer bias was estimated by comparing each observer's independent sampling throughout the respective field season; hence this method was not a direct test of observer error. Whether observer differences in detection abilities for individual species contributed to annual variation is unknown. Observer differences may have contributed to annual variation in species richness and total bird abundance, perhaps, for example, by contributing to the significantly higher estimates of these parameters in 1995.

Scope and Limitations

Before the results of this study may be used in a management context, certain limitations need to be addressed. First, these results apply specifically to the longleaf pine ecosystem characteristic of the Fort Bragg Military Installation in North Carolina. Although many of these species abundance and richness patterns may be comparable to those found in other longleaf pine-dominated forests, the results should not be extrapolated for all longleaf forests throughout the Southeast without supporting data.

Several types of longleaf pine communities exist in the Southeast, influenced mostly by soil moisture and geographic variation (Peet and Allard 1993). Peet and Allard (1993) recognized four major series that are related to soil moisture: xeric, subxeric, mesic, and seasonally wet longleaf pine vegetation. These series were then classified into 23 communities related mostly to geography and physiographic province. Each of these communities can further vary according to forest age, fire history, and management history (e.g., timber production). Because of this variation, bird communities may vary as well. For example, Engstrom (*in prep*) found that breeding bird species richness in an old-growth longleaf pine forest associated with mesic soils was greater than in other longleaf pine forests of the Southeast. To fully understand the dynamics of the breeding bird assemblages of longleaf pine communities, studies should be conducted across different longleaf pine-dominated communities throughout the range of longleaf pine to reveal ubiquitous patterns for all communities and unique patterns to a specific location or community. One such regional study is being completed by researchers from Tall

Timbers Research Station and Mississippi State University (Engstrom et al. 1996). These researchers are studying the influence of dormant and growing season burns on avian, small mammal, and amphibian species in longleaf pine forests in Florida and North Carolina.

Additionally, results are not applicable to habitat types occurring on Fort Bragg that were not sampled, such as wildlife food plots, artillery-impact zones, parachute drop zones, other fields, young pine plantations, and lakes. Some species may use these other habitats regardless of fire history or location relative to drains and thus might exist at Fort Bragg even if prescribed burns were discontinued. For example, small forest openings, canopy gaps, and field/forest ecotones are important for Indigo Buntings. Prairie Warblers and Northern Cardinals sometimes nested in dense pine or hardwood sapling patches on the base. Furthermore, Bachman's Sparrows may be found in early pine successional stages such as 1 to 7 year-old clearcuts (Pulliam et al. 1994).

Third, although relative abundance values of all bird species detected within the 50-m count stations are given in Appendices V and VI, the sampling protocol best estimated abundances of diurnal species. The data are unlikely to accurately portray abundance patterns of nocturnal species, such as the nightjars and owls.

Lastly, a positive relationship between fire treatment or location and relative abundance of a particular species is not necessarily an indicator of high quality habitat or an ability to support reproductively sustaining populations (Van Horne 1983). Possibly, some species are more abundant in one fire treatment but have greater reproductive success in another treatment. Data on productivity of select bird species in the two fire treatments were reported by Krieger (1997). Krieger found that nesting success did not differ across fire treatment for the passerine community (i.e., data were pooled for the 14 species nesting across both treatments) or for the Blue-gray Gnatcatcher, Eastern Wood Pewee, and Summer Tanager individually. These three species were the only ones that had enough data were available to make comparisons across treatments. Although statistical significance was not found for the Eastern Wood Pewee, this species had notably higher nest success in fire suppressed sites versus intense sites (71.4%, n=14 and 46.7%, n=15, respectively). Krieger found that predation of eggs/young was higher (though not statistically different) for the pewee in fire intense sites versus fire suppressed sites (62.5% and 25%, respectively). Although pewees are more abundant in fire intense sites based on point count data, these areas may be suboptimal habitat since reproductive success appears to be lower. Thus, my earlier inclusion of the pewee into the longleaf pine species assemblage may be incorrect. Conversely, nesting data for the Bachman's Sparrow and Prairie Warbler support my earlier conclusion that these species are part of the longleaf pine bird species assemblage since almost all nests were found in fire intense sites (11/11 and 11/12, respectively).

MANAGEMENT IMPLICATIONS

Much attention has been focused on the population declines of Neotropical migratory landbirds. Some of the Neotropical migrants found on Fort Bragg, for example, the Wood Thrush, Acadian Flycatcher, Black-and-white Warbler, and Ovenbird, are not usually thought of as associated with open longleaf pine woodlands and savannas, and may not have occurred in this system historically. Hunter et al. (1994) assert that management of high priority open pine associates, such as the Red-cockaded Woodpecker and Bachman's Sparrow, and non-open pine associates is best accomplished using a landscape or regional perspective. Different bird assemblages need not be managed for in the same locale. Hence, continued management of Fort Bragg for the longleaf pine community likely will cause a large decline or elimination of some species from the fire suppressed assemblage, but this is justifiable due to positive effects on longleaf pine and drain associates.

Based on this study, continued widespread prescribed fires for longleaf pine restoration is expected to influence the relative abundance of many bird species. Appendix IX lists whether continued burning is expected to negatively or positively affect each species. Without fire suppressed forests, the Wood Thrush is the one species of this assemblage that would most likely be eliminated. The Acadian Flycatcher, Yellow-throated Vireo, Black-and-white Warbler, and Ovenbird may also suffer a large decline but should still be present in drain habitats. The Red-eyed Vireo and Tufted Titmouse, may decline in overall abundance across the base but they likely would be abundant in the proximity of drains. These species that would be negatively affected by longleaf pine restoration efforts can be managed for more effectively in other regional locations where mixed pine-hardwood, hardwood, or bottomland hardwood forests exist and are the appropriate historical forest types. For example, the Wood Thrush is a relatively common member of bird species assemblages in eastern deciduous hardwood forests, thus this species would be best managed for in these forests.

Longleaf pine restoration efforts would greatly benefit two species of the longleaf pine bird species assemblage, the Red-cockaded Woodpecker and Bachman's Sparrow, since these species are limited to the southeastern U.S. and are highly associated with longleaf pine communities. Several other species would likely benefit from longleaf pine restoration but do not necessarily depend on the longleaf pine ecosystem for their continued existence. The Red-headed Woodpecker, Brown-headed Nuthatch, Pine Warbler, Prairie Warbler, Chipping Sparrow, and possibly the Eastern Wood Pewee (see comments on pewee above) may become more abundant with increasing areas of open longleaf pine forests. Most species of the drain assemblage would probably not be negatively affected by restoration efforts and certain species, such as the Common Yellowthroat and Eastern Towhee, may become more abundant if prescribed burning influences the development of more dense, shrubby drain habitat. It is unknown how much, if at all, restoration efforts would affect the generalist species assemblage. As discussed earlier, canopy species, such as the Blue Jay, Great Crested Flycatcher, and Summer Tanager, may not be greatly affected. On the other hand, Krieger (1997) found that Summer Tanagers mostly used oaks (*Quercus* spp.), rather than pines, in higher proportion than their availability for nest location. Thus, a decline in oaks may lead to a decline in tanager abundance.

Based on this study, assuming that greater species richness and total bird abundance would occur in structurally complex fire suppressed habitats than could be supported in open, fire intense longleaf pine stands is unwarranted. Management for old-growth stands and its associated diverse ground layer may increase species richness in longleaf pine stands, especially for ground and shrub nesting or foraging species (Engstrom *in prep*). Engstrom suggests that the old-growth characteristics of larger and older trees and snags, uneven stand age, spatial patchiness of vegetation, diverse ground flora, and tip-up mounds of fallen trees may contribute to higher bird species richness in longleaf systems. Furthermore, Dickson and Segelquist (1979) concluded for a Texas study of pine and pine-hardwood forests that breeding bird diversity and density is promoted especially by maximizing vegetation layers near the ground. Hence, a spatially and vertically diverse ground layer in longleaf pine habitats may be an important factor contributing to species richness and total bird abundance.

The complex drain vegetation within this longleaf pine ecosystem is associated with higher bird species richness and total bird abundance compared to upland areas. This vegetation is vital for the continued existence of the drain species assemblage, and most species of the fire suppressed assemblage may occur within this vegetation even if absent from upland longleaf pine habitats. In essence, drains provide structurally and floristically unique vegetation that directly influences avian biodiversity in the otherwise structurally simplistic longleaf pine forests. The presence of a certain amount of complex drain vegetation in a longleaf pine landscape would be an appropriate management goal to provide habitat for the drain species assemblage identified in this study.

In this study, only drains having shrubby vegetation were sampled. In fire intense areas, the drains were more dense than in the fire suppressed areas, suggesting that fire promotes a higher density of shrubs. Yet, the vegetation density of drains can also be influenced by fire frequency, intensity and/or time since the last burn. For example, a prescribed fire could render a drain devoid of shrub vegetation in the short term such that the drain may not provide suitable habitat for some species during that short time period. Thus spatial and temporal variation in drain vegetation is likely in fire-maintained longleaf pine systems, and this may influence the bird communities. Further research may be necessary to compare bird species productivity, abundance, richness, and assemblages in drains in relation to fire frequency, intensity, and/or time since last burn.

Additionally, research on the temporal effects of burning on ground and shrub nesting bird species, such as the Bachman's Sparrow and Prairie Warbler, would complement this study and the work of Krieger (1997). It is especially important to determine how their distributions shift spatially and breeding productivity varies accordingly over the current three year burning rotation.

CONCLUSIONS

Fire treatment and the riparian-upland gradient have a strong effect on the

distribution and abundance of many bird species through impacts on vegetation structure and floristics. Total bird abundance, and possibly bird species richness, are not necessarily lower in the longleaf pine savannas/woodlands even though these habitats are not as vertically complex as fire suppressed habitats. Drains, offering the greatest structural complexity and floristic diversity, were characterized by the highest bird species richness and total bird abundance. The existence of several species in this system (White-eyed Vireo, Common Yellowthroat, Hooded Warbler, and Eastern Towhee) may very well depend on these riparian habitats. Continued longleaf pine restoration will likely cause a decline in species of the mixed pine-hardwood and hardwood forests, such as the Acadian Flycatcher, Black-and-white Warbler, Ovenbird, Red-eyed Vireo, and in particular, the Wood Thrush. However, most of these species may remain at least present within the floristically-rich drain habitats, and these species are better managed for in non-longleaf pine ecosystems. Longleaf pine restoration efforts will benefit not only the well-known Red-cockaded Woodpecker and Bachman's Sparrow, but probably also the Red-headed Woodpecker, Brown-headed Nuthatch, Pine Warbler, Prairie Warbler, and Chipping Sparrow. Conversion of fire suppressed habitats to longleaf pine communities through the use of prescribed fire may also benefit drain species associates, such as the Common Yellowthroat and White-eyed Vireo, by producing shrubbier, denser vegetation.

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Table 1: Bonferroni multiple comparison procedure results of location effects for the vegetation variables measured at Fort Bragg, NC for the 4-YR and 1-YR data set.

	4-YR[a]			1-YR		
Variables	D	I	U	D	I	U
Slope	a	a	b	a	a	b
% Canopy Cover	a	b	b	a	b	b
Canopy Height (m)	a	a	a	a	b	b
Litter Depth (cm)	a	b	b	a	b	b
% Green Cover	a	b	b	a	b	b
% Grass Cover	a	b	b	a	b	b
% Shrub Cover	a	b	b	a	b	b
% Forb Cover	-	-	-	a	b	b
% Fern Cover	a	b	b	a	b	b
% Downed Logs	a	a	a	a	b	b
% Leaf Litter	-	-	-	a	b	b
% Bare Ground	a	b	b	a	b	b
# Shrubs <2.5 cm	a	b	b	a	b	c
# Shrubs > 2.5 cm	a	b	b	a	ab	b
# Saplings <2.5 cm	-	-	-	a	a	a
# Saplings > 2.5 cm	-	-	-	a	ab	b
# Trees 8-23 cm dbh	a	ab	b	-	-	-
# Trees >23-38 cm dbh	-	-	-	-	-	-
# Trees >38 cm dbh	-	-	-	a	ab	b
# Longleaf Pine Saplings	-	-	-	-	-	-
# Other Pine Saplings	-	-	-	a	b	b
# Other Species Saplings	-	-	-	a	a	a
# Longleaf Pine Trees	a	b	b	a	b	b
# Other Pine Trees	a	b	b	a	b	b
# Other Species Trees	a	ab	b	a	b	b
Shrub Species Richness	a	b	b	a	b	c
Sapling Species Richness	a	b	b	a	b	b
Tree Species Richness	a	b	c	a	b	b
# Snags ≥12 cm dbh	a	b	b	-	-	-

[a] D=Drain; I=Intermediate; U=Upland; Locations with different letters are significantly different according to Bonferroni MCPs

Table 2: Results for MANOVA and univariate one-way factorial tests comparing the two vegetation data sets (4-YR and 1-YR) from Fort Bragg, NC for each combination of fire treatment and location. Overall significance for the MANOVA test is indicated by the p-value (i.e., Pr>F statistic) for the Wilks' Lambda statistic. Each vegetation variable was tested for no difference between the two data sets by a one-way factorial test and the significantly different variables ($p \leq 0.05$) are listed.

	Fire Intense			Fire Suppressed		
	Drain	Intermediate	Upland	Drain	Intermediate	Upland
4-YR:	n=16	n=16	n=16	n=6	n=5	n=6
1-YR:	n=19	n=20	n=34	n=29	n=23	n=31
MANOVA: Pr>F (df)[a]	0.1981 (df=29,5)	0.4046 (df= 28,7)	0.1153 (df=27,22)	0.0572 (df=29,5)	--[c]	0.4096 (df=29,7)
Significant Variables[b]	litter depth %green cover %shrub cover %forb cover %leaf litter #shrubs(<2.5cm) #saplings(<2.5cm) #other pine species(saplings) #other species (saplings) shrub species richness sapling species richness	canopy cover %grass cover %forb cover #saplings(<2.5cm) #other species (saplings) #Longleaf trees shrub species richness	%forb cover	%forb cover %fern cover #shrubs(<2.5cm) #shrubs(>2.5cm) shrub species richness	slope %forb cover #shrubs(>2.5cm) #Longleaf trees	

[a] The hypothesis of no difference between the vegetation data sets (for each fire treatment and location combination) was tested by a MANOVA performed with GLM procedures on ranked values; Degrees of freedom (numerator, denominator) are given for each MANOVA; For each MANOVA, significance values (Pr>F) across the four MANOVA statistics (Wilks' Lambda, Pillai's Trace, Hotelling-Lawley Trace, and Roy's Maximum Root) were identical because k=2 (k is the number of groups, or the two independent data sets in this case[2])

[b] Individual variables were also tested for no difference between the data sets by a one-way factorial performed on ranked values by a GLM procedure

[c] No MANOVA possible because insufficient degrees of freedom in the denominator

Table 3: Comparison of relative abundance patterns by fire treatment between the 4-YR and 1-YR data sets for species with significant treatment effects in either data set for the breeding birds of Fort Bragg, NC. Results of statistical tests for fire treatment effects are not shown.

	Treatment with Higher Abundance[a]	
Species	4-YR n=65	1-YR n=156
Mourning Dove	I	I
Red-cockaded Woodpecker	I	I
Red-headed Woodpecker	I	I
Acadian Flycatcher	S	S
Eastern Wood Pewee	I	I
Tufted Titmouse	S	S
Brown-headed Nuthatch	I	I
Eastern Bluebird	I	I
Wood Thrush	S	S
Blue-gray Gnatcatcher	S	I
Red-eyed Vireo	S	S
White-eyed Vireo	I	S
Yellow-throated Vireo	S	S
Black-and-white Warbler	S	S
Common Yellowthroat	I	I
Ovenbird	S	S
Pine Warbler	I	I
Prairie Warbler	I	I
Northern Cardinal	S	S
Bachman's Sparrow	I	I
Chipping Sparrow	I	I

[a] I=Fire Intense; S=Fire Suppressed

Table 4: Comparison of relative abundance patterns across locations between the 4-YR and 1-YR data sets for species with location effects in either data set for the breeding birds of Fort Bragg, NC. Locations are ordered in decreasing mean abundance. Results of statistical tests for location effects are not included.

	Abundance Order for Location [a]	
Species	4-YR n=65	1-YR n=156
Red-cockaded Woodpecker	U D I	U I D
Great Crested Flycatcher	D I U	U D I
Acadian Flycatcher	D I U	D U I
Tufted Titmouse	D I U	D I U
Brown-headed Nuthatch	U I D	U I D
Carolina Wren	D I U	D I U
Wood Thrush	D U I	D U I
Blue-gray Gnatcatcher	D I U	D I U
Red-eyed Vireo	D I U	D I U
White-eyed Vireo	D I U	D I U
Yellow-throated Vireo	D I U	D I U
Black-and-white Warbler	D I U	D I U
Common Yellowthroat	D I U	D I U
Hooded Warbler	D I U	D I U
Ovenbird[b]	D I U	I D U
Pine Warbler	U I D	I U D
Yellow-throated Warbler	D I U	I D U
Brown-headed Cowbird	I D U	I D U
Northern Cardinal	D I U	D I U
Rufous-sided Towhee	D I U	D I U
Chipping Sparrow	U I D	U I D

[a] D=Drain; I=Intermediate; U=Upland

[b] In 1-YR for Ovenbird, relative abundance for I and D are close in value: I=0.401; D=0.408

Table 5: Species assemblages for the breeding birds of Fort Bragg, NC.

Assemblage	Species
Longleaf pine	Red-cockaded Woodpecker
	Red-headed Woodpecker
	Eastern Wood Pewee
	Brown-headed Nuthatch
	Pine Warbler
	Prairie Warbler
	Chipping Sparrow
	Bachman's Sparrow
Fire Suppressed	Acadian Flycatcher
	Blue-gray Gnatcatcher
	Wood Thrush
	Red-eyed Vireo
	Yellow-throated Vireo
	Black-and-white Warbler
	Ovenbird
	Tufted Titmouse
Drain	Carolina Wren
	White-eyed Vireo
	Common Yellowthroat
	Hooded Warbler
	Northern Cardinal
	Eastern Towhee
Generalist	Red-bellied Woodpecker
	Blue Jay
	Carolina Chickadee
	Great Crested Flycatcher
	Summer Tanager

Table 6: Results of testing for year effects and interactions of year with fire treatment and location for seven breeding bird species during 1994-1997 (n=65) at Fort Bragg, NC. P-values from the three-way factorial tests are shown.[a]

Species[a]	Year	Year* Treatment	Year* Location	Year* Treatment* Location
Great Crested Flycatcher	0.1489	0.1449	0.5119	0.6999
Carolina Chickadee	0.8614	0.6736	0.6586	0.8321
Tufted Titmouse	0.0839	0.3200	0.6071	0.8197
Blue-gray Gnatcatcher	0.0014	0.5645	0.3151	0.3427
Red-eyed Vireo	0.0048	0.8154	0.3432	0.9882
Pine Warbler	0.0001	0.3250	0.1275	0.7400
Summer Tanager	0.1901	0.3200	0.6071	0.8197

[a] GLM procedures on ranked values used to perform the three-way factorial tests

Table 7: Observer variation in species richness and total bird abundance each year from 1994-1997 for the breeding birds of Fort Bragg, NC. Results are shown for observer effects and interactions of observer with fire treatment and location. Significant differences are indicated by p-values from the three-way factorial tests (using GLM procedures) and letters showing differences between observers based on Bonferroni multiple comparison procedures (MCP).

			Species Richness[a]		Total Birds[a]	
Year: Effect	Obs.	n	Mean (SE)	p-value/ MCP[b]	Mean (SE)	p-value/ MCP[b]
1994: Observer				0.0001		0.0001
	1	56	2.48 (0.27)	a	3.36 (0.39)	a
	2	47	4.19 (0.34)	b	5.77 (0.50)	b
	3	50	2.44 (0.19)	a	3.18 (0.27)	a
	4	42	2.50 (0.26)	a	3.26 (0.37)	a
Obs*Trt				0.1351		0.0968
Obs*Loc				0.0001		0.0001
1995: Observer				0.0077		0.0150
	1	65	4.43 (0.28)	a	5.85 (0.40)	a
	2	65	3.63 (0.27)	b	5.06 (0.40)	ab
	3	65	3.45 (0.28)	b	4.32 (0.37)	b
Obs*Trt				0.8323		0.4411
Obs*Loc				0.0001		0.0004
1996: Observer				0.0001		0.0001
	1	121	3.51 (0.22)	a	4.13 (0.25)	a
	2	128	3.43 (0.20)	a	4.26 (0.26)	a
	3	113	2.55 (0.19)	b	3.03 (0.24)	b
	4	86	2.77 (0.21)	ab	3.37 (0.28)	ab
Obs*Trt				0.0011		0.0012
Obs*Loc				0.0001		0.0001
1997: Observer				0.0001		0.0007
	1	177	3.19 (0.17)	a	3.88 (0.22)	a
	2	115	3.61 (0.22)	a	4.93 (0.33)	b
	3	137	2.46 (0.16)	b	3.40 (0.23)	a
Obs*Trt				0.3831		0.3422
Obs*Loc				0.0001		0.0006

[a] Species richness is the number of species per 50-m radius count; Total bird abundance is the number of birds per 50-m radius count; Mean species richness and total bird detections and their standard errors per observer are shown

[b] No 3-way significant interaction found (i.e., obs*trt*loc)

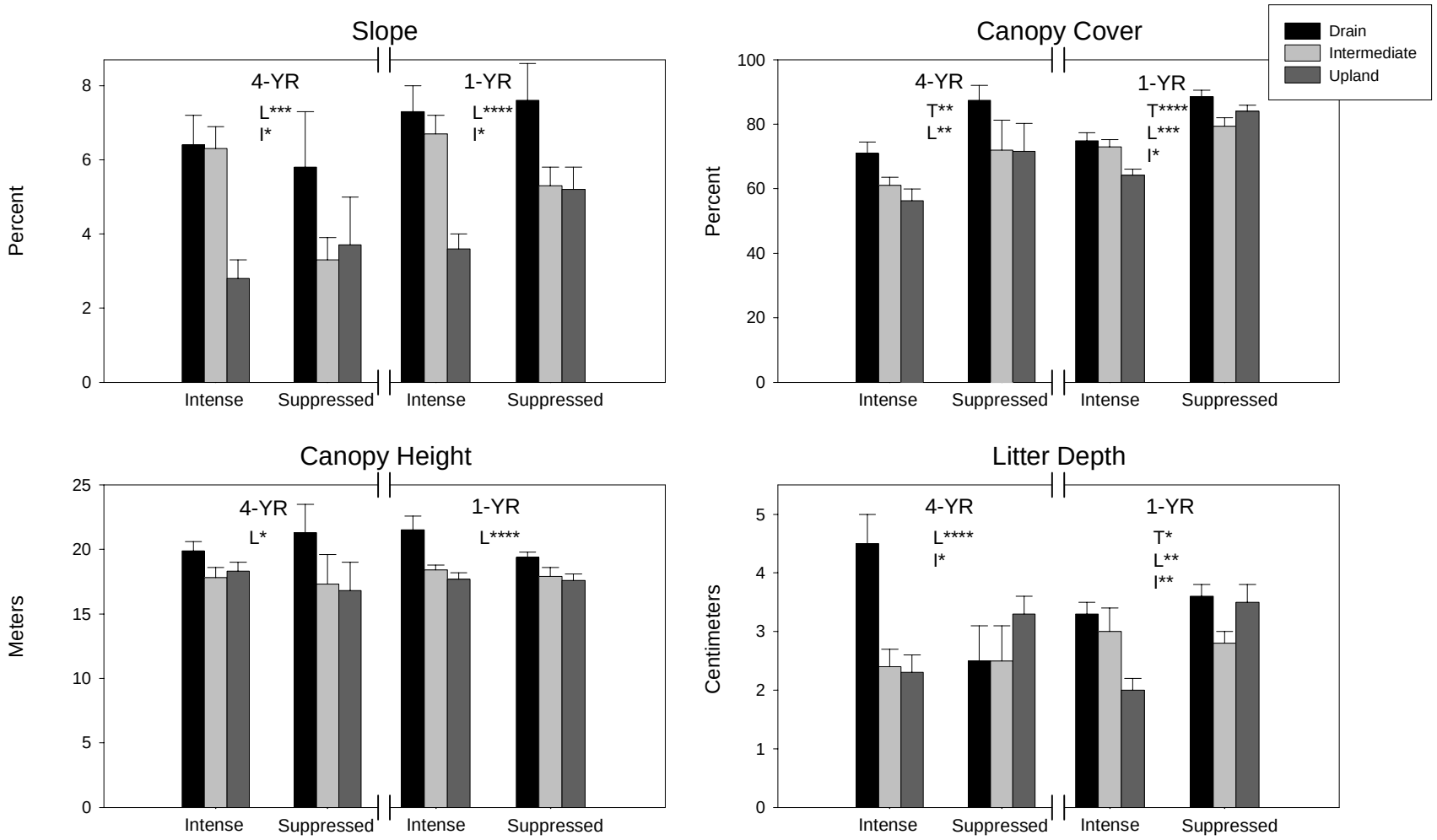
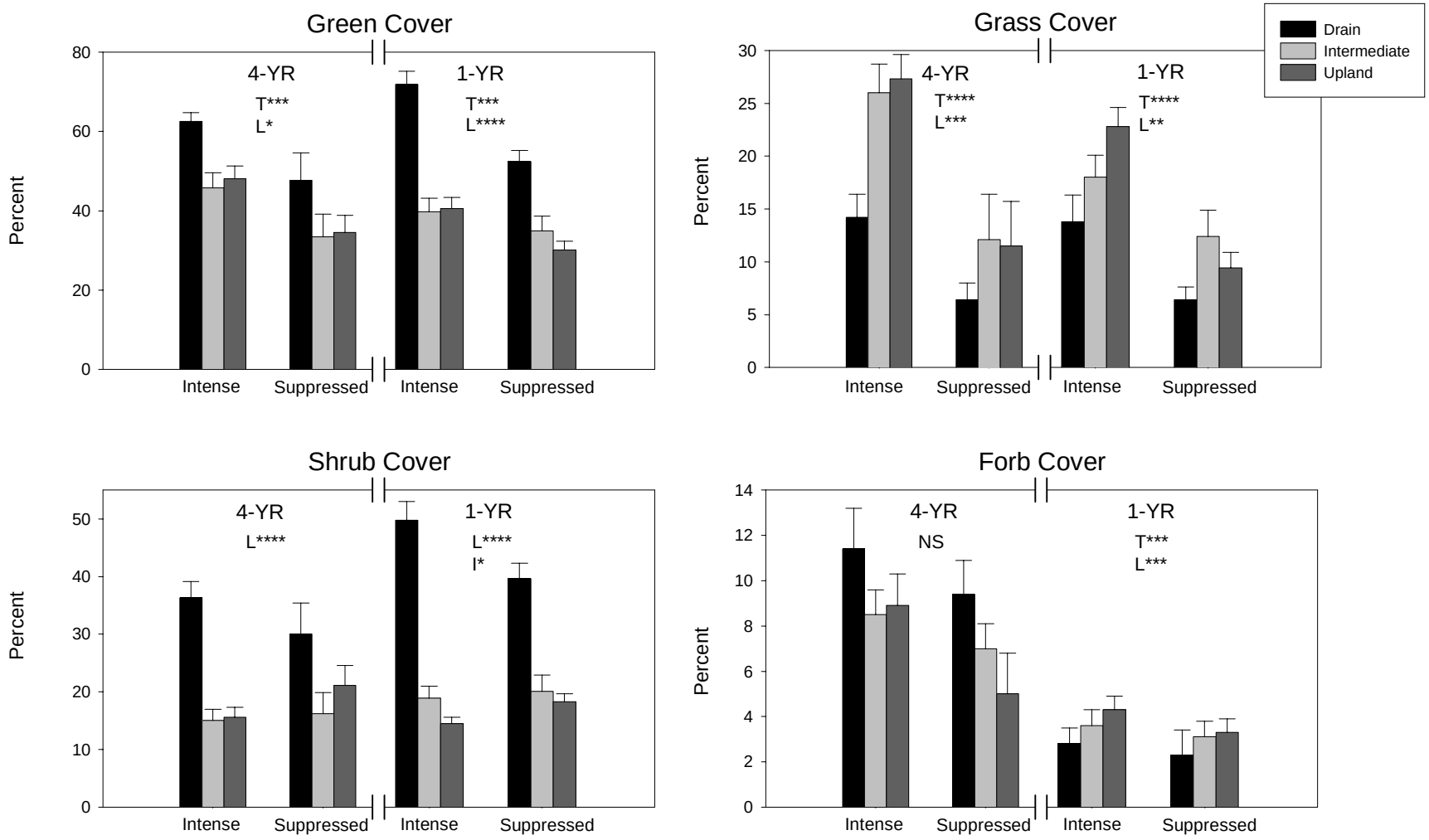


Figure 1: Mean values and standard error bars of vegetation variables of the point count stations at Fort Bragg, NC in the 4-YR (1994-97) and 1-YR (1996) data sets to test for fire treatment, location, and interaction effects. Two-way factorial test results are indicated by letter and asterick codes: T=fire treatment effect, L=location effect, I=interaction effect, NS=not significant, *=p<0.05, **=p<0.01, ***=p<0.001, ****=p<0.0001.



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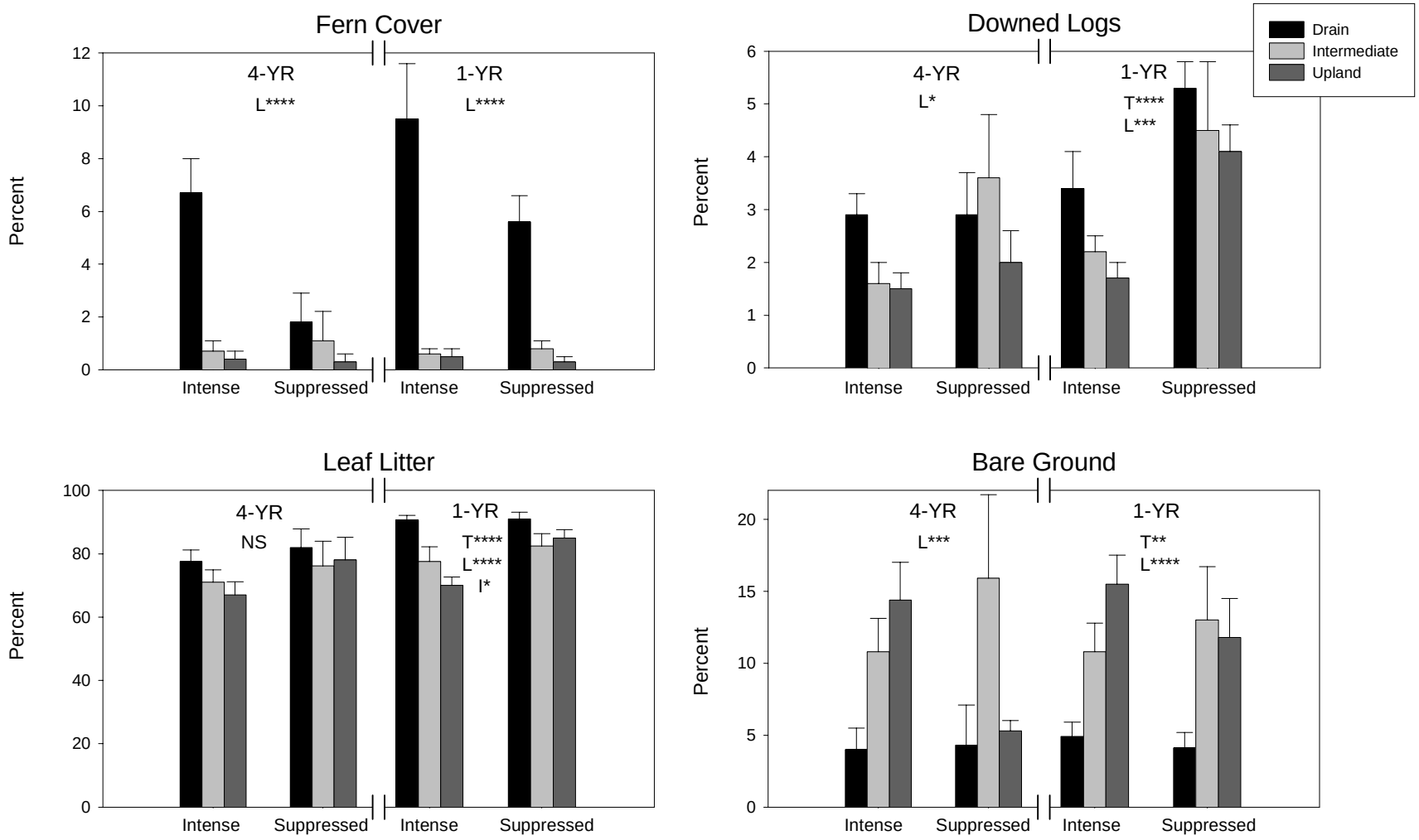

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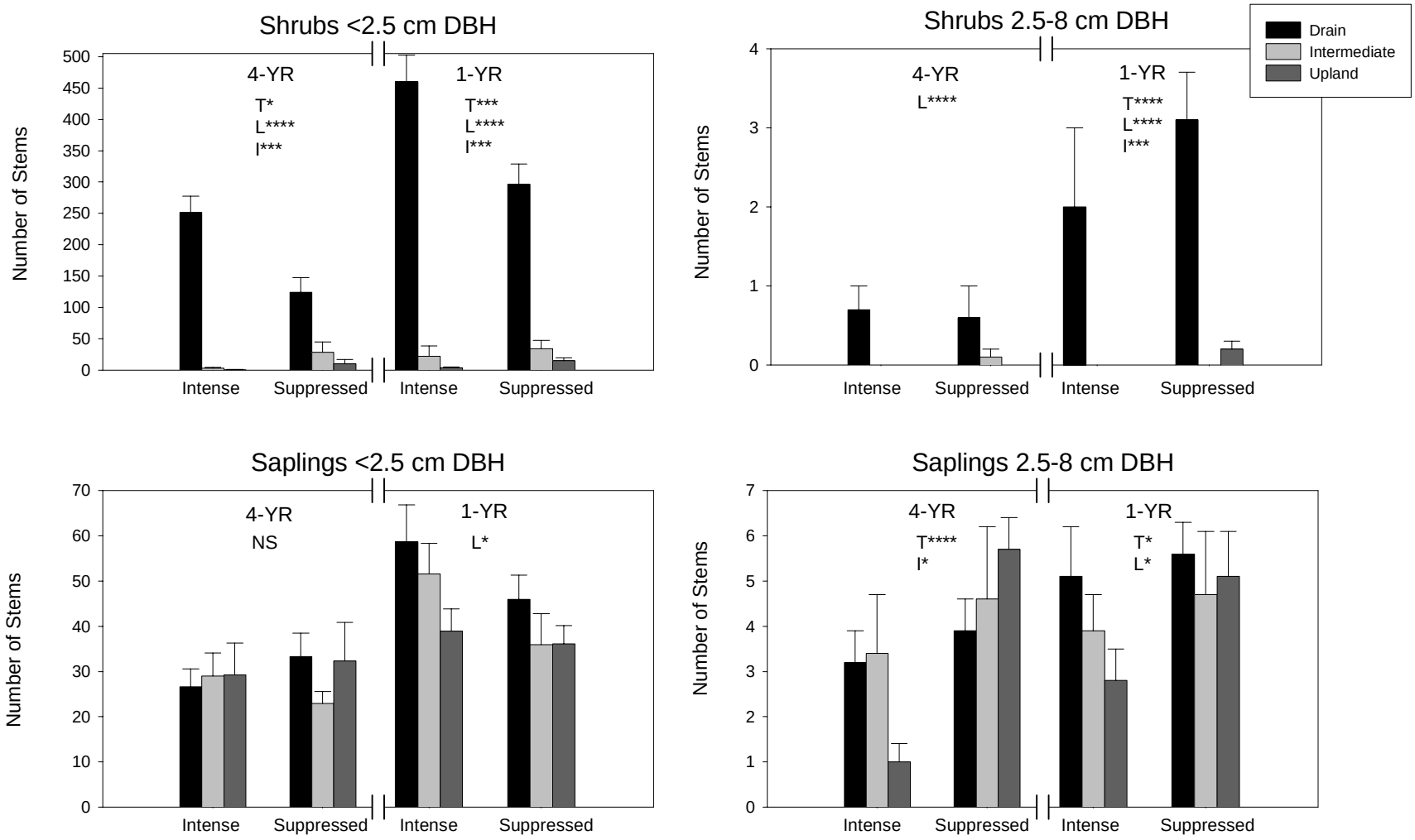

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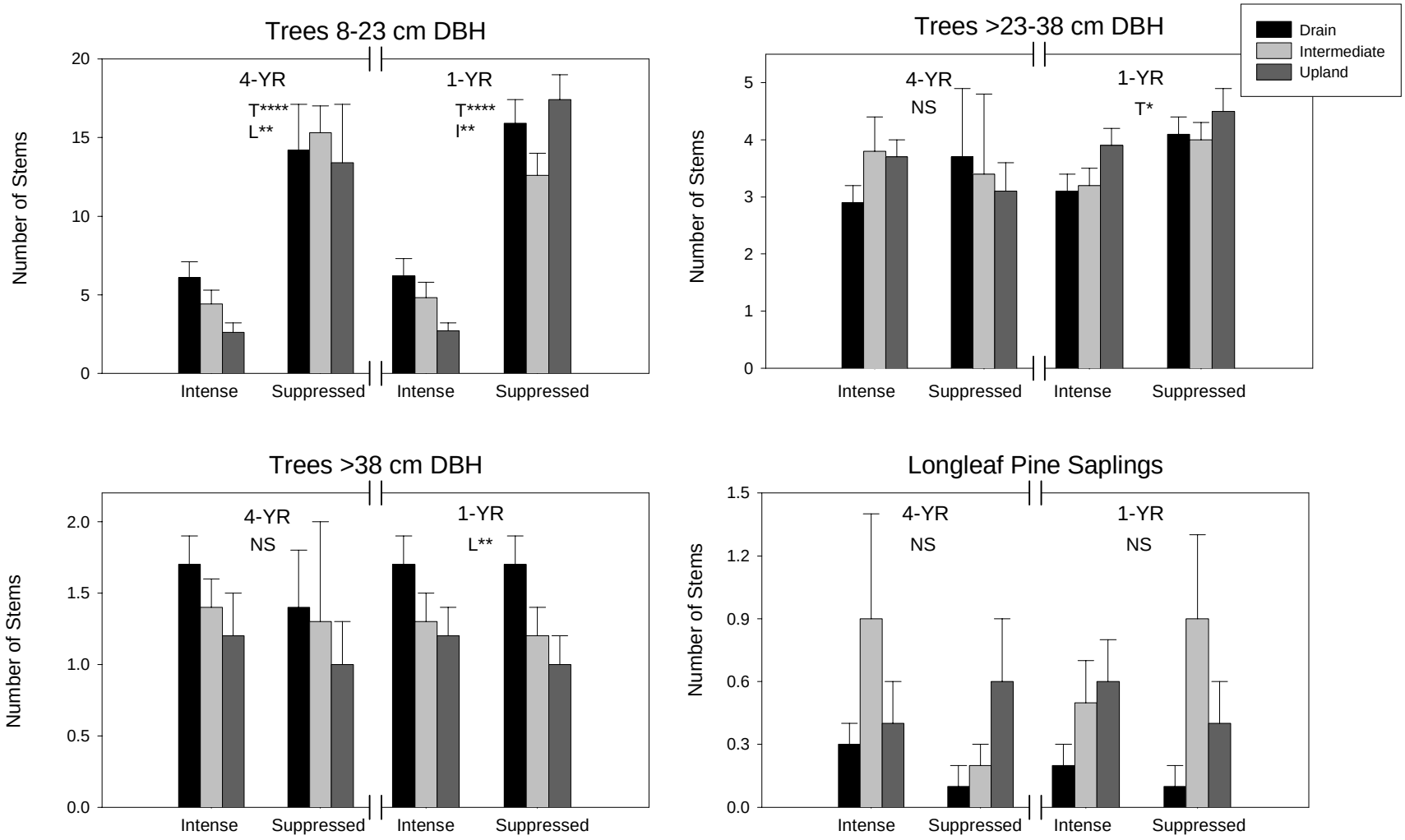

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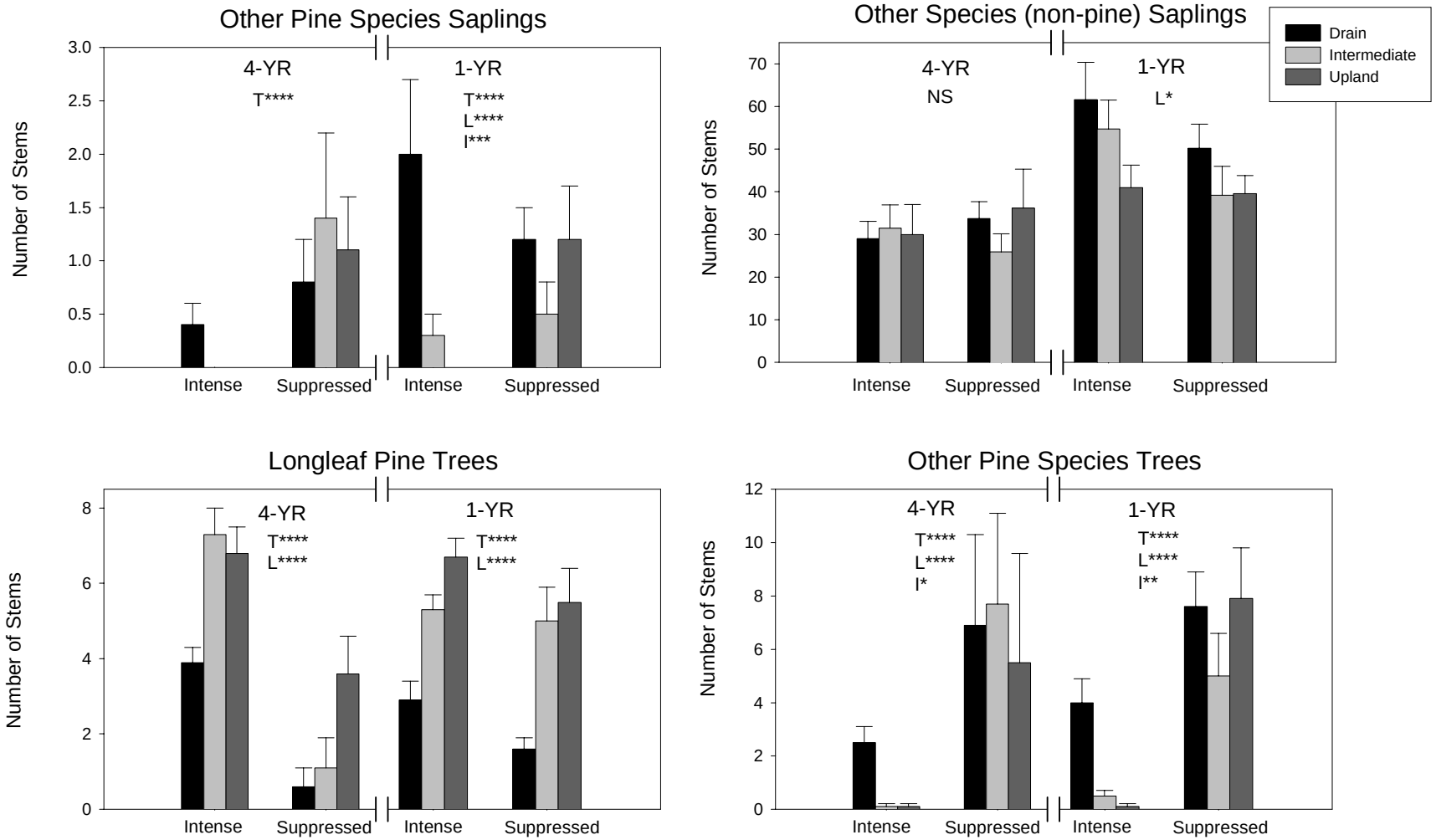

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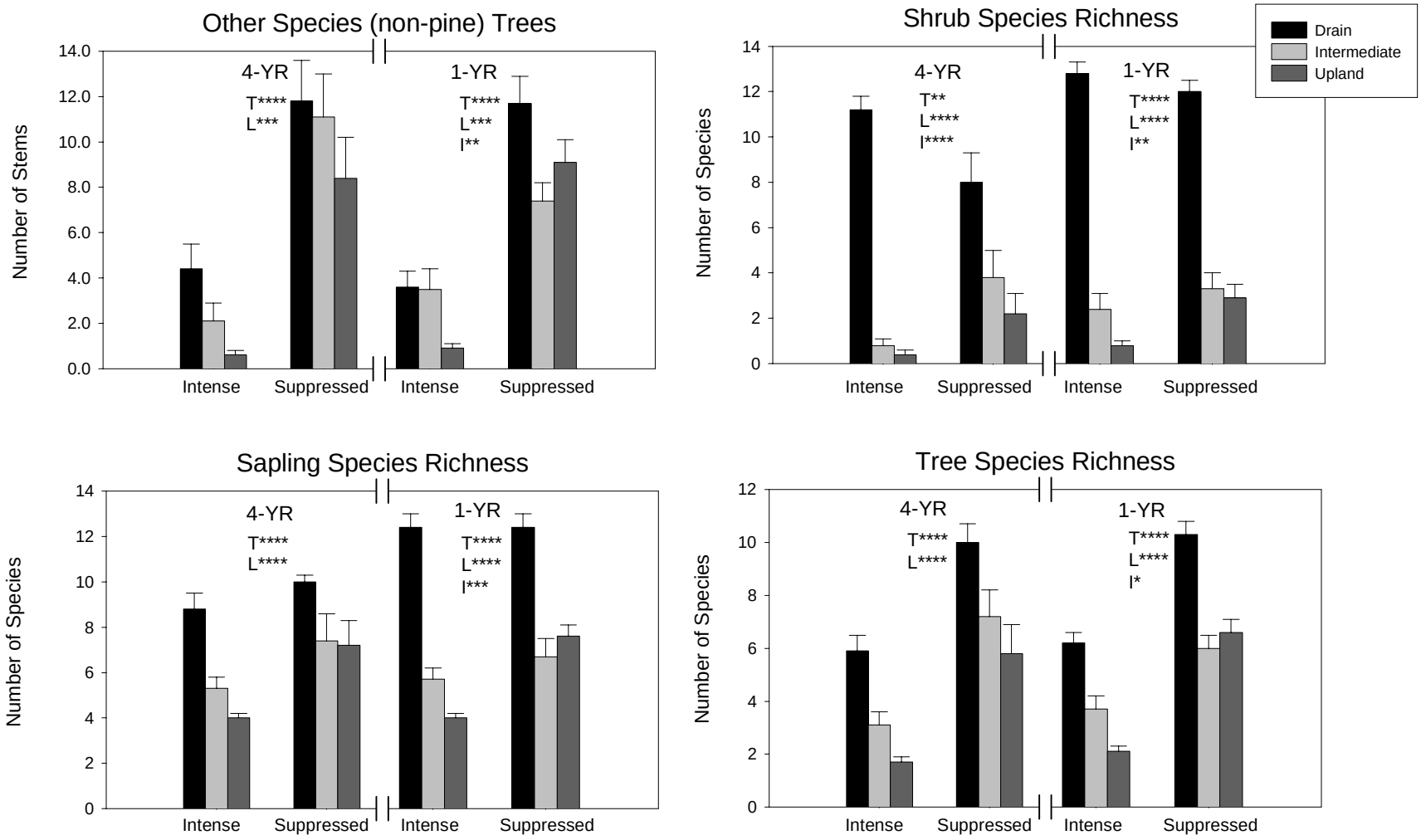

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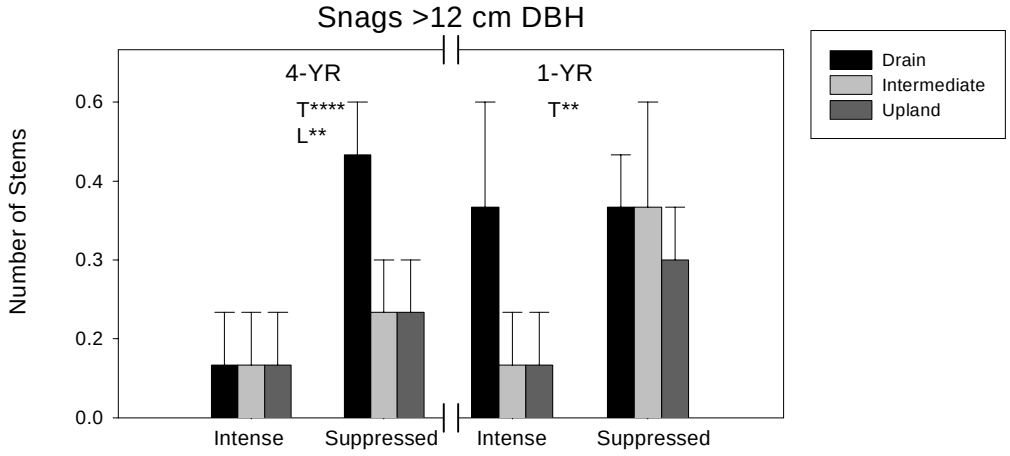

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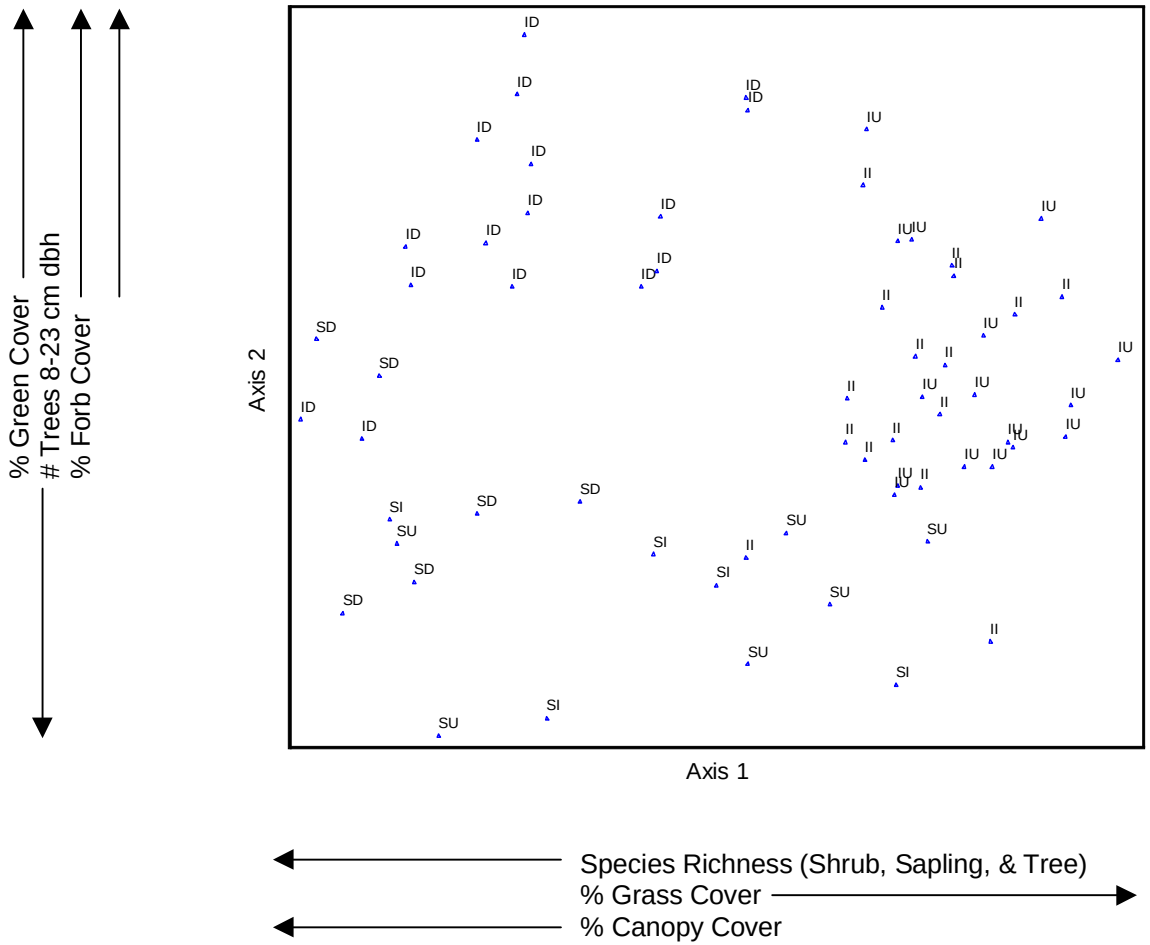


Figure 2: Principal components analysis of the vegetation parameters for the 4-YR data set (n=65) at Fort Bragg, NC. Fire treatment and location of each count station labeled by 2-letter code. First letter indicates fire treatment (I=Intense; S=Suppressed) and second letter indicates location (D=Drain; I=Intermediate; U=Upland).

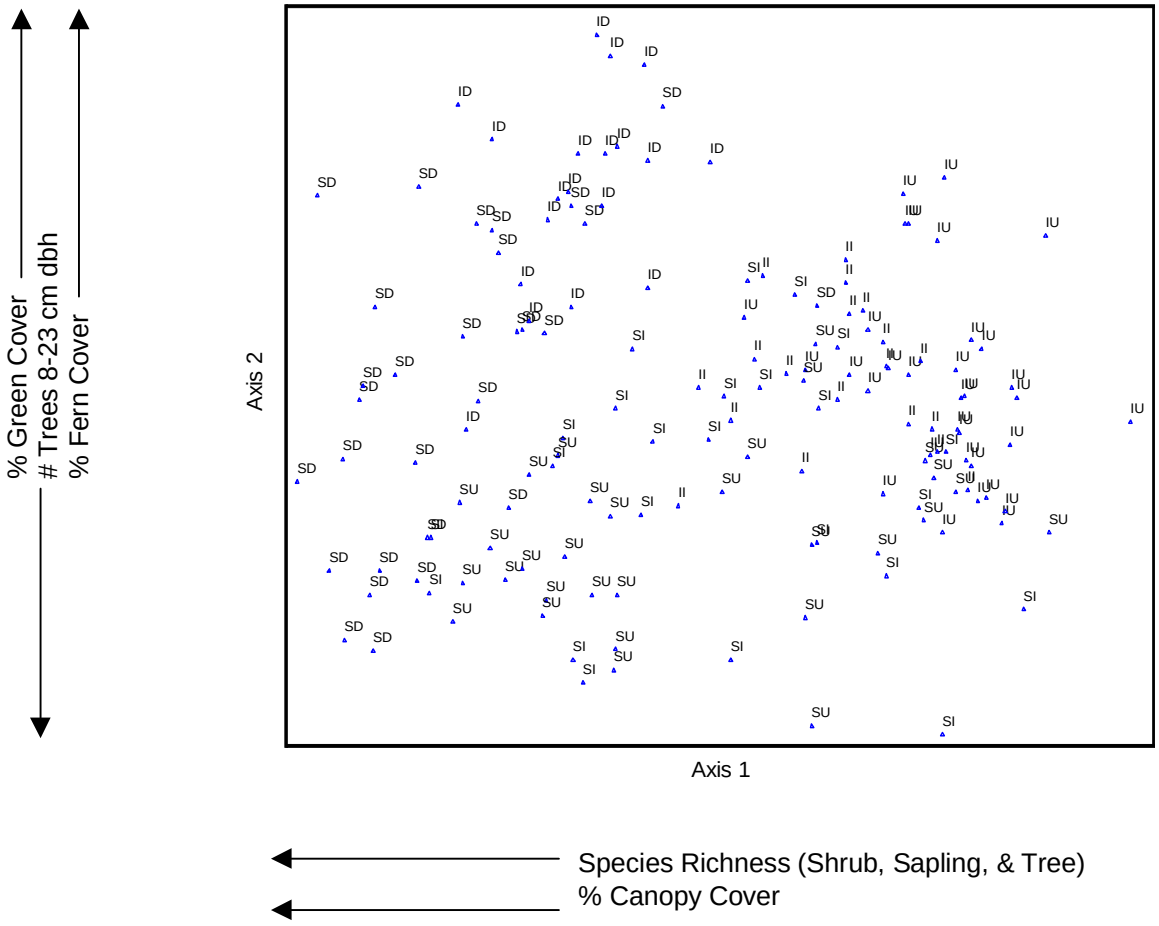


Figure 3: Principal components analysis of the vegetation parameters for the 1-YR data set (n=155) at Fort Bragg, NC. Fire treatment and location of each count station labeled by 2-letter code. First letter indicates fire treatment (I=Intense; S=Suppressed) and second letter indicates location (D=Drain; I=Intermediate; U=Upland).

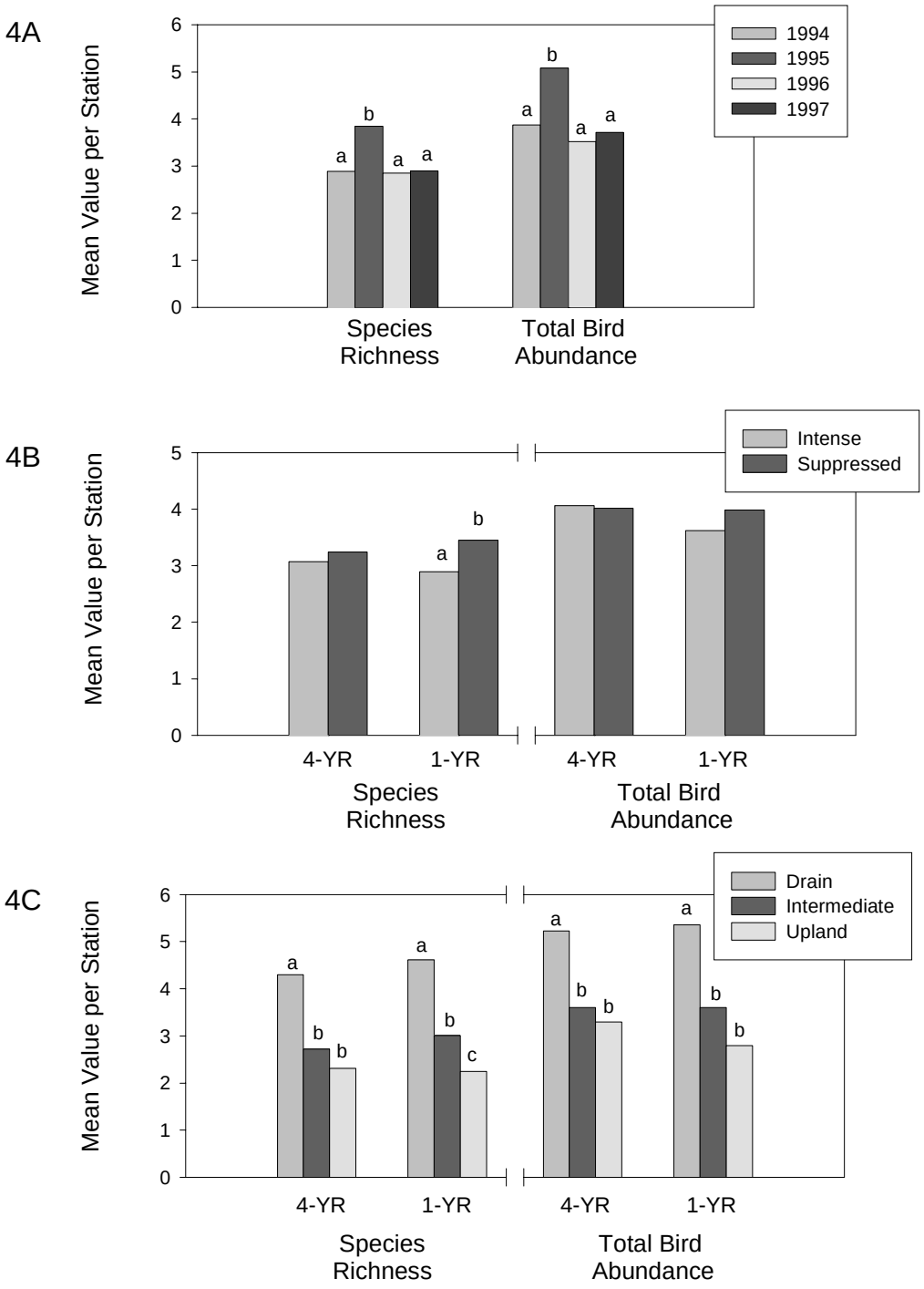


Figure 4. Mean species richness and total bird abundance in 4-YR and 1-YR by year, fire treatment and location during 1994-1997 at Fort Bragg, NC. Different letters within a bar group indicate significant differences. (4A) Mean values per year during the 4-YR study; n=65; (4B) Mean values per fire treatment; n=(4-YR: Intense=48, Suppressed=17 ; 1-YR: Intense=73, Suppressed=83); (4C) Mean values per location; n=(4-YR: Drain=22, Intermediate=21, Upland=22; 1-YR: Drain=48, Intermediate=43, Upland=65)

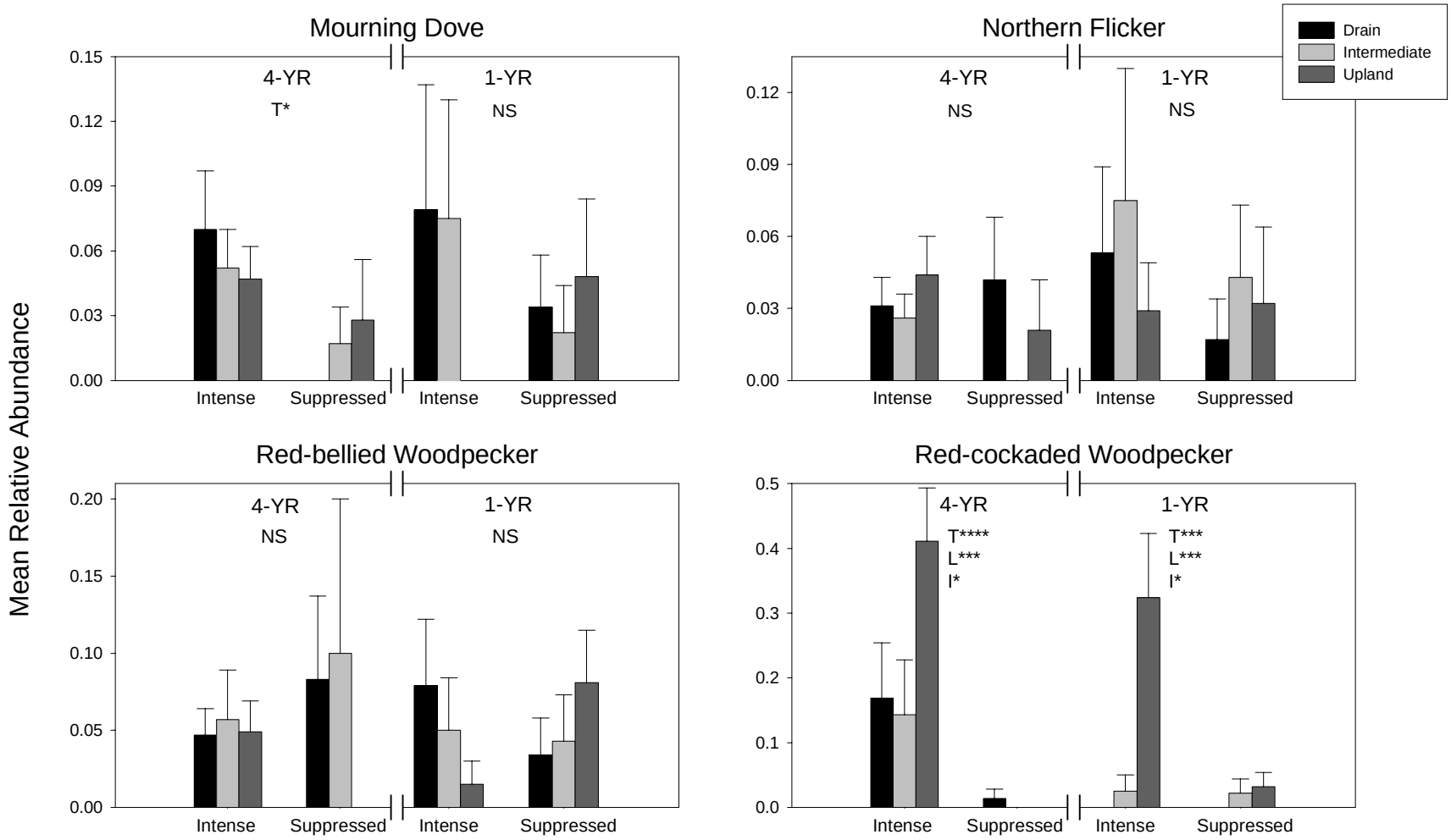


Figure 5: Mean values and standard errors of the relative abundance of breeding birds of Fort Bragg, NC in the 4-YR (individuals/station/survey/year; 1994-97) and 1-YR (individuals/station/survey; 1996) data to test for fire treatment, location, and interaction effects. Significant results by two-way factorial test are indicated by letters and symbols: T=treatment, L=location, I=interaction, NS=not significant, NT=insufficient observations to analyze, *=p<0.05, **=p<0.01, ***=p<0.001, ****=p<0.0001.

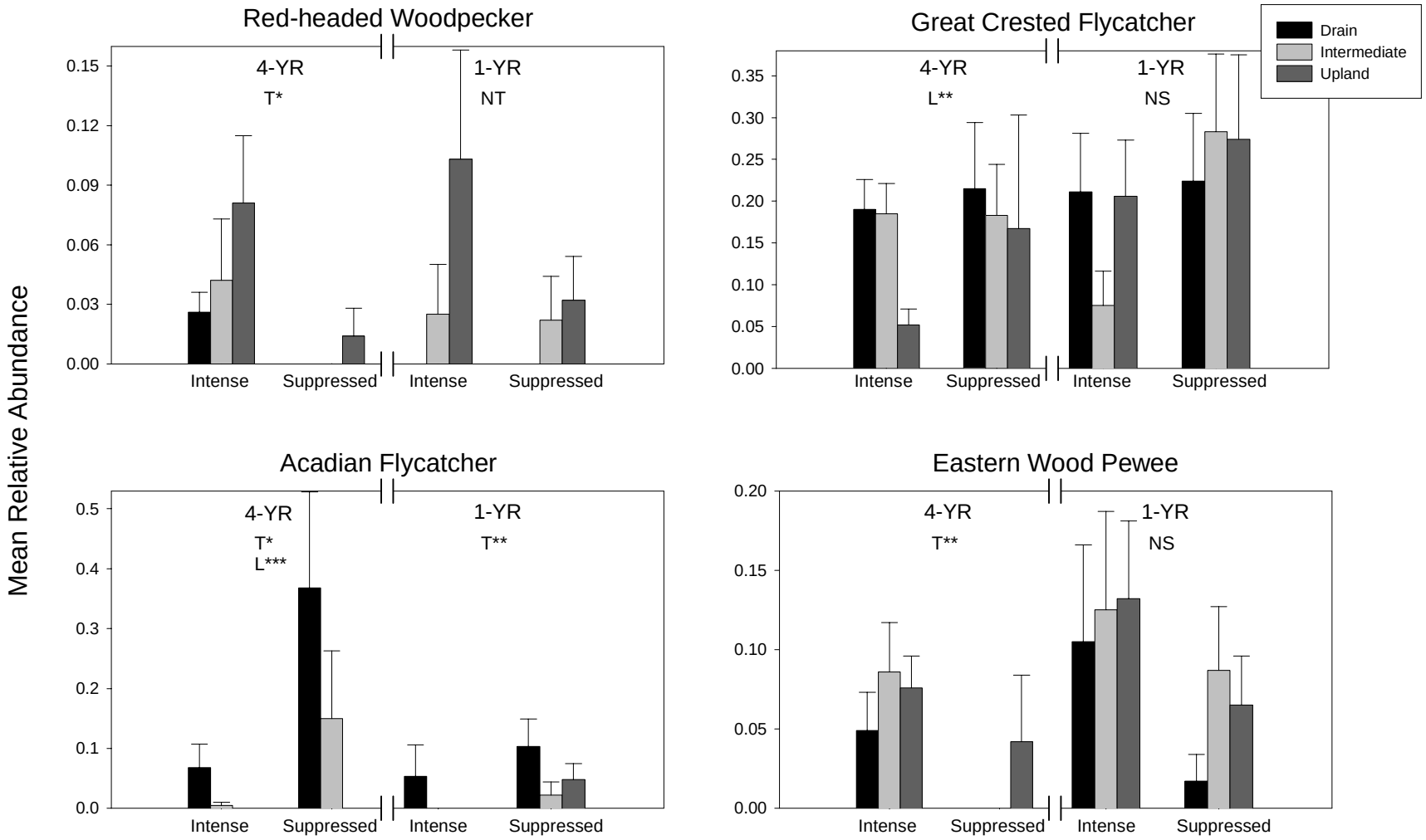
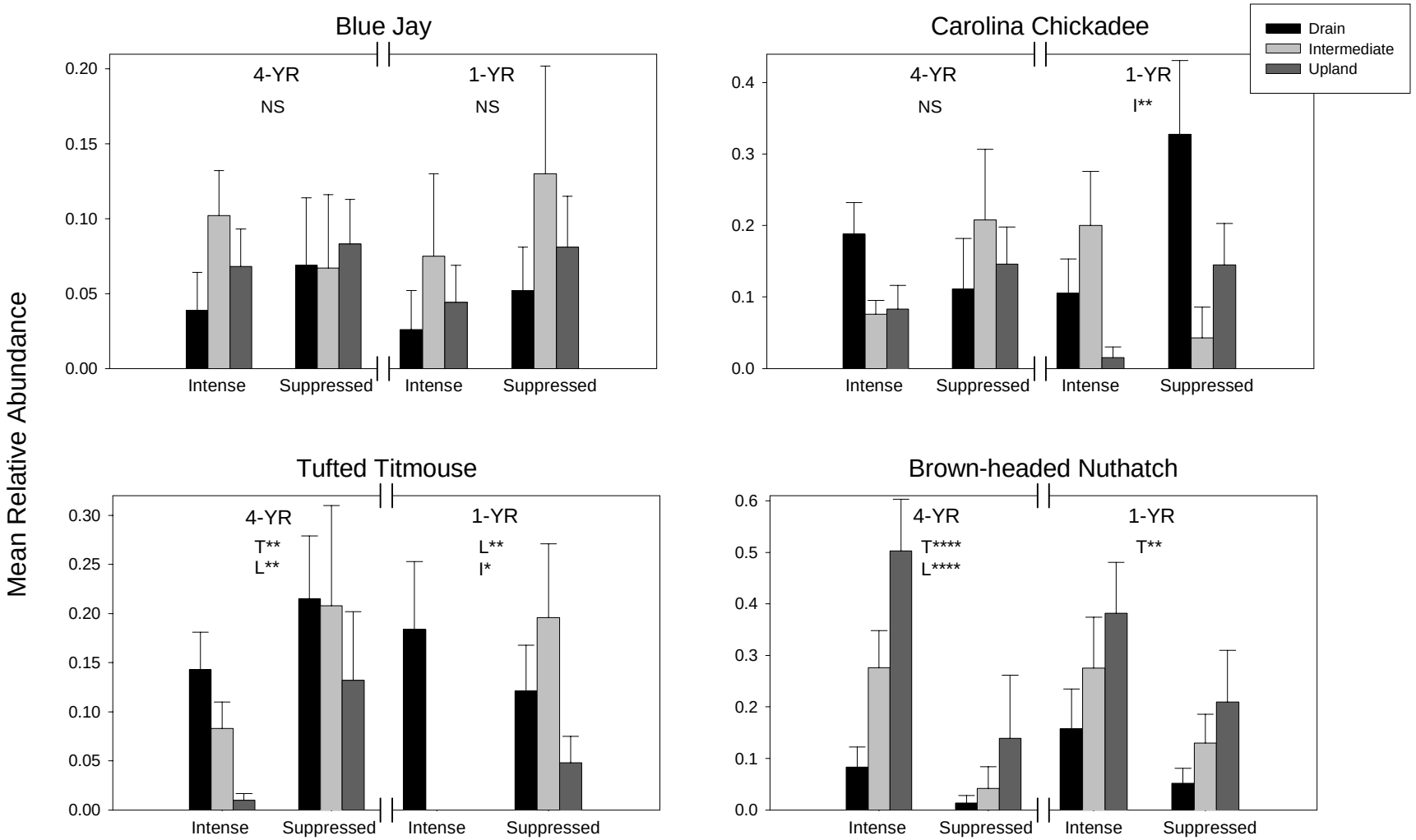


Figure 5 continued.



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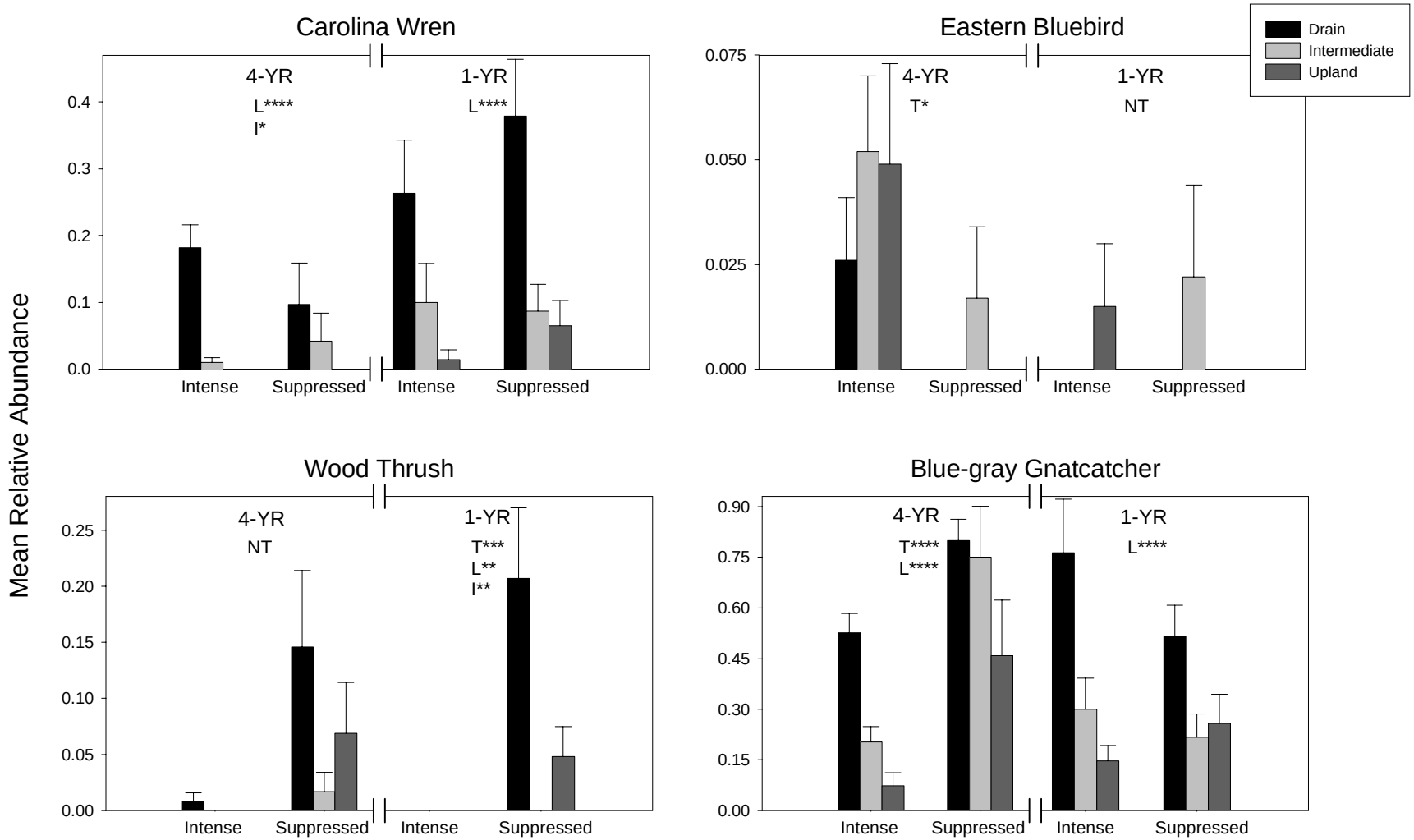

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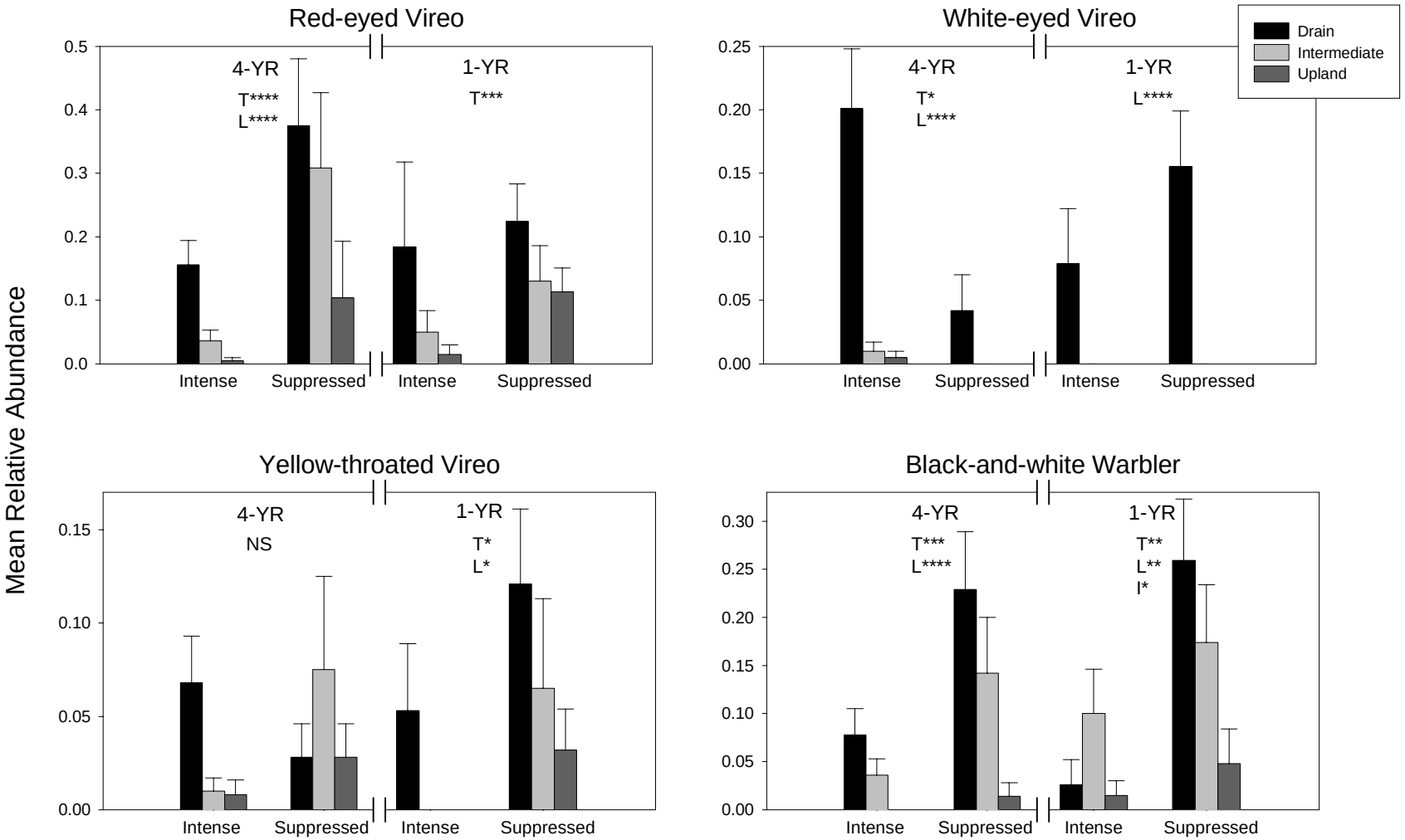

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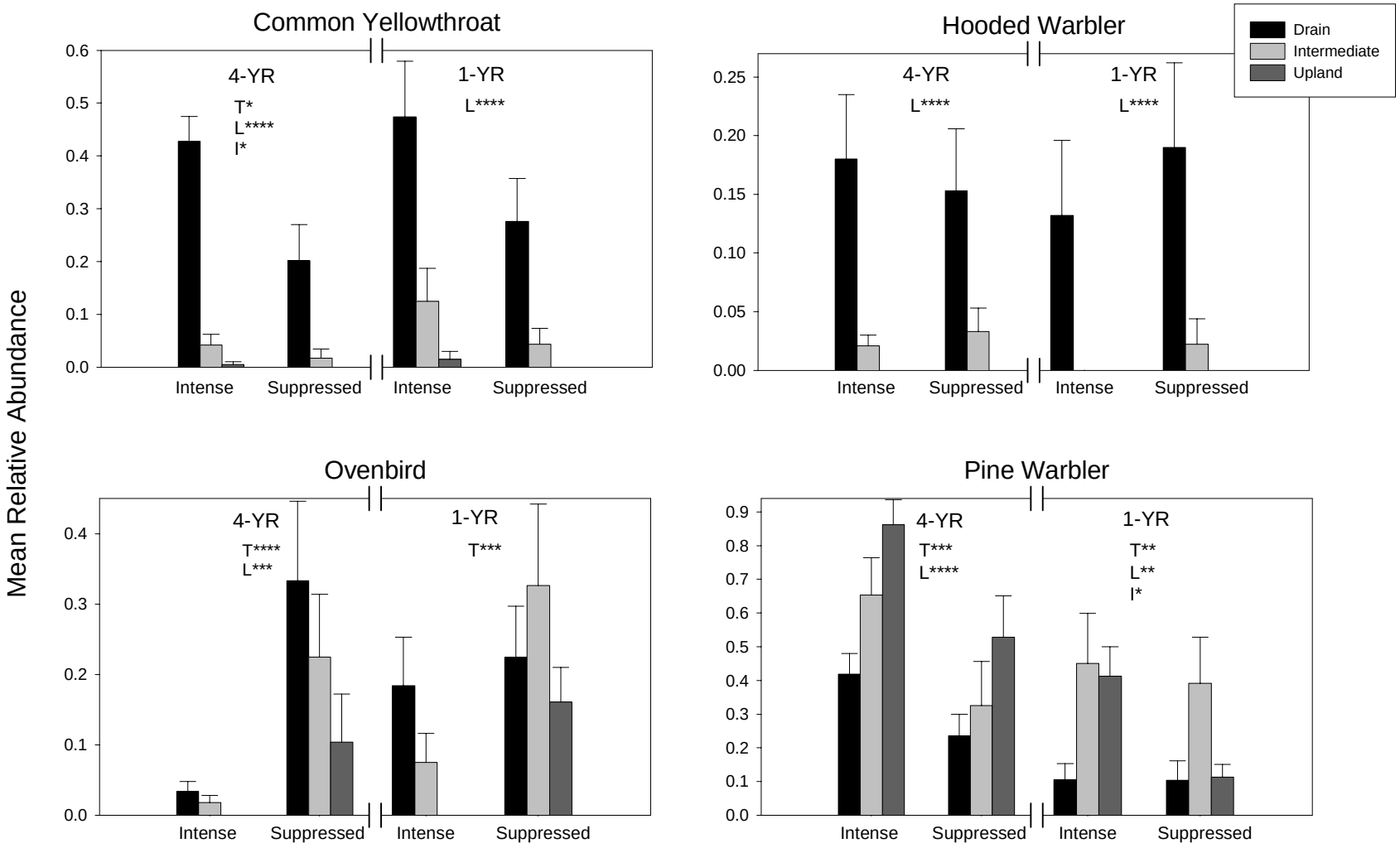

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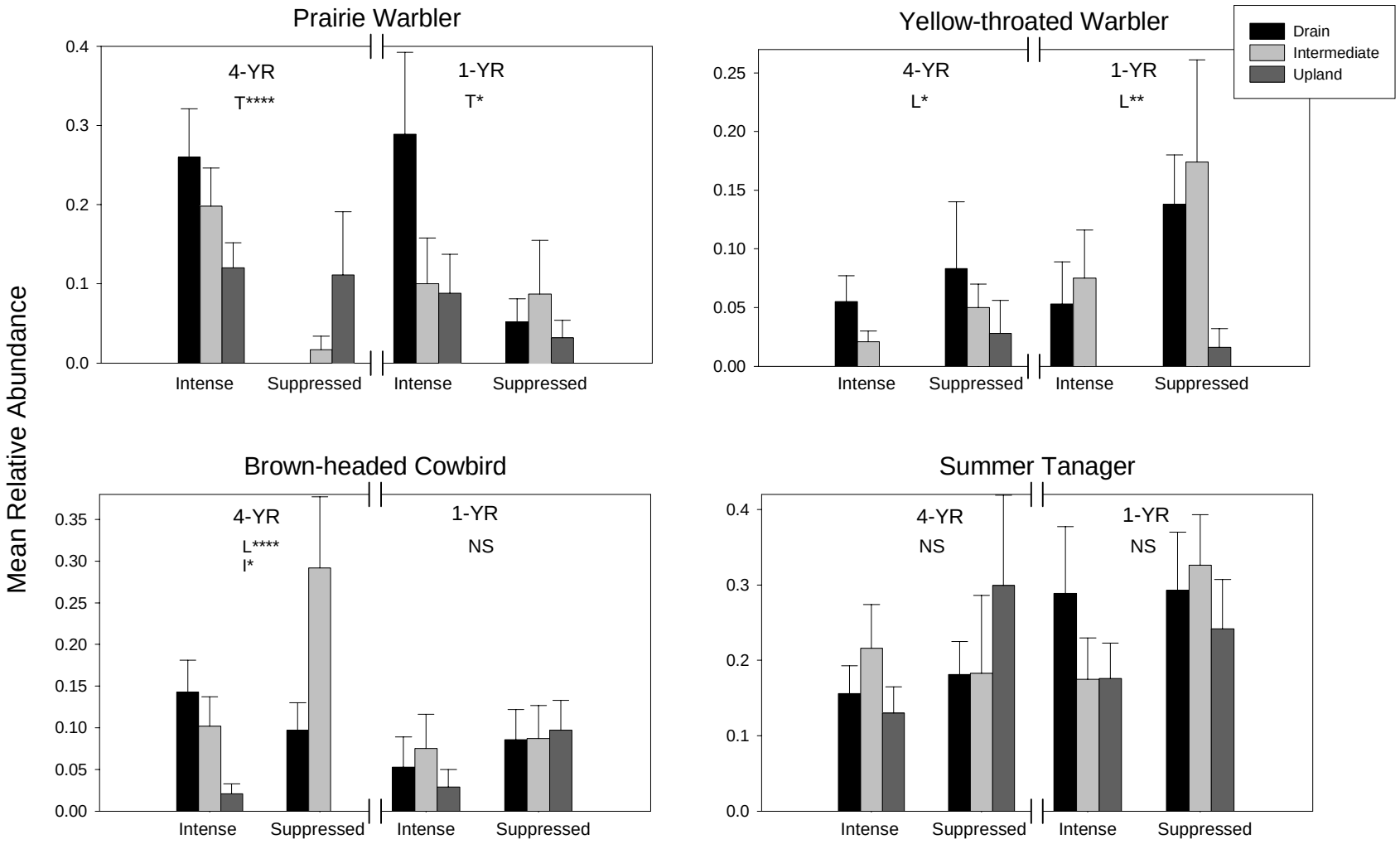

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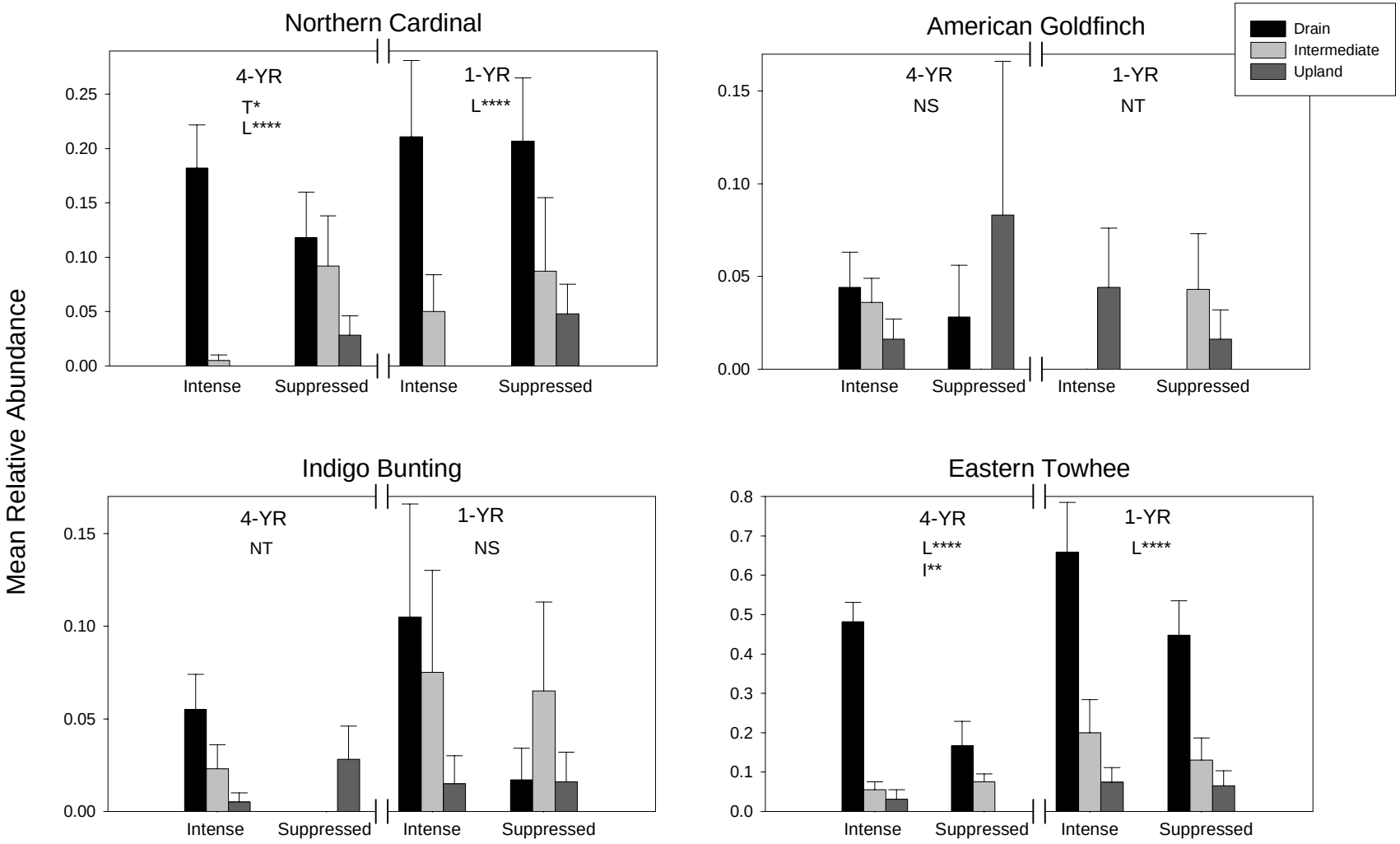

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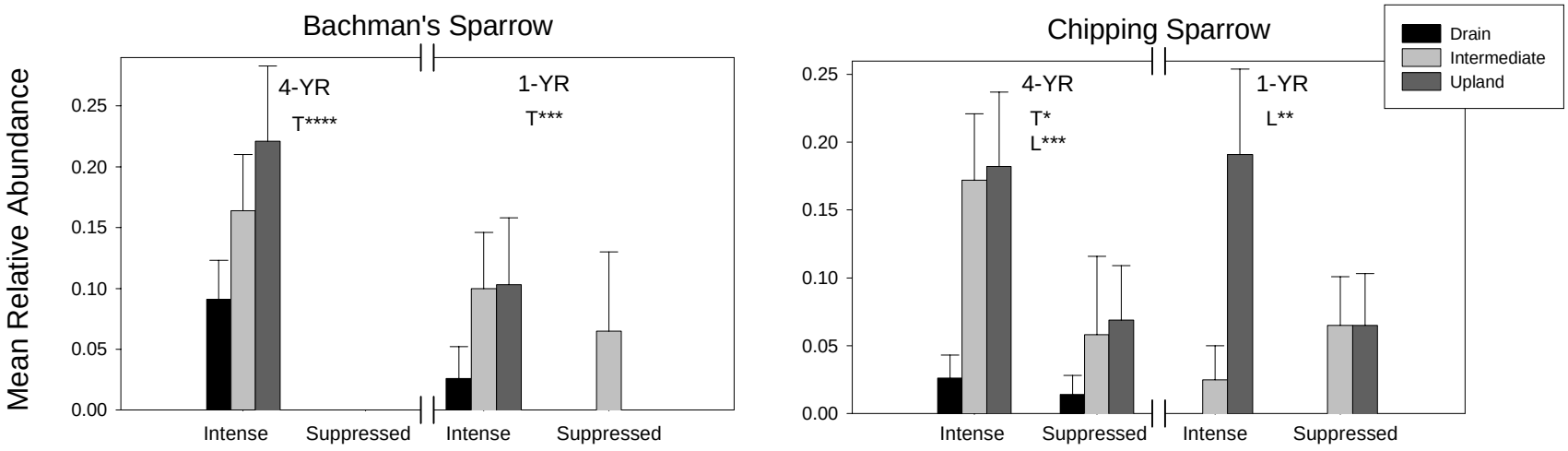

Figure 5 continued.

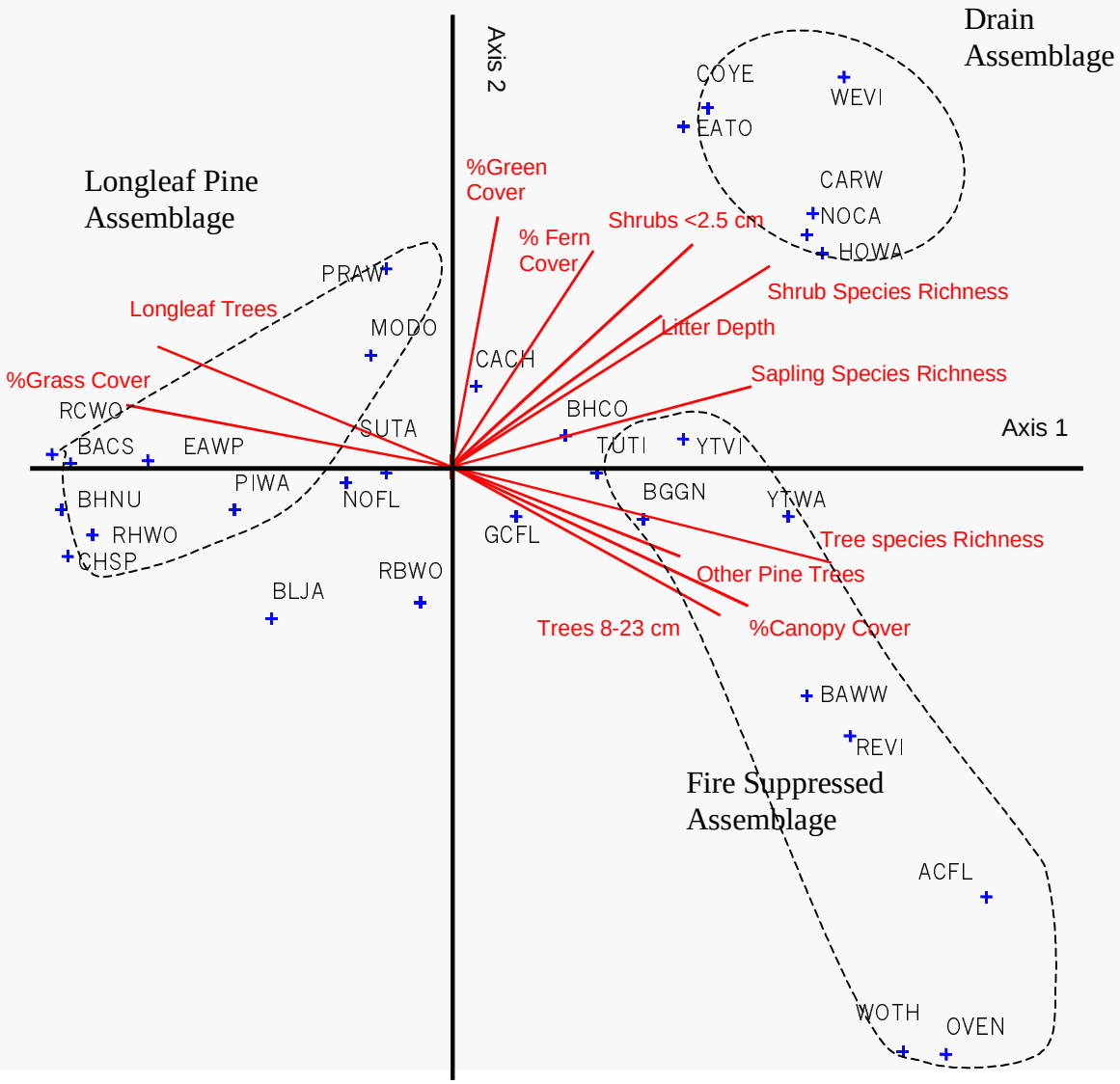

Figure 6: Bi-plot of canonical correspondence analysis for the ordination of the breeding bird community of Fort Bragg, NC in relation to habitat variables for the 4-YR data set (n=65). Species codes for the birds are given in Appendix I. Polygons indicate birds priorly defined as members of the longleaf pine, fire suppressed or drain assemblages.

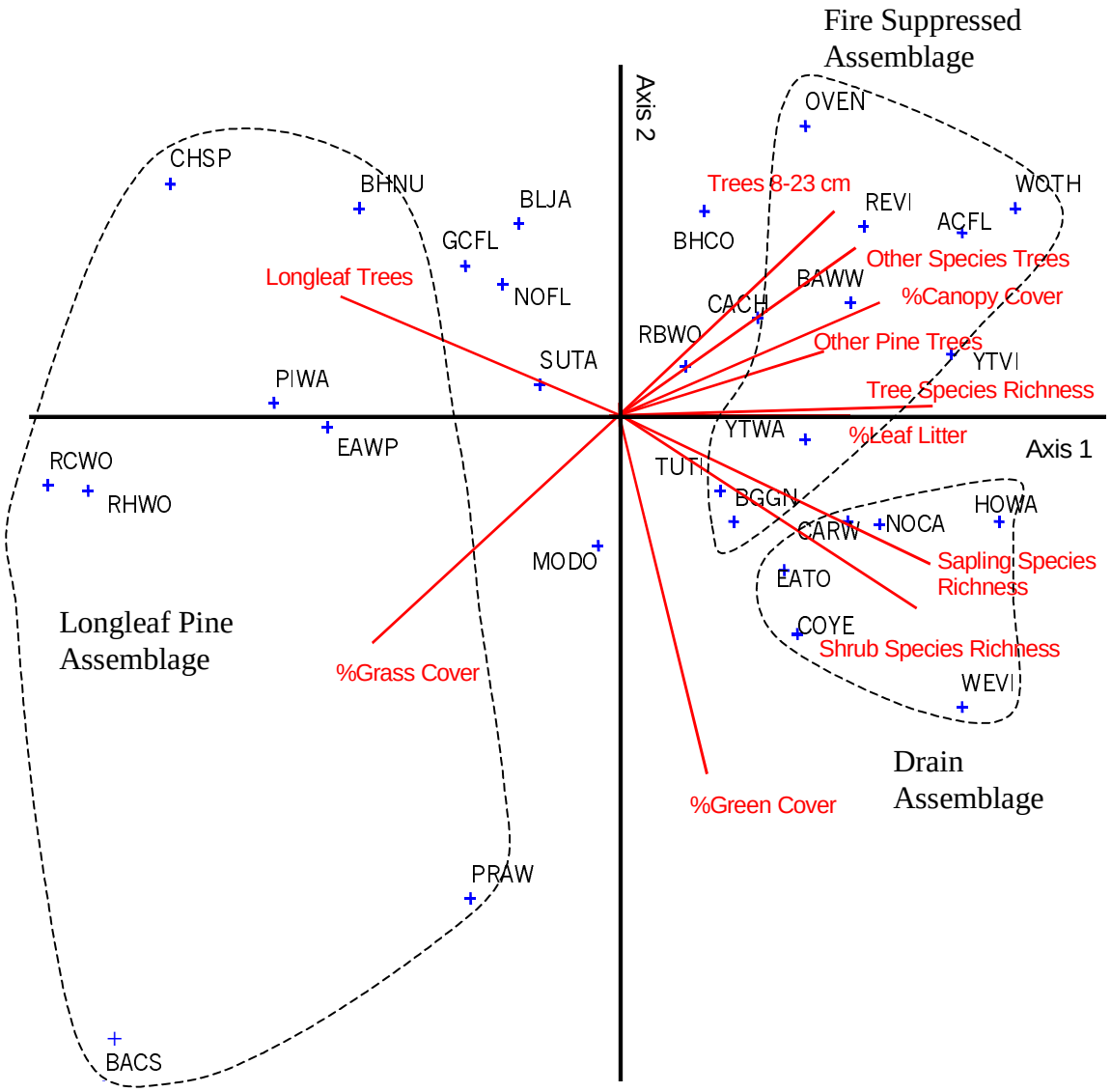

Figure 7: Bi-plot of canonical correspondence analysis for the ordination of the breeding bird community of Fort Bragg, NC in relation to habitat variables for the 1-YR data set (n=155). Species codes for the birds are given in Appendix I. Polygons indicate birds priorly defined as members of the longleaf pine, fire suppressed or drain assemblages.

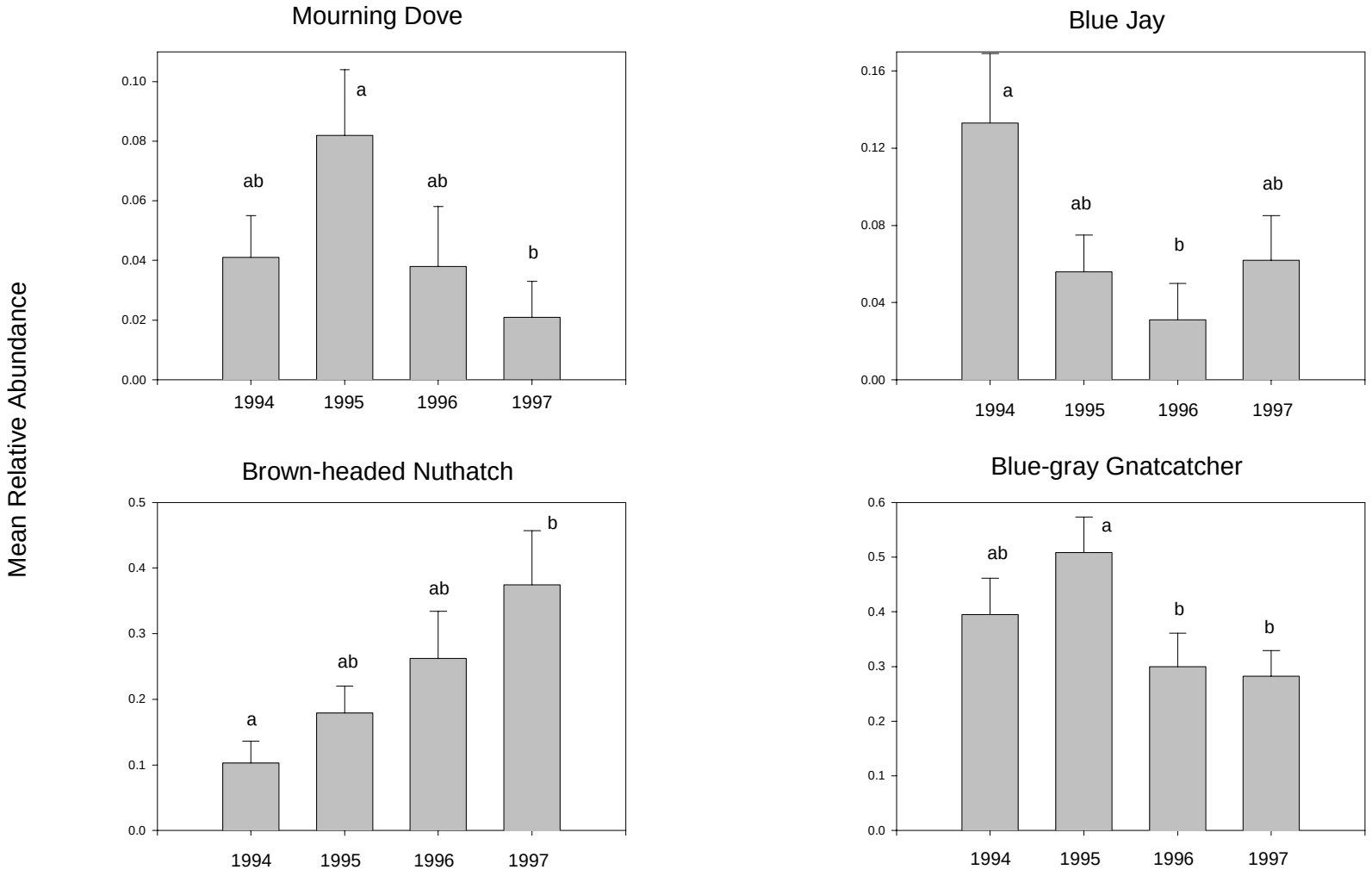

Figure 8: Mean relative abundance and standard error values from 1994 to 1997 for breeding bird species of Fort Bragg, NC with a year effect by Kruskal-Wallis tests. Different letters indicate significant differences between years by Bonferroni multiple comparison procedures.

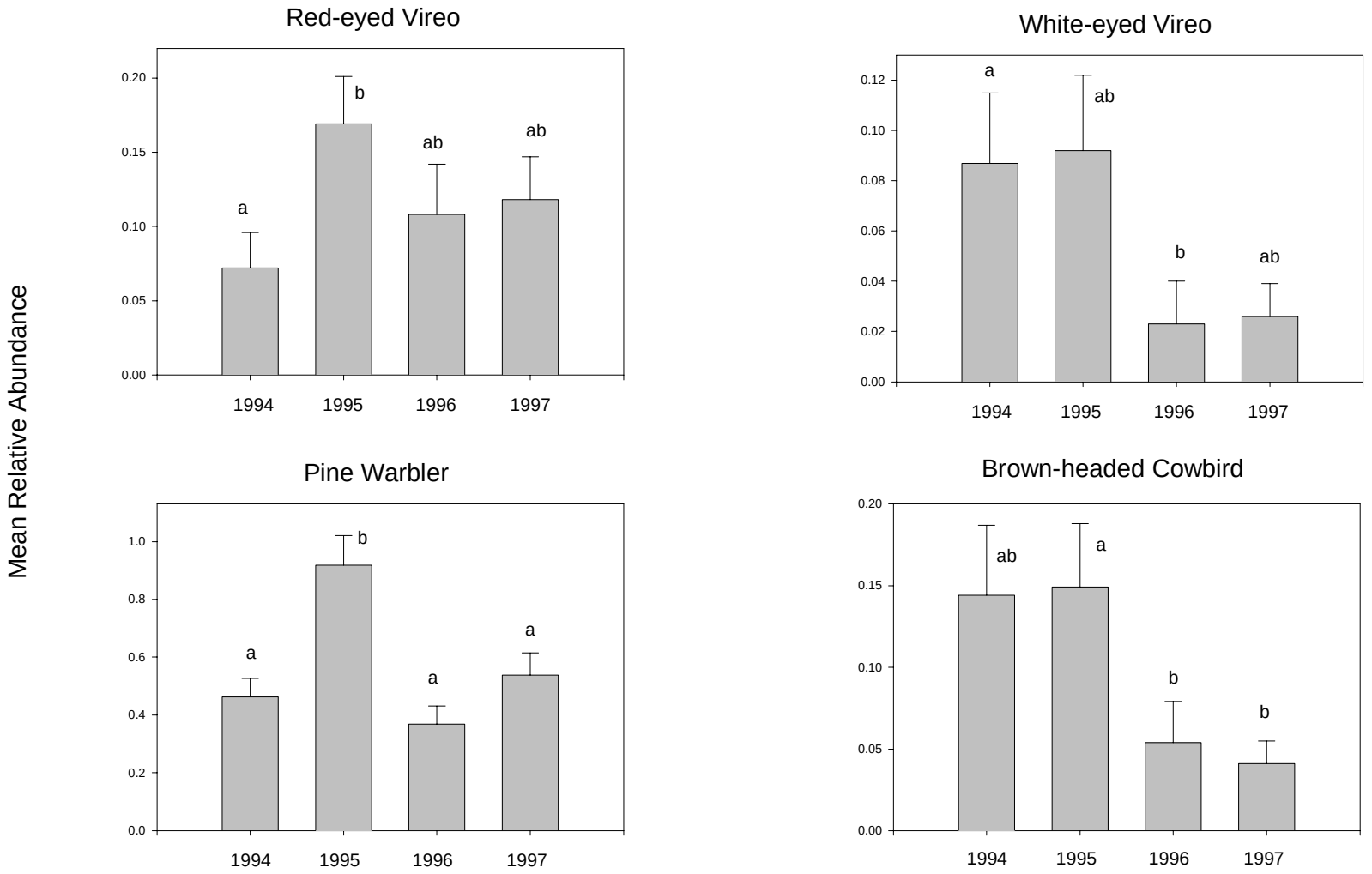

Figure 8 continued.

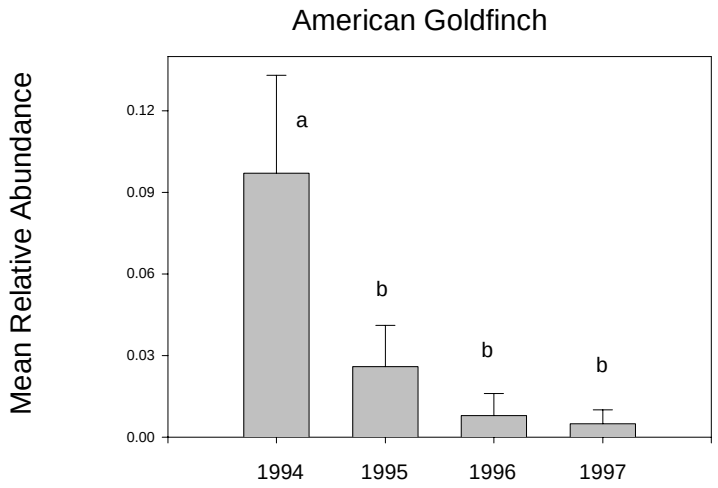

Figure 8 continued.

Appendix I. Bird species detected during unbounded point counts from 1994-1997 on Fort Bragg, NC and their species code and migratory status (R=Resident; TM=Temperate Migrant; NM=Neotropical Migrant). Scientific names based on the American Ornithologists' Union check-list of North American birds.

Common Names	Scientific Names	Species Code	Migratory Status
Canada Goose	*Branta canadensis*	CAGO	R
Wood Duck	*Aix sponsa*	WODU	TM
Turkey Vulture	*Cathartes aura*	TUVU	TM
Sharp-shinned Hawk	*Accipiter striatus*	SSHA	TM
Red-shouldered Hawk	*Buteo lineatus*	RSHA	TM
Red-tailed Hawk	*Buteo jamaicensis*	RTHA	TM
American Kestrel	*Falco sparverius*	AMKE	TM
Wild Turkey	*Meleagris gallopavo*	WITU	R
Northern Bobwhite	*Colinus virginianus*	NOBO	R
Mourning Dove	*Zenaida macroura*	MODO	TM
Yellow-billed Cuckoo	*Coccyzus americanus*	YBCU	NM
Barred Owl	*Strix varia*	BAOW	R
Eastern Screech Owl	*Otus asio*	ESOW	R
Chuck-will's-widow	*Caprimulgus carolinensis*	CWWI	NM
Common Nighthawk	*Chordeiles minor*	CONI	NM
Whip-poor-will	*Caprimulgus vociferus*	WPWI	NM
Chimney Swift	*Chaetura pelagica*	CHSW	NM
Ruby-throated Hummingbird	*Archilochus colubris*	RTHU	NM
Belted Kingfisher	*Ceryle alcyon*	BEKI	TM
Downy Woodpecker	*Picoides pubescens*	DOWO	R
Hairy Woodpecker	*Picoides villosus*	HAWO	R
Northern Flicker	*Colaptes auratus*	NOFL	TM
Pileated Woodpecker	*Dryocopus pileatus*	PIWO	R
Red-bellied Woodpecker	*Melanerpes carolinus*	RBWO	R
Red-cockaded Woodpecker	*Picoides borealis*	RCWO	R
Red-headed Woodpecker	*Melanerpes erythrocephalus*	RHWO	TM
Eastern Kingbird	*Tyrannus tyrannus*	EAKI	NM
Great Crested Flycatcher	*Myiarchus crinitus*	GCFL	NM
Eastern Phoebe	*Sayornis phoebe*	EAPH	TM
Acadian Flycatcher	*Empidonax virescens*	ACFL	NM
Eastern Wood-Pewee	*Contopus virens*	EAWP	NM
Barn Swallow	*Hirundo rustica*	BARS	NM
Purple Martin	*Progne subis*	PUMA	NM
American Crow	*Corvus brachyrhynchos*	AMCR	TM
Fish Crow	*Corvus ossifragus*	FICR	TM
Blue Jay	*Cyanocitta cristata*	BLJA	R
Carolina Chickadee	*Parus carolinensis*	CACH	R
Tufted Titmouse	*Parus bicolor*	TUTI	R
Brown-headed Nuthatch	*Sitta pusilla*	BHNU	R
Red-breasted Nuthatch [a]	*Sitta canadensis*	RBNU	TM

Appendix I continued.

Common Names	Scientific Names	Species Code	Migratory Status
White-breasted Nuthatch	*Sitta carolinensis*	WBNU	R
Carolina Wren	*Thryothorus ludovicianus*	CAWR	R
Brown Thrasher	*Toxostoma rufum*	BRTH	TM
Gray Catbird	*Dumetella carolinensis*	GRCA	NM
Northern Mockingbird	*Mimus polyglottos*	NOMO	TM
American Robin	*Turdus migratorius*	AMRO	TM
Eastern Bluebird	*Sialia sialis*	EABL	TM
Veery [a]	*Catharus fuscescens*	VEER	NM
Wood Thrush	*Hylocichla mustelina*	WOTH	NM
Blue-gray Gnatcatcher	*Polioptila caerulea*	BGGN	NM
Golden-crowned Kinglet [a]	*Regulus satrapa*	GCKI	TM
Ruby-crowned Kinglet [a]	*Regulus calendula*	RCKI	TM
Red-eyed Vireo	*Vireo olivaceus*	REVI	NM
Blue-headed Vireo [b] (solitary)	*Vireo solitarius*	SOVI	NM
White-eyed Vireo	*Vireo griseus*	WEVI	NM
Yellow-throated Vireo	*Vireo flavifrons*	YTVI	NM
American Redstart	*Setophaga ruticilla*	AMRE	NM
Bay-breasted Warbler [a]	*Dendroica castanea*	BBWA	NM
Black-and-white Warbler	*Mniotilta varia*	BAWW	NM
Black-throated Blue Warbler [a]	*Dendroica caerulescens*	BTBW	NM
Black-throated Green Warbler [a]	*Dendroica virens*	BTGW	NM
Canada Warbler [a]	*Wilsonia canadensis*	CAWA	NM
Common Yellowthroat	*Geothlypis thrichas*	COYE	NM
Hooded Warbler	*Wilsonia citrina*	HOWA	NM
Kentucky Warbler	*Oporornis formosus*	KEWA	NM
Northern Parula	*Parula americana*	NOPA	NM
Ovenbird	*Seiurus aurocapillus*	OVEN	NM
Pine Warbler	*Dendroica pinus*	PIWA	TM
Prairie Warbler	*Dendroica discolor*	PRAW	NM
Prothonotary Warbler	*Protonotaria citrea*	PROW	NM
Swainson's Warbler [a]	*Limnothlypis swainsonii*	SWWA	NM
Worm-eating Warbler	*Helmitheros vermivorus*	WEWA	NM
Yellow-breasted Chat	*Icteria virens*	YBCH	NM
Yellow-rumped Warbler [a]	*Dendroica coronata*	YRWA	TM
Yellow-throated Warbler	*Dendroica dominica*	YTWA	NM
Brown-headed Cowbird	*Molothrus ater*	BHCO	TM
Common Grackle	*Quiscalus quiscula*	COGR	TM
Eastern Meadowlark	*Sturnella magna*	EAME	TM
Red-winged Blackbird	*Agelaius phoeniceus*	RWBL	TM
Orchard Oriole	*Icterus spurius*	OROR	NM
Scarlet Tanager [c]	*Piranga olivacea*	SCTA	NM

Appendix I continued.

Common Names	Scientific Names	Species Code	Migratory Status
Summer Tanager	*Piranga rubra*	SUTA	NM
Northern Cardinal	*Cardinalis cardinalis*	NOCA	R
Blue Grosbeak	*Guiraca caerulea*	BLGR	NM
Indigo Bunting	*Passerina cyanea*	INBU	NM
American Goldfinch	*Carduelis tristis*	AMGO	TM
Eastern Towhee	*Pipilo erythrophthalmus*	EATO	TM
Bachman's Sparrow	*Aimophila aestivalis*	BACS	TM
Chipping Sparrow	*Spizella passerina*	CHSP	NM
Field Sparrow	*Spizella pusilla*	FISP	TM
White-throated Sparrow [a]	*Zonotrichia albicollis*	WTSP	TM

Other Bird species observed but not during point counts:

Broad-winged Hawk	*Buteo platypterus*
Green Heron	*Butorides striatus*
Common Snipe	*Gallinago gallinago*
Great Horned Owl	*Bubo virginianus*
Horned Larks [a] (drop zones)	*Eremophila alpestris*
Hermit Thrush [a]	*Catharus guttatus*
Loggerhead Shrike (drop zones)	*Lanius ludovicianus*
Palm Warbler [a]	*Dendroica palmarum*
Rose-breasted Grosbeaks [a]	*Pheucticus ludovicianus*
Pine Siskin [a]	*Carduelis pinus*
Savanna Sparrow (drop zones)	*Passerculus sandwichensis*
Swamp Sparrow [a]	*Melospiza melodia*

[a] Non-breeding migratory species

[b] Breeding and non-breeding migratory individuals were observed

[c] May be a breeding resident on western corner of Fort Bragg, but not included in any analyses

Appendix II. List of vegetation species recorded at point count stations and designations of each as sapling or shrub for understory data (<50 cm above ground). Scientific names based on Radford et al. (1968).

Scientific Name	Common Name	Sapling/shrub
Acer rubrum	red maple	sapling
Alnus spp.	alder	sapling
Amelanchier spp.	serviceberry	sapling
Arundinaria tecta	cane	shrub (grass)
Baptisia cinerea [a]	ashy wild indigo	shrub
Carpinus caroliniana [a]	ironwood	sapling
Carya spp.	hickory	sapling
Chamaecyparis thyoides [a]	Atlantic white cedar	sapling
Clethra alnifolia	coast pepperbush	shrub
Cornus florida	flowering dogwood	sapling
Crataegus spp. [a]	hawthorn	shrub
Cyrilla racemiflora	titi	shrub
Diospyros virginiana	persimmon	sapling
Gaylussacia spp.	huckleberry	shrub
Hamamelis virginiana	witch-hazel	sapling
Ilex coriacea	tall gallberry holly	shrub
Ilex glabra	low gallberry holly	shrub
Ilex opaca	American holly	sapling
Kalmia angustifolia [a]	sheep laurel	shrub
Liquidambar styraciflua	sweetgum	sapling
Liriodendron tulipifera	yellow poplar	sapling
Lonicera spp. [a]	honeysuckle	shrub (vine)
Lyonia ligustrina [a]	maleberry	shrub
Lyonia lucida	fetterbush	shrub
Lyonia mariana	staggerbush	shrub
Magnolia virginiana	sweetbay magnolia	sapling
Morus rubra	red mulberry	sapling
Myrica cerifera	common waxmyrtle	shrub
Myrica heterophylla	black bayberry	shrub
Nyssa sylvatica	sourgum; black gum	sapling
Osmanthus americana	devilwood	sapling
Osmunda cinnamomea	cinnamon fern	shrub (fern)
Osmunda regalis [a]	royal fern	shrub (fern)
Oxydendrum arboreum	sourwood	sapling
Parthenocissus quinquefolia [a]	Virginia creeper	shrub (vine)
Persea borbonia	redbay	sapling
Pinus echinata	shortleaf pine	sapling
Pinus elliottii [a]	slash pine	sapling
Pinus palustris	longleaf pine	sapling
Pinus serotina	pond pine	sapling
Pinus taeda	loblolly pine	sapling
Pinus virginiana [a]	Virginia pine; scrub pine	sapling

Appendix II continued.

Scientific Name	Common Name	Sapling/shrub
Prunus serotina	cherry	sapling
Pteridium aquilinum	bracken fern	shrub (fern)
Pyrus arbutifolia	red chokeberry	shrub
Quercus alba	white oak	sapling
Quercus coccinea [a]	scarlet oak	sapling
Quercus falcata	southern red oak	sapling
Quercus incana	bluejack oak	sapling
Quercus laevis	turkey oak	sapling
Quercus margaretta	sand post oak	sapling
Quercus marilandica	blackjack oak	sapling
Quercus nigra	water oak	sapling
Quercus phellos [a]	willow oak	sapling
Quercus prinus [a]	chestnut oak	sapling
Quercus stellata	post oak	sapling
Quercus velutina	black oak	sapling
Rhododendron maximum	great rhododendron	sapling
Rhododendron spp.	azalea	shrub
Rhus copallina	winged sumac	shrub
Rhus vernix	poison sumac	sapling
Robinia pseudo-acacia	black locust	sapling
Rubus spp.	blackberry/raspberry	shrub
Sassafras albidum	sassafras	sapling
Smilax spp.	greenbriar	shrub
Symplocos tinctoria	sweetleaf	sapling
Taxodium distichum [a]	bald cypress	sapling
Ulnus spp. [a]	elm	sapling
Vaccinium spp.	blueberry	shrub
Viburnum nudum	southern wild raisin	shrub
Vitis rotundifolia	muscadine grape	shrub (vine)
Wisteria frutescens [a]	American wisteria	shrub (vine)

[a] species observed at ≤5 count stations

Appendix III. Summary of principal components analysis for the 4-YR vegetation data set.

Eigenvalues and variance explained for 4-YR data set

Axis	Eigenvalue	Variance (%)
1	6.831	26.273
2	3.279	12.611
3	2.748	10.570
4	2.176	8.371
5	1.533	5.896
6	1.258	4.839
7	1.243	4.782
8	1.024	3.940
9	0.786	3.024
10	0.728	2.799

First Four Eigenvectors

Variable	1	2	3	4
% Slope	-0.096	0.159	0.001	0.073
% Canopy Cover	-0.276	-0.105	-0.278	-0.121
Canopy Height	-0.161	0.167	-0.351	-0.240
Litter Depth	-0.202	0.117	-0.162	0.294
% Green Cover	-0.075	0.428	0.233	0.104
% Grass Cover	0.278	0.226	0.114	0.037
% Forb Cover	-0.038	0.319	0.180	-0.082
% Fern Cover	-0.169	0.304	0.038	0.068
% Downed Logs	-0.149	0.010	0.266	-0.053
% Leaf Litter	-0.203	-0.126	-0.294	0.291
% Bare Ground	0.218	-0.093	0.208	-0.353
Shrubs <2.5 cm	-0.257	0.283	0.057	0.061
Shrubs 2.5-8 cm	-0.171	0.117	-0.021	-0.004
Saplings <2.5 cm	0.008	-0.002	0.201	0.387
Saplings 2.5-8 cm	-0.100	-0.170	0.124	0.362
# Trees 8-23 cm dbh	-0.219	-0.344	0.101	-0.005
# Trees >23-38 cm dbh	-0.015	0.007	-0.425	0.151
# Trees >38 cm dbh	-0.106	0.233	-0.212	-0.319
# Longleaf Pine Saplings	0.085	-0.085	0.110	0.308
# Other Pine Species Saplings	-0.179	-0.178	0.156	-0.106
# Longleaf Pine Trees	0.245	0.138	-0.218	0.256
# Other Pine Species Trees	-0.226	-0.197	0.066	-0.027
Shrub Species Richness	-0.312	0.216	0.089	-0.002
Sapling Species Richness	-0.286	0.019	0.230	0.055
Tree Species Richness	-0.308	-0.155	0.018	-0.101
# Snags >12 cm dbh	-0.187	-0.073	0.166	-0.078

Appendix IV. Summary of principal components analysis for the 1-YR vegetation data set.

Eigenvalues and variance explained for 1-YR data set

Axis	Eigenvalue	Variance (%)
1	6.677	25.680
2	3.242	12.469
3	2.067	7.948
4	1.642	6.317
5	1.543	5.934
6	1.359	5.227
7	1.168	4.492
8	1.039	3.995
9	0.889	3.419
10	0.833	3.202

First four eigenvectors for 1-YR data set

Variable	1	2	3	4
% Slope	-0.117	0.082	-0.173	0.053
% Canopy Cover	-0.293	-0.186	0.107	0.094
Canopy Height	-0.144	0.240	0.332	0.255
Litter Depth	-0.188	-0.001	0.055	-0.284
% Green Cover	-0.087	0.453	-0.057	-0.133
% Grass Cover	0.222	0.247	-0.006	-0.071
% Forb Cover	0.078	0.014	-0.061	0.227
% Fern Cover	-0.146	0.287	-0.047	-0.030
% Downed Logs	-0.210	-0.139	-0.033	-0.012
% Leaf Litter	-0.250	0.078	0.159	-0.326
% Bare Ground	0.217	-0.164	-0.229	0.226
Shrubs 2.5-8 cm	-0.158	0.156	-0.162	0.010
Saplings <2.5 cm	-0.037	0.091	-0.128	-0.527
Saplings 2.5-8 cm	-0.086	-0.090	-0.506	-0.128
# Trees 8-23 cm dbh	-0.243	-0.349	-0.066	-0.015
# Trees >23-38 cm dbh	-0.072	-0.230	0.391	-0.144
# Trees >38 cm dbh	-0.090	0.264	0.133	0.384
# Longleaf Pine Saplings	0.084	0.022	-0.449	0.035
# Other Pine Species Saplings	-0.124	0.110	-0.088	0.186
# Longleaf Pine Trees	0.226	-0.091	0.137	-0.262
# Other Pine Species Trees	-0.246	-0.178	0.104	0.030
# Other Species (non-pine) Trees	-0.245	-0.263	-0.149	0.143
Shrub Species Richness	-0.290	0.258	-0.052	0.006
Sapling Species Richness	-0.310	0.146	-0.118	-0.036
Tree Species Richness	-0.332	-0.072	-0.076	0.121
# Snags >12 cm dbh	-0.128	-0.029	-0.031	-0.079

Appendix V. Mean values of relative abundance (and standard errors) by fire treatment for the breeding birds detected within 50 m of count stations for Fort Bragg, NC are shown for the 4-YR (individuals/station/survey/year; n=65) and 1-YR (individuals/station/survey; n=156) data sets collected from 1994 to 1997.

	4-YR		1-YR	
	Intense	Suppressed	Intense	Suppressed
Bird Species	n=48	n=17	n=73	n=83
Wood Duck	0.000	0.010 (0.010)	0.000	0.000
Turkey Vulture	0.000	0.005 (0.005)	0.000	0.000
Sharp-shinned Hawk	0.000	0.010 (0.010)	0.000	0.000
Red-shouldered Hawk	0.000	0.010 (0.010)	0.000	0.000
American Kestrel	0.007 (0.004)	0.010 (0.010)	0.000	0.000
Northern Bobwhite	0.014 (0.006)	0.010 (0.010)	0.027 (0.013)	0.012 (0.008)
Mourning Dove	0.056 (0.012)	0.015 (0.011)	0.041 (0.021)	0.036 (0.017)
Yellow-billed Cuckoo	0.011 (0.004)	0.034 (0.019)	0.014 (0.010)	0.042 (0.015)
Barred Owl	0.000	0.000	0.000	0.012 (0.008)
Chuck-will's-widow	0.000	0.000	0.000	0.006 (0.006)
Common Nighthawk	0.009(0.004)	0.005 (0.005)	0.021 (0.012)	0.018 (0.010)
Whip-poor-will	0.002 (0.002)	0.000	0.000	0.000
Chimney Swift	0.000	0.010 (0.010)	0.014 (0.014)	0.000
Ruby-throated Hummingbird	0.002 (0.002)	0.017 (0.009)	0.014 (0.010)	0.018 (0.010)
Belted Kingfisher	0.000	0.000	0.000	0.006 (0.006)
Downy Woodpecker	0.018 (0.006)	0.025 (0.025)	0.021 (0.012)	0.012 (0.008)
Hairy Woodpecker	0.002 (0.002)	0.020 (0.011)	0.007 (0.007)	0.012 (0.008)
Northern Flicker	0.034 (0.007)	0.022 (0.012)	0.048 (0.020)	0.030 (0.016)
Pileated Woodpecker	0.014 (0.005)	0.025 (0.009)	0.014 (0.010)	0.024 (0.011)
Red-bellied Woodpecker	0.051 (0.013)	0.059 (0.034)	0.041 (0.0.16)	0.048 (0.016)
Red-cockaded Woodpecker	0.241 (0.050)	0.005 (0.005)	0.158 (0.050)	0.018 (0.094)
Red-headed Woodpecker	0.049 (0.016)	0.005 (0.005)	0.055 (0.027)	0.018 (0.010)

Appendix V continued

	4-YR		1-YR	
	Intense	Suppressed	Intense	Suppressed
Bird Species	n=48	n=17	n=73	n=83
Eastern Kingbird	0.000	0.005 (0.005)	0.007 (0.007)	0.024 (0.012)
Great Crested Flycatcher	0.142 (0.020)	0.189 (0.055)	0.171 (0.038)	0.259 (0.053)
Acadian Flycatcher	0.024 (0.014)	0.174 (0.073)	0.014 (0.014)	0.060 (0.020)
Eastern Wood Pewee	0.070 (0.015)	0.015 (0.015)	0.123 (0.032)	0.054 (0.017)
Barn Swallow	0.002 (0.002)	0.000	0.000	0.000
Purple Martin	0.002 (0.002)	0.000	0.000	0.000
American Crow	0.017 (0.007)	0.000	0.000	0.006 (0.006)
Fish Crow	0.010 (0.010)	0.000	0.000	0.018 (0.018)
Blue Jay	0.069 (0.016)	0.074 (0.022)	0.048 (0.020)	0.084 (0.025)
Carolina Chickadee	0.115 (0.020)	0.152 (0.041)	0.089 (0.026)	0.181 (0.045)
Tufted Titmouse	0.079 (0.017)	0.184 (0.043)	0.048 (0.020)	0.114 (0.029)
Brown-headed Nuthatch	0.287 (0.050)	0.066 (0.045)	0.295 (0.058)	0.133 (0.042)
White-breasted Nuthatch	0.010 (0.010)	0.010 (0.010)	0.000	0.012 (0.008)
Carolina Wren	0.064 (0.017)	0.047 (0.026)	0.103 (0.029)	0.181 (0.038)
Brown Thrasher	0.028 (0.011)	0.015 (0.008)	0.014 (0.010)	0.024 (0.015)
Gray Catbird	0.020 (0.008)	0.020 (0.013)	0.055 (0.029)	0.006 (0.006)
American Robin	0.022 (0.009)	0.010 (0.010)	0.021 (0.015)	0.012 (0.008)
Eastern Bluebird	0.043 (0.011)	0.005 (0.005)	0.007 (0.007)	0.006 (0.006)
Wood Thrush	0.003 (0.003)	0.081 (0.030)	0.000	0.090 (0.026)
Blue-gray Gnatcatcher	0.267 (0.039)	0.664 (0.081)	0.349 (0.060)	0.337 (0.051)
Red-eyed Vireo	0.066 (0.017)	0.260 (0.063)	0.068 (0.037)	0.157 (0.030)
Solitary Vireo	0.003 (0.002)	0.000	0.000	0.006 (0.006)
White-eyed Vireo	0.072 (0.020)	0.015 (0.011)	0.021 (0.012)	0.054 (0.017)
Yellow-throated Vireo	0.029 (0.010)	0.042 (0.017)	0.014 (0.010)	0.072 (0.021)

Appendix V continued.

	4-YR		1-YR	
Bird Species	Intense n=48	Suppressed n=17	Intense n=73	Suppressed n=83
American Redstart	0.004 (0.003)	0.010 (0.010)	0.000	0.000
Black-and-white Warbler	0.038 (0.011)	0.127 (0.034)	0.041 (0.016)	0.157 (0.032)
Common Yellowthroat	0.158 (0.033)	0.076 (0.033)	0.164 (0.039)	0.108 (0.032)
Hooded Warbler	0.067 (0.022)	0.064 (0.025)	0.034 (0.018)	0.072 (0.027)
Kentucky Warbler	0.002 (0.002)	0.015 (0.011)	0.000	0.012 (0.008)
Northern Parula	0.007 (0.004)	0.000	0.000	0.012 (0.008)
Ovenbird	0.017 (0.006)	0.221 (0.056)	0.068 (0.022)	0.229 (0.045)
Pine Warbler	0.645 (0.054)	0.365 (0.067)	0.342 (0.061)	0.187 (0.047)
Prairie Warbler	0.193 (0.029)	0.044 (0.030)	0.144 (0.040)	0.054 (0.023)
Prothonotary Warbler	0.000	0.007 (0.007)	0.000	0.012 (0.008)
Worm-eating Warbler	0.002 (0.002)	0.000	0.000	0.000
Yellow-breasted Chat	0.010 (0.010)	0.000	0.014 (0.010)	0.006 (0.006)
Yellow-throated Warbler	0.025 (0.008)	0.054 (0.023)	0.034 (0.015)	0.102 (0.029)
Brown-headed Cowbird	0.089 (0.019)	0.120 (0.039)	0.048 (0.017)	0.090 (0.021)
Common Grackle	0.003 (0.002)	0.015 (0.008)	0.000	0.000
Summer Tanager	0.168 (0.026)	0.223 (0.053)	0.205 (0.035)	0.283 (0.040)
Northern Cardinal	0.062 (0.018)	0.078 (0.022)	0.068 (0.022)	0.114 (0.030)
Blue Grosbeak	0.008 (0.004)	0.005 (0.005)	0.007 (0.007)	0.000
Indigo Bunting	0.028 (0.008)	0.010 (0.010)	0.055 (0.023)	0.030 (0.016)
American Goldfinch	0.032 (0.009)	0.039 (0.030)	0.021 (0.015)	0.018 (0.010)
Eastern Towhee	0.189 (0.036)	0.081 (0.028)	0.261 (0.052)	0.217 (0.041)
Bachman’s Sparrow	0.159 (0.028)	0.000	0.082 (0.029)	0.018 (0.018)
Chipping Sparrow	0.127 (0.027)	0.047 (0.022)	0.096 (0.032)	0.042 (0.018)
Field Sparrow	0.000	0.000	0.014 (0.010)	0.000

Appendix VI. Mean values and standard errors of relative abundance by location for the breeding birds detected within 50 m of count stations for Fort Bragg, NC are shown for the 4-YR (individuals/station/survey/year; n=65) and 1-YR (individuals/station/survey; n=156) data sets collected from 1994 to 1997.

	4-YR			1-YR		
	Drain	Intermediate	Upland	Drain	Intermediate	Upland
Bird Species	n=22	n=21	n=22	n=48	n=43	n=65
Wood Duck	0.000	0.000	0.008(0.008)	0.000	0.000	0.000
Turkey Vulture	0.000	0.004(0.004)	0.000	0.000	0.000	0.000
Sharp-shinned Hawk	0.000	0.000	0.008(0.008)	0.000	0.000	0.000
Red-shouldered Hawk	0.000	0.000	0.008(0.008)	0.000	0.000	0.000
American Kestrel	0.000	0.008(0.008)	0.015(0.009)	0.000	0.000	0.000
Northern Bobwhite	0.019(0.009)	0.020(0.012)	0.000	0.021(0.015)	0.012(0.012)	0.023(0.013)
Mourning Dove	0.051(0.021)	0.044(0.015)	0.042(0.013)	0.052(0.027)	0.047(0.028)	0.023(0.017)
Yellow-billed Cuckoo	0.034(0.015)	0.010(0.007)	0.008(0.008)	0.031(0.018)	0.035(0.020)	0.023(0.013)
Barred Owl	0.000	0.000	0.000	0.021(0.015)	0.000	0.000
Chuck-will's-widow	0.000	0.000	0.000	0.000	0.012(0.012)	0.000
Common Nighthawk	0.004(0.004)	0.004(0.004)	0.015(0.009)	0.021(0.015)	0.023(0.016)	0.015(0.011)
Whip-poor-will	0.000	0.000	0.004(0.004)	0.000	0.000	0.000
Chimney Swift	0.008(0.008)	0.000	0.000	0.000	0.024(0.024)	0.000
Ruby-throated Hummingbird	0.000	0.010(0.007)	0.008(0.005)	0.031(0.018)	0.000	0.015(0.011)
Belted Kingfisher	0.000	0.000	0.000	0.010(0.010)	0.000	0.000
Downy Woodpecker	0.025(0.011)	0.016(0.009)	0.019(0.008)	0.010(0.010)	0.023(0.016)	0.015(0.011)
Hairy Woodpecker	0.004(0.004)	0.016(0.009)	0.000	0.021(0.015)	0.000	0.008(0.008)
Northern Flicker	0.034(0.011)	0.020(0.008)	0.038(0.013)	0.031(0.018)	0.058(0.030)	0.031(0.019)
Pileated Woodpecker	0.021(0.009)	0.022(0.009)	0.008(0.005)	0.000	0.023(0.016)	0.031(0.015)
Red-bellied Woodpecker	0.057(0.019)	0.067(0.033)	0.036(0.015)	0.052(0.022)	0.035(0.020)	0.046(0.018)
Red-cockaded Woodpecker	0.127(0.063)	0.109(0.066)	0.299(0.071)	0.000	0.023(0.016)	0.185(0.055)
Red-headed Woodpecker	0.019(0.008)	0.032(0.024)	0.062(0.025)	0.000	0.023(0.016)	0.069(0.031)

Appendix VI continued.

	4-YR			1-YR		
Bird Species	Drain n=22	Intermediate n=21	Upland n=22	Drain n=48	Intermediate n=43	Upland n=65
Eastern Kingbird	0.000	0.000	0.004(0.004)	0.010(0.010)	0.035(0.020)	0.008(0.008)
Great Crested Flycatcher	0.197(0.033)	0.185(0.031)	0.083(0.039)	0.219(0.056)	0.186(0.055)	0.238(0.059)
Acadian Flycatcher	0.150(0.057)	0.040(0.029)	0.000	0.083(0.034)	0.012(0.012)	0.023(0.013)
Eastern Wood Pewee	0.036(0.018)	0.065(0.025)	0.066(0.018)	0.052(0.027)	0.105(0.036)	0.100(0.029)
Barn Swallow	0.000	0.000	0.004(0.004)	0.000	0.000	0.000
Purple Martin	0.000	0.004(0.004)	0.000	0.000	0.000	0.000
American Crow	0.008(0.005)	0.016(0.009)	0.015(0.012)	0.010(0.010)	0.000	0.000
Fish Crow	0.000	0.012(0.009)	0.011(0.011)	0.000	0.000	0.023(0.023)
Blue Jay	0.047(0.022)	0.093(0.025)	0.072(0.020)	0.042(0.020)	0.105(0.046)	0.062(0.021)
Carolina Chickadee	0.167(0.037)	0.107(0.029)	0.100(0.028)	0.240(0.067)	0.116(0.044)	0.077(0.029)
Tufted Titmouse	0.163(0.033)	0.113(0.032)	0.044(0.022)	0.146(0.039)	0.105(0.043)	0.023(0.013)
Brown-headed Nuthatch	0.064(0.029)	0.220(0.059)	0.403(0.086)	0.094(0.035)	0.198(0.056)	0.300(0.071)
White-breasted Nuthatch	0.025(0.012)	0.004(0.004)	0.000	0.010(0.010)	0.000	0.008(0.008)
Carolina Wren	0.159(0.030)	0.018(0.011)	0.000	0.333(0.060)	0.093(0.034)	0.038(0.020)
Brown Thrasher	0.032(0.011)	0.016(0.009)	0.025(0.020)	0.052(0.027)	0.000	0.008(0.008)
Gray Catbird	0.055(0.018)	0.004(0.004)	0.000	0.063(0.038)	0.035(0.026)	0.000
American Robin	0.023(0.010)	0.008(0.008)	0.025(0.017)	0.000	0.000	0.038(0.020)
Eastern Bluebird	0.019(0.011)	0.044(0.015)	0.036(0.018)	0.000	0.012(0.012)	0.008(0.008)
Wood Thrush	0.045(0.023)	0.004(0.004)	0.019(0.013)	0.125(0.041)	0.000	0.023(0.013)
Blue-gray Gnatcatcher	0.600(0.052)	0.333(0.071)	0.178(0.063)	0.615(0.085)	0.256(0.056)	0.200(0.048)
Red-eyed Vireo	0.216(0.044)	0.101(0.039)	0.032(0.025)	0.208(0.063)	0.093(0.034)	0.062(0.021)
Solitary Vireo	0.008(0.005)	0.000	0.000	0.000	0.000	0.008(0.008)
White-eyed Vireo	0.157(0.038)	0.008(0.005)	0.004(0.004)	0.125(0.032)	0.000	0.000
Yellow-throated Vireo	0.057(0.019)	0.026(0.014)	0.013(0.007)	0.094(0.028)	0.035(0.026)	0.015(0.011)

Appendix VI continued.

	4-YR			1-YR		
Bird Species	Drain n=22	Intermediate n=21	Upland n=22	Drain n=48	Intermediate n=43	Upland n=65
American Redstart	0.017(0.008)	0.000	0.000	0.000	0.000	0.000
Black-and-white Warbler	0.119(0.029)	0.062(0.021)	0.004(0.004)	0.167(0.043)	0.140(0.038)	0.031(0.019)
Common Yellowthroat	0.366(0.045)	0.036(0.016)	0.004(0.004)	0.354(0.065)	0.081(0.033)	0.008(0.008)
Hooded Warbler	0.172(0.042)	0.024(0.008)	0.000	0.167(0.050)	0.012(0.012)	0.000
Kentucky Warbler	0.011(0.008)	0.004(0.004)	0.000	0.021(0.015)	0.000	0.000
Northern Parula	0.011(0.008)	0.004(0.004)	0.000	0.021(0.015)	0.000	0.000
Ovenbird	0.116(0.042)	0.067(0.029)	0.028(0.020)	0.208(0.051)	0.209(0.067)	0.077(0.025)
Pine Warbler	0.369(0.050)	0.575(0.093)	0.771(0.070)	0.104(0.039)	0.419(0.010)	0.269(0.053)
Prairie Warbler	0.189(0.051)	0.155(0.040)	0.117(0.031)	0.146(0.047)	0.093(0.045)	0.062(0.028)
Prothonotary Warbler	0.000	0.000	0.000	0.021(0.015)	0.000	0.000
Worm-eating Warbler	0.004(0.004)	0.000	0.000	0.000	0.000	0.000
Yellow-breasted Chat	0.021(0.014)	0.000	0.000	0.031(0.018)	0.000	0.000
Yellow-throated Warbler	0.062(0.022)	0.028(0.009)	0.008(0.008)	0.104(0.030)	0.128(0.050)	0.008(0.008)
Brown-headed Cowbird	0.131(0.029)	0.147(0.037)	0.015(0.009)	0.073(0.026)	0.081(0.028)	0.062(0.021)
Common Grackle	0.004(0.004)	0.008(0.005)	0.008(0.005)	0.000	0.000	0.000
Summer Tanager	0.163(0.029)	0.208(0.049)	0.176(0.043)	0.292(0.057)	0.256(0.045)	0.208(0.039)
Northern Cardinal	0.165(0.032)	0.026(0.014)	0.008(0.005)	0.208(0.044)	0.070(0.039)	0.023(0.013)
Blue Grosbeak	0.000	0.014(0.008)	0.008(0.005)	0.010(0.010)	0.000	0.000
Indigo Bunting	0.040(0.015)	0.018(0.010)	0.011(0.006)	0.052(0.027)	0.070(0.036)	0.015(0.011)
American Goldfinch	0.040(0.016)	0.028(0.010)	0.034(0.024)	0.000	0.023(0.016)	0.031(0.019)
Eastern Towhee	0.396(0.049)	0.060(0.016)	0.023(0.018)	0.531(0.074)	0.163(0.049)	0.069(0.027)
Bachman’s Sparrow	0.066(0.025)	0.125(0.038)	0.161(0.049)	0.010(0.010)	0.081(0.041)	0.054(0.029)
Chipping Sparrow	0.023(0.012)	0.145(0.041)	0.152(0.042)	0.000	0.047(0.022)	0.131(0.038)
Field Sparrow	0.000	0.000	0.000	0.021(0.015)	0.000	0.000

Appendix VII. Summary statistics and correlations between the first three axes of the CCA and the vegetation variables and species for the 4-YR data set.

Summary Statistics

Statistic	Axis 1	Axis 2	Axis 3
Eigenvalue	0.400	0.179	0.102
% Variance accounted for in species data	20.9	9.4	5.3
Kendall Correlation[a]	0.781	0.616	0.670

[a] Rank correlation coefficients between sample scores for an axis derived from the species data and sample scores that are linear combinations of the vegetation variables (McCune & Mefford 1997)

	Intraset Correlations[a]			Interset Correlations[b]		
Variable	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
% Slope	0.227	0.361	-0.199	0.216	0.325	-0.168
% Canopy Cover	0.676	-0.316	0.210	0.644	-0.284	0.178
Canopy Height	0.260	-0.275	0.522	0.248	-0.247	0.442
Litter Depth	0.483	0.349	0.286	0.461	0.313	0.242
% Green Cover	0.103	0.569	0.417	0.098	0.511	0.353
% Grass Cover	-0.739	0.144	0.112	-0.705	0.130	0.095
% Forb Cover	0.085	0.152	0.453	0.081	0.137	0.383
% Fern Cover	0.326	0.495	0.217	0.311	0.445	0.184
% Downed Logs	0.335	0.123	0.296	0.319	0.110	0.251
% Leaf Litter	0.517	-0.083	0.002	0.494	-0.075	0.001
% Bare Ground	-0.473	-0.099	-0.304	-0.451	-0.089	-0.257
# Shrubs <2.5 cm	0.554	0.511	0.235	0.529	0.460	0.199
# Shrubs 2.5-8 cm	0.433	0.185	0.238	0.413	0.166	0.201
# Saplings <2.5 cm	0.046	0.084	-0.171	0.044	0.076	-0.145
# Saplings 2.5-8 cm	0.353	-0.009	-0.182	0.337	-0.008	-0.154
# Trees 8-23 cm dbh	0.615	-0.337	-0.245	0.586	-0.303	-0.207
# Trees >23-38 cm dbh	0.060	-0.263	0.321	0.057	-0.236	0.272
# Trees >38 cm dbh	0.187	-0.099	0.358	0.178	-0.089	0.303
# Longleaf Pine Saplings	-0.147	0.101	-0.283	-0.140	0.090	-0.239
# Other Pine Species Saplings	0.392	-0.045	-0.182	0.374	-0.040	-0.154
# Longleaf Pine Trees	-0.669	0.276	0.097	-0.639	0.248	0.082
# Other Pine Species Trees	0.525	-0.202	0.064	0.501	-0.181	0.054
Shrub Species Richness	0.726	0.462	0.274	0.692	0.415	0.232
Sapling Species Richness	0.684	0.187	-0.050	0.652	0.168	-0.043
Tree Species Richness	0.868	-0.220	-0.183	0.828	-0.198	-0.155
# Snags >12 cm dbh	0.409	-0.195	-0.002	0.390	-0.175	-0.002

[a] Intraset correlations are the correlations of the variables with the ordination site scores that are derived by linear combinations of the vegetation variables (i.e., LC scores). Intraset correlations are not strictly independent measures of the relationship between communities and the vegetation variables since the LC scores are dependent on the vegetation variables (McCune & Mefford 1997)

[b] Interset correlations are the correlations of the variables with the ordination site scores that are obtained by weighted averaging of the species scores (i.e., WA scores). These correlations are also not independent measures since the ordination axes were constrained by regression to the vegetation variables (McCune & Mefford 1997)

Appendix VII continued.

Kendall Correlations with axes.

Species	Axis 1	Axis 2	Axis 3
Mourning Dove	-0.085	0.162	0.046
Northern Flicker	-0.048	0.077	0.181
Red-bellied Woodpecker	-0.004	-0.041	0.055
Red-cockaded Woodpecker	-0.371	0.097	0.231
Red-headed Woodpecker	-0.168	0.008	0.123
Great Crested Flycatcher	0.232	0.075	-0.292
Acadian Flycatcher	0.422	-0.026	0.206
Eastern Wood Pewee	-0.303	0.004	0.059
Blue Jay	-0.140	-0.157	-0.151
Carolina Chickadee	0.123	0.110	-0.200
Tufted Titmouse	0.344	0.011	-0.198
Brown-headed Nuthatch	-0.482	0.024	-0.031
Carolina Wren	0.419	0.304	0.217
Wood Thrush	0.299	-0.277	0.109
Blue-gray Gnatcatcher	0.525	-0.004	-0.201
Red-eyed Vireo	0.568	-0.145	0.029
White-eyed Vireo	0.405	0.381	0.094
Yellow-throated Vireo	0.276	0.055	-0.034
Black-and-white Warbler	0.463	-0.138	-0.071
Common Yellowthroat	0.372	0.421	0.111
Hooded Warbler	0.469	0.192	0.168
Ovenbird	0.527	-0.355	-0.015
Pine Warbler	-0.385	0.016	-0.055
Prairie Warbler	-0.094	0.378	0.034
Yellow-throated Warbler	0.320	-0.003	-0.049
Brown-headed Cowbird	0.255	0.013	-0.151
Summer Tanager	0.052	0.071	-0.365
Northern Cardinal	0.438	0.200	0.122
Eastern Towhee	0.394	0.416	0.060
Bachman’s Sparrow	-0.375	0.147	0.183
Chipping Sparrow	-0.371	-0.103	-0.053

Appendix VIII. Summary statistics and correlations between the first three axes and the vegetation variables and species of the CCA for the 1-YR data set.

Summary Statistics

Statistic	Axis 1	Axis 2	Axis 3
Eigenvalue	0.369	0.156	0.103
% Variance accounted for in species data	6.6	2.8	1.8
Kendall Correlation[a]	0.636	0.447	0.445

[a] Rank correlation coefficients between sample scores for an axis derived from the species data and sample scores that are linear combinations of the vegetation variables (McCune & Mefford 1997)

	Intraset Correlations[a]			Interset Correlations[b]		
Variable	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
% Slope	0.339	-0.158	-0.118	0.292	-0.113	-0.079
% Canopy Cover	0.639	0.245	-0.172	0.551	0.175	-0.116
Canopy Height	0.265	-0.275	0.319	0.229	-0.196	0.214
Litter Depth	0.309	0.067	0.101	0.267	0.048	0.068
% Green Cover	0.214	-0.772	0.056	0.185	-0.551	0.038
% Grass Cover	-0.612	-0.491	-0.032	-0.528	-0.351	-0.022
% Forb Cover	-0.346	-0.198	-0.469	-0.298	-0.141	-0.316
% Fern Cover	0.358	-0.334	0.346	0.309	-0.238	0.233
% Downed Logs	0.381	0.003	-0.098	0.329	0.002	-0.066
% Leaf Litter	0.571	0.002	0.179	0.493	0.001	0.120
% Bare Ground	-0.362	0.193	-0.230	-0.313	0.137	-0.155
# Shrubs 2.5-8 cm	0.415	-0.153	-0.037	0.358	-0.109	-0.025
# Saplings <2.5 cm	0.096	-0.235	-0.034	0.083	-0.168	-0.023
# Saplings 2.5-8 cm	0.196	0.061	-0.441	0.170	0.043	-0.297
# Trees 8-23 cm dbh	0.534	0.441	-0.293	0.460	0.315	-0.197
# Trees >23-38 cm dbh	0.093	0.302	0.313	0.080	0.215	0.211
# Trees >38 cm dbh	0.117	-0.325	0.149	0.101	-0.232	0.100
# Longleaf Pine Saplings	-0.369	-0.167	-0.420	-0.318	-0.119	-0.282
# Other Pine Saplings	0.344	-0.096	-0.108	0.297	-0.068	-0.073
# Longleaf Pine Trees	-0.689	0.253	0.030	-0.594	0.181	0.020
# Other Pine Species Trees	0.503	0.138	0.038	0.434	0.098	0.026
# Other Species Trees (non-pine)	0.586	0.360	-0.389	0.505	0.257	-0.261
Shrub Species Richness	0.736	-0.422	0.135	0.635	-0.302	0.091
Sapling Species Richness	0.767	-0.324	-0.104	0.662	-0.231	-0.070
Tree Species Richness	0.775	0.020	-0.163	0.669	0.015	-0.109
# Snags >12 cm dbh	0.278	0.064	0.163	0.240	0.046	0.109

[a] Intraset correlations are the correlations of the variables with the ordination site scores that are derived by linear combinations of the vegetation variables (i.e., LC scores). Intraset correlations are not strictly independent measures of the relationship between communities and the vegetation variables since the LC scores are dependent on the vegetation variables (McCune & Mefford 1997)

[b] Interset correlations are the correlations of the variables with the ordination site scores that are obtained by weighted averaging of the species scores (i.e., WA scores). These correlations are also not independent measures since the ordination axes were constrained by regression to the vegetation variables (McCune & Mefford 1997)

Appendix VIII continued.

Kendall Correlations with axes.

Species	Axis 1	Axis 2	Axis 3
Mourning Dove	0.027	-0.085	-0.026
Northern Flicker	-0.003	-0.013	-0.065
Red-bellied Woodpecker	0.106	-0.030	0.211
Red-cockaded Woodpecker	-0.284	-0.099	-0.001
Red-headed Woodpecker	-0.170	-0.040	0.036
Great Crested Flycatcher	-0.031	0.034	0.013
Acadian Flycatcher	0.209	0.056	0.163
Eastern Wood Pewee	-0.182	-0.063	0.050
Blue Jay	0.028	0.027	-0.092
Carolina Chickadee	0.157	-0.027	0.051
Tufted Titmouse	0.151	-0.111	0.082
Brown-headed Nuthatch	-0.165	0.042	0.075
Carolina Wren	0.306	-0.168	0.054
Wood Thrush	0.283	0.076	-0.158
Blue-gray Gnatcatcher	0.278	-0.240	0.144
Red-eyed Vireo	0.297	0.079	0.007
White-eyed Vireo	0.248	-0.187	-0.090
Yellow-throated Vireo	0.255	-0.034	0.045
Black-and-white Warbler	0.262	-0.005	-0.125
Common Yellowthroat	0.230	-0.247	0.074
Hooded Warbler	0.251	-0.118	-0.130
Ovenbird	0.276	0.130	-0.196
Pine Warbler	-0.307	-0.055	0.079
Prairie Warbler	-0.031	-0.324	-0.119
Yellow-throated Warbler	0.185	-0.116	0.120
Brown-headed Cowbird	0.134	0.075	-0.103
Summer Tanager	-0.014	-0.098	-0.069
Northern Cardinal	0.286	-0.171	0.099
Eastern Towhee	0.301	-0.266	0.069
Bachman’s Sparrow	-0.182	-0.243	-0.126
Chipping Sparrow	-0.241	0.060	0.074

Appendix IX. Possible effects of widespread burning for the restoration of longleaf pine communities on relative abundances of breeding bird species at Fort Bragg, NC.

	Increase		Decrease		No Effect/
Species	Expected	Possible	Expected	Possible	Unknown
Longleaf Pine Assemblage					
Red-cockaded Woodpecker	X				
Red-headed Woodpecker	X				
Eastern Wood Pewee		X			
Brown-headed Nuthatch	X				
Pine Warbler	X				
Prairie Warbler	X				
Bachman's Sparrow	X				
Chipping Sparrow	X				
Fire Suppressed Assemblage					
Acadian Flycatcher			X		
Tufted Titmouse				X	
Wood Thrush			X		
Blue-gray Gnatcatcher				X	
Red-eyed Vireo				X	
Yellow-throated Vireo			X		
Black-and-white Warbler			X		
Ovenbird			X		
Drain Assemblage					
Carolina Wren					X
White-eyed Vireo		X			
Common Yellowthroat	X				
Hooded Warbler					X
Northern Cardinal				X	
Eastern Towhee		X			
Generalists					
Red-bellied Woodpecker					X
Great Crested Flycatcher					X
Blue Jay					X
Carolina Chickadee					X
Summer Tanager					X
Unclassified					
Mourning Dove		X			
Northern Flicker		X			
Eastern Bluebird		X			
Yellow-throated Warbler				X	
Brown-headed Cowbird					X
American Goldfinch					X
Indigo Bunting		X			

CHAPTER 3

MULTI-SCALE HABITAT RELATIONSHIPS FOR THE BREEDING BIRD SPECIES OF A LONGLEAF PINE ECOSYSTEM

INTRODUCTION

Odum (1971) defined the habitat of a species simply as where an animal lives. Fretwell (1972) defined it is an area that a species can colonize and inhabit at a density above zero. More recently, the definition of a species' habitat is the resources and environmental conditions that support occupancy, survival and reproduction (Morrison et al. 1992; Hall et al. 1997). Southwood (1977) suggested that habitat features were the template for the evolved ecological strategies of species through reproductive success, and that habitat and species were part of a dynamic system variable over space and time. These prevalent views of habitat have been the foundation for decades of species-habitat studies, based on the assumption that habitat suitability is related to population size and demographic parameters. Most of these studies are based on the concept of habitat selection, first explicitly introduced by Lack (1933). The premise of habitat selection is that innate and learned behavioral responses allow an individual to select what habitat to use (Hutto 1985; Block and Brennan 1993; Hall et al. 1997). These behavioral responses are thought to be elicited by habitat features, or cues, that are directly or indirectly related to survival and reproductive potentials (Block and Brennan 1993). Fretwell (1972) speculated that the distribution of a species may be caused by habitat selection and that this distribution may be influenced by behavioral responses that maximize survival and reproduction. Similarly, Rotenberry (1981) proposed that an observed species-habitat relationship was caused by habitat selection and was adaptive.

Much previous work on bird-habitat relationships has been done at a microhabitat scale (e.g., Hilden 1965; James 1971; Willson 1974; Rotenberry and Wiens 1980; Cody 1985; Rotenbery 1985), which Block and Brennan (1993) identify as the level where specific environmental features act as proximate cues to elicit settling responses. Yet, habitat selection by vagile species such as birds may occur at several hierarchical spatial scales, from a geographic scale to resources within an individual territory (Johnson 1980; Wiens et al. 1986). Currently, larger spatial scales are emphasized for bird-habitat research, especially the landscape scale (e.g., Lehmkuhl et al. 1991; Flather et al. 1992; Pearson 1993; McGarigal and McComb 1995; Flather and Sauer 1996; Probst and Weinrich 1996). For Neotropical migratory birds, Freemark et al. (1995) defined the landscape scale as intermediate between a physiographic region and the territory or home range. In many bird studies conducted at the landscape scale, the landscape is dominated by a non-forested matrix or a matrix heavily managed for timber. These studies generally focus on forest fragmentation effects, defined as reduced fitness or density in remaining patches (Walters 1998). In fragmentation studies conducted in a non-forested matrix, species richness and occurrence, especially for forest-interior and Neotropical migratory songbirds, were found to be greatly affected by forest patch area and the distance to other

forest patches (e.g., Whitcomb et al. 1981; Lynch and Whigham 1984; Freemark and Merriam 1986; Askins et al. 1987; Robbins et al 1989; Lynch and Saunders 1991; Robinson and Wilcove 1994). Similar patterns have been found for certain grassland birds of the Midwest (Herkert 1994). The theory of island biogeography (MacArthur and Wilson 1967), which relates species richness to island area and degree of isolation, generally is applicable to these mainland fragmentation studies. More complex and individualistic patterns arise from fragmentation studies conducted in landscapes managed for timber (e.g., Lehmkuhl et al. 1991; Keller and Anderson 1992; McGarigal and McComb 1995). In these studies, several components of landscape structure often were associated with bird distribution and abundance patterns, such as the amount of edge, degree of fragmentation, spatial heterogeneity, proportion of forested habitats, and the type of habitat surrounding the fragmented habitat type.

These aforementioned studies have demonstrated that landscape structure can influence bird distribution and abundance patterns in a fragmented landscape, where fragmentation events are a type of landscape structural change that converts forests to unsuitable, non-forested habitats or early successional habitats. Yet few researchers have determined whether landscape attributes, such as percent area of a habitat type, amount of edge, or spatial heterogeneity, greatly influence birds in a forested, relatively unfragmented landscape (i.e., there is a low proportion of non-forested area) that is composed of varying proportions of different forested habitats (Jokimaki and Huhta 1996; Penhollow and Stauffer 2000). Many landscapes may be largely forested yet much of the matrix may contain unsuitable or suboptimal forested habitats, such as timber forests, for certain bird species (Estades and Temple 1999; Penhollow and Stauffer 2000). Although suitable habitat types for a particular species may be "fragmented" by unsuitable habitat types, conclusions from traditional forest fragmentation studies may not apply in a forest-dominated landscape.

Until relatively recently, few studies have addressed multi-scale approaches to understanding habitat use for avian species. It is important to consider multiple spatial scales because factors affecting species distributions may function at different scales (Wiens 1989; Jokimaki and Huhta 1996). Habitat selection at a geographic scale is principally innate, but selection at smaller spatial scales can be influenced by an animal's behavioral responses to factors such as the foraging base, mate availability, and interspecific interactions (Morrison et al. 1992). Operationally, the lines between hierarchical scales are somewhat arbitrary and selection at each scale most likely is not independent of other spatial scales. Some studies incorporating multiple scales target different microhabitat levels, such as the territorial and nesting site selection study of female Yellow-headed Blackbirds by Orians and Wittenberger (1991). Only a few studies examine more distinctive spatial scales, such as the work by Wiens et al. (1987), who compared habitat occupancy patterns of shrubsteppe birds at biogeographical, regional, patch, and territorial scales. Of late, more research is being conducted comparing the relative influence of microhabitat and landscape factors on bird distribution patterns (e.g., Hinsley et al. 1995; Jokimaki and Huhta 1996; Berry and Bock 1998; Saab 1999).

In this study, I examine species-habitat relationships at multiple spatial scales, specifically the microhabitat and landscape scales, for the breeding birds of a longleaf pine (scientific names of flora in Chapter 2, Appendix II) ecosystem found at the Fort Bragg Military Installation in North Carolina. Few studies have been conducted on landscape influence on bird species, especially Neotropical migrants, of the forests of the southeastern U.S. (Freemark et al. 1995). I defined the microhabitat scale as an individual bird's territory and defined the landscape as intermediate between a physiographic region and a territory, following Freemark et al. (1995). More specifically, I limited the landscape scale for this study to a 300-m to 1500-m radius scale. Wiens (1989) and McGarigal and McComb (1995) emphasize that the size and perceived heterogeneity of a landscape are species-dependent; thus, several landscape scales were included in this study since the critical scale may vary across the many bird species examined. The forested landscape of Fort Bragg is relatively unfragmented, but it is a spatially heterogeneous mosaic of several habitat types influenced by timber practices, military activity, and prescribed burning. Hence, analyses of species distributions across the base may provide insight into whether landscape structure affects habitat use in an unfragmented yet still spatially heterogeneous system, or if habitat variation at the microhabitat scale is more important. Additionally, the historical vegetation community type was longleaf pine savannas and woodlands, but past fire suppression and land-use activities have broken up these forests by establishing patches of mixed pine-hardwood forests. Current land management activities are focused on restoring a greater proportion of the forests back to historical vegetation conditions. Thus, this study will provide information on how changes in microhabitat and landscape features may affect bird species associated with longleaf pine savannas and woodlands.

STUDY AREA DESCRIPTION

The Fort Bragg Military Installation is located in the Sandhills physiographic region of North Carolina and encompasses 63,143 hectares, with approximately 40,000 hectares forested (Cantrell et al. 1995). Currently, mostly second- and third-growth stands exist on the base. Prior to 1989, the Natural Resources Branch conducted dormant season burns on a 5-year rotation. Since 1989, Fort Bragg has adopted a three-year growing season rotation for prescribed burns to enhance and conserve this longleaf pine ecosystem. Fort Bragg is a heterogeneous landscape of upland pine, successional communities of mixed pine-hardwood and hardwood stands, and streamhead pocosins (i.e., drains) influenced greatly by fire, land management history and soil moisture gradients (i.e., a drain to upland gradient).

Many areas have been actively managed with prescribed fire, and in some cases, mechanical thinning of trees to restore the longleaf pine/scrub oak community. These areas are classified as fire intense for this study. Longleaf pine dominates the canopy, the ground layer is highly diverse, and there is virtually no vertical structural diversity. These areas are often described as open park-like savannas or woodlands. Areas that have lacked periodic growing season fires until recently, though dormant season burns may have occurred, are classified as fire suppressed. They are dominated by longleaf

pine and/or loblolly pine and hardwoods in the overstory, have a hardwood or mixed pine and hardwood midstory, and have low ground cover diversity.

Throughout the base, plant community composition is also influenced by the soil-moisture gradient. Drains, the riparian habitat of streamhead pocosins, are features common to both fire intense and fire suppressed stands. The vegetation, especially the shrub layer, is more speciose and dense than the nearby upland habitats. If a recent intense fire had removed the shrub layer in any drains, these drains were not included in this study.

A more detailed study area description is provided in Chapter 2 (*this manuscript*).

STUDY SITE SELECTION

Since fire history and the soil-moisture gradient were hypothesized to greatly influence vegetation composition and structure within the study area at a microhabitat scale (see Chapter 2, *this manuscript*), bird point count stations were positioned in areas classified by fire treatment, either fire intense or fire suppressed, and were also placed at one of three locations (i.e., distances from) relative to a drain, drain (0 m), intermediate (75 m), and upland (≥150 m). Eighty-seven count stations for this study were selected from a pool of 221 stations from previous studies by Krieger (1997) and Allen (Chapter 2, *this manuscript*). I randomly chose count stations so that within each fire treatment, sample sizes were balanced across the three locations. This randomization process was constrained in two ways. First, I excluded stations that were near the boundaries of Fort Bragg since landscape attributes could not be quantified outside of the base. Second, I limited continued selection of additional stations in a particular area because I wanted to maximize the distribution of stations across the entire base.

DATA COLLECTION METHODS

Vegetation Sampling

I collected vegetation structure and floristics data from four subplots at each count station based on the sampling protocol of BBIRD (Martin 1994). The first subplot was centered on the count station and the second subplot was 30 m away at a random azimuth. The third and fourth subplots were 120 degrees in opposite directions from the previous azimuth and 30 m from the first subplot center. Each subplot consisted of nested 5-m and 11.3-m radius plots. Within the 5-m radius plots, I measured shrubs, saplings, litter depth, and ground cover characteristics. I quantified shrub and sapling species ≥50 cm above ground by counting number of stems, and I counted stems separately if they branched at <10 cm above the ground. I delineated two shrub diameter size classes, <2.5 cm and >2.5 cm, measured at 10 cm above the ground, and two sapling diameter size classes, <2.5 cm and 2.5-8 cm. I measured organic litter depth at twelve points, spaced 2 m apart, along two 10-m long transects that intersected and were

centered within each 5-m radius plot. I defined ground cover ≤50 cm above ground and quantified the following variables: % green cover, % grass cover, % shrub cover, % forb cover, % fern cover, % leaf litter, % downed logs, % bare ground and % water. Within each 11.3-m radius plot, I tallied the number of trees >8 cm for diameter at breast height (dbh) by species and three size classes: >8-23, >23-38, and >38 cm dbh. Also, I counted the number of snags >12 cm dbh and taller than 1.4 m. Breast height for measuring tree diameters was 1.4 m. Finally, I estimated canopy cover and height, aspect, and slope for each subplot.

Landscape Attributes

Landscape composition and configuration attributes (Table 1), i.e., landscape structure, were derived for the 87 count stations by using a geographic information system produced by Fort Bragg biologists. From this GIS, a spatial cover type layer was generated based on forest inventory stand data containing stocking rates of overstory and midstory trees. This spatial cover type layer represented various habitats across the base thought to influence bird populations. The minimum resolution, or minimum patch size, was 10 acres (4.05 hectares), i.e., no polygons were defined at a smaller resolution (Schultz and Howell, pers. comm.). A patch was defined as a homogeneous area distinct from the surrounding area by its cover type classification. Field staff and I verified this cover type map through extensive field inspections. Since the minimum resolution of the GIS was 10 acres, smaller patches were not represented, as expected. Although a patch depicted as one cover type was often somewhat heterogeneous at a finer resolution, the overall patch was regularly dominated by the one cover type. Also, the boundaries between patches were often gradual. I address this issue below.

Ten general cover types were defined to produce a map of distinct cover type patches. Forested stands were classified for both the overstory and midstory as either dominated by pine, mixed pine and hardwood, or hardwood trees and then they were further delineated by open (basal area < 11.5 m^2/hectare (50 ft^2/acre)) or dense (basal area > 11.5 m^2/hectare) stand densities for the overstory trees. Forested cover types were pine/pine open (where the "pine/pine" nomenclature refers to the dominant tree group in the overstory and then the midstory), pine/pine dense, pine/mix open (mix refers to mixed pine and hardwood trees), pine/mix dense, mix/mix open, mix/mix dense, and upland hardwoods. Pine/pine open and pine/pine dense consistently represented longleaf pine savannas and woodlands, though loblolly pine was a predominant canopy species for a few patches. Pine/mix open and dense, mix/mix open and dense, and upland hardwoods characterized the main successional communities of fire suppressed habitats. The drain cover type was the riparian zone along streams, which typically was a dense shrub-dominated habitat. The young open cover type represented early successional fields or bare soil areas, such as parachute drop zones, artillery impact areas, and wildlife food fields. The young dense cover type represented later successional habitats, such as scrub/shrub and young pine stands. Lakes were also classified as a separate cover type but the lake cover type was not included in any further analyses because it only represented a small percentage of Fort Bragg.

Originally, five scales were chosen to quantify landscape attributes since not all species may be sensitive to the same scale. The scales were 300-m, 600-m, 900-m, 1200-m, and 1500-m radius areas around each point count station. The minimum scale was intended to be the next scale larger than the microhabitat scale (50-m radius) that might reasonably have a separate effect on a bird species. The maximum scale was limited to 1500 m because larger scales caused a high degree of overlap in landscapes, and caused some landscapes to incorporate land off the base, for where a similar GIS database was lacking.

FRAGSTATS, a spatial pattern analysis program developed by McGarigal and Marks (1995) to quantify landscape structure, was used in conjunction with the GIS to quantify landscape composition and configuration attributes (Howell, pers. comm.). The formula for each landscape attribute used in this study can be found in Appendix 3 of McGarigal and Marks (1995). I characterized landscape composition with three attributes, the percentage of landscape for each of the 10 cover types, patch richness density (cover types/100 ha), and Simpson's evenness index. Patch richness density and Simpson's evenness index are diversity indices. Patch richness refers to the number of patch cover types in the landscape, and evenness refers to the distribution of area among different patch cover types. As the evenness index approaches one, landscape diversity approaches perfect evenness (McGarigal and Marks 1995). I quantified landscape configuration with five attributes: patch density (number of patches/100 ha), mean patch size, patch size coefficient of variation (%), contrast-weighted edge density (m/ha), and interspersion and juxtaposition index (%). Patch density is not spatially explicit but it is commonly used as a measure of spatial heterogeneity (McGarigal and Marks 1995). Patch size coefficient of variation measures the relative variability about the mean and so is influenced by both the mean and variance of patch sizes. The interspersion and juxtaposition index measures the extent that cover types are interspersed. This relative index is based on patch cover type adjacencies and higher values imply greater interspersion of patch types within a landscape. The index is calculated as the observed level of interspersion based on a percentage of the maximum possible interspersion given the total number of patch types (McGarigal and Marks 1995). Since patch richness, number of patches, and amount of edge can be influenced by the landscape scale, I used density indices instead of these variables to standardize values and facilitate comparison across scales.

An edge was originally defined as the boundary between patches. However, some neighboring patches may have similar cover types, e.g., pine/pine open and pine/pine dense, and this type of patch boundary may not be viewed as distinct by many bird species. Realizing that not all patch boundaries are necessarily true edges, I used the contrast-weighted edge density index, weighing edge types from 0 to 1, with 0 defined as no contrast and 1 defined as maximum contrast. A matrix of contrast weights was developed by a consensus of researchers from Virginia Polytechnic Institute and State University and Fort Bragg Wildlife Branch (Appendix I).

In FRAGSTATS, the outer perimeter of the landscape can be defined as a boundary or a border (McGarigal and Marks 1995). Basically, a boundary is the outer perimeter line defined by a set scale. Since this line is often artificial and can intersect a patch, a boundary can create an artificial edge and thus overestimate the amount of edge habitat in the landscape. A border is a strip of area around the landscape where the patch cover types are also defined, which thus provides information on patch type adjacencies for edges at the landscape boundary. For this study, the landscape perimeter was defined as a boundary (i.e., no borders were delineated) and all boundary edges were defined as the background cover type, which was given a contrast-weight index of zero. Hence, the distances along boundaries were not included in the edge metric calculations. This method was reasonable since there were few true edges near the landscape boundaries (Howell, pers. comm.). Additionally, the choice between a boundary or a border can affect the interspersion metric. Again, because there were few edges near the boundary, the boundary method was acceptable.

Bird Counts

During the breeding seasons of 1996 and 1997, I used a 50-m fixed-radius point count method to census the avifauna at each count station (Hutto et al. 1986). Trees were marked at 25 m and 50 m from each point count center to aid in distance estimation. Count surveys were conducted from the beginning of May to mid-June. The birds were surveyed at each station for 10 minutes by sight and sound between 0545 and 1000, and each bird observation was recorded as within 50 m or >50 m from the point center. Birds were surveyed twice at each station in 1996 and three times in 1997. Prior to analysis, one survey period was dropped from the 1997 data to conform to the 1996 data because the probability of detecting a species at a count station may have been greater in 1997 since an additional survey was conducted that year. The survey period excluded differed by species, with the lowest survey count dropped per species because it was assumed that the lowest survey count reflected a time period when a species was less observable, possibly due to the peak reproductive activity during the sampling period (May to mid-June) varying per species. The observer, order, and time of counts were varied for each survey to minimize systematic detection biases. Four observers conducted bird counts in 1996 and three observers conducted counts in 1997. In addition, observers practiced bird identification skills and distance estimation for three weeks in 1996 and four weeks in 1997 prior to the first survey.

ANALYTICAL METHODS

Statistical analyses were conducted in SAS/STAT software (SAS Institute Inc. 1997) and PC-ORD (McCune and Mefford, 1997). For the statistical analyses, the bird census data were averaged across surveys within each sampling season and then again averaged by sampling season (i.e., year). This step resulted in a relative abundance index for each species. To develop species occurrence data, the abundance data were converted

to presence and absence data. Sample size was 87 except where noted. An alpha level of 0.05 was used to determine statistical significance unless otherwise specified.

To describe potential yet separate influences of microhabitat and landscape attributes on species numbers, I first conducted analyses relating species numbers to microhabitat attributes and then landscape attributes. Next, I related species occurrence to all attributes simultaneously, both microhabitat and landscape attributes, by using regression procedures. This latter analysis allowed me to distinguish whether the microhabitat or landscape spatial scale was most associated with variation in species occurrence.

Variable Reduction

Since many variables (>200) could have been generated from the vegetation features measured (e.g., shrub, sapling, and tree data were recorded by species and diameter size class), I reduced this data set to 29 variables that represent both structural and floristic attributes of the ground cover, under-, mid-, and overstory (Appendix II). I used nine variables to characterize ground cover attributes: litter depth and cover percentages for the categories green, grass, shrub, forb, fern, downed logs, leaf litter, and bare ground. I retained the variables percent slope, canopy cover, canopy height, and number of snags ≥12 cm dbh. To characterize the under-, mid-, and overstory structure, I pooled the shrub, sapling, and tree species data into these seven composite variables: number of shrubs <2.5 cm and >2.5 cm, number of saplings <2.5 cm and >2.5-8 cm, and number of trees 8-23 cm dbh, >23-38 cm dbh and >38 cm dbh. To reflect major floristic differences in the mid- and overstory species composition, I combined the tree and sapling species data into six additional composite variables: number of longleaf pine saplings, number of other pine (i.e., not longleaf) saplings, number of other species (i.e., non-pine) saplings, number of longleaf pine trees, number of other pine trees, and number of other species trees. I then created three species richness variables: shrub, sapling, and tree species richness.

I performed Pearson's correlation coefficient tests between the 29 microhabitat variables, and dropped one variable from any pair with a correlation of ≥0.8. When possible, the harder variable to interpret or measure in the field was dropped. Two variables were dropped by this method, the number of shrubs <2.5 cm and the number of other species (non-pine) saplings; hence 27 microhabitat variables were included in subsequent analyses.

For the landscape composition and configuration data, Pearson's correlation coefficient tests were performed between all landscape variables, including across all scales. Each scale was highly correlated (>0.8) to the previous and the next larger scale so intermediate scales were dropped. Thus, three scales were used for further analysis: 300-m, 900-m, and 1500-m radius. Pearson's correlations between the remaining variables were examined again and mean patch size was dropped because it was highly correlated with patch density across all scales, and since patch size coefficient of

variation is sensitive to mean patch size. After these steps, 16 variables per landscape scale (i.e., a total of 48 variables) were used for further analyses (Appendix III). Of these 48 landscape structure variables, 36 attributes represented landscape composition and 12 represented landscape configuration.

Bird Species-Microhabitat Patterns

I analyzed the relationship between the distribution patterns of the breeding bird species and the microhabitat variables using canonical correspondence analysis (CCA). Similar analyses were conducted in a previous study (see Chapter 2, *this manuscript*). For the current study, this analysis was repeated because this data set is different from that analyzed in Chapter 2, and also to verify that species-microhabitat patterns for this data set are similar to those found in Chapter 2. CCA is a direct gradient analysis that extracts ordination axes of community variation, which are restricted by being linear combinations of environmental variables, such that community variation is directly related to the environmental variation (Ter Braak 1986). In other words, ordination of the bird species matrix is performed by reciprocal averaging and this ordination is constrained by multiple linear regression on the microhabitat variables.

For the CCA, bird species relative abundance data were used. Axis scores were centered and standardized to unit variance and species scores were optimized for axis scaling. Only species with ≥10 observations over the study period were included for the CCA (see Appendix IV for the species included in this analysis). Abundance of these species was related to the 27 microhabitat variables, described earlier, that summarized the main patterns of floristic and structural variation at the microhabitat scale. Since CCA can find relationships that do not exist biologically, I performed reciprocal averaging (RA) and detrended correspondence analysis (DCA) on the bird species matrix before I accepted the CCA ordination. These latter two techniques are pure ordination methods (i.e., the ordination is based only on community data and is not constrained by environmental variables). The ordinations produced from these two methods supported the findings of the CCA, so the RA and DCA results are not reported.

Bird Species-Landscape Patterns

I computed descriptive statistics (mean, standard error, range) for each landscape variable and compared mean values across the three scales. To test whether a bird species' distribution was associated with landscape attributes, I compared the mean value per landscape variable across the entire sampling area (n=87) to the mean value per landscape variable for count stations where a bird species was present using the two-sample mean Wilcoxon rank sum test. For this test, the sample size was unique to each species. A CCA was performed for this data set but the resulting ordination did not account for a sufficient level of variation in species numbers. The species-landscape relationships depicted in the ordination were not accepted as valid; hence this analysis is not reported.

Multi-Scale Bird-Habitat Patterns

I used logistic regression to develop predictive models of species occurrence based on variables representative of microhabitat and landscape scales. Before these analyses, I reduced the variable set since the total number of variables (n=75) was nearly equal to the sample size (n=87). I used principal components analysis (PCA) for this variable reduction step. I performed three PCAs, one for the 27 microhabitat floristic and structural variables, one for the 36 landscape composition variables, and another one for the 12 landscape configuration variables. I used the Factor Procedure of SAS/STAT (SAS Institute Inc. 1997) to perform PCA based on a correlation matrix. An orthogonal rotation (Varimax) was used to maximize dispersion of the ordination to facilitate interpretation (Smith, pers. comm.). Rotation of the axes typically is recommended because the variables may load on more than one component for the unrotated ordination. A rotation such as varimax minimizes the number of variables with high loadings on one component and causes the loadings of each variable across components to be more clearly differentiated. Principal components with an eigenvalue >1 were retained for further analyses because these component variables accounted for more variation in the data set than one variable potentially could by itself. These analyses produced 21 component variables representing microhabitat, landscape composition, and landscape configuration attributes.

I related the 21 principal component variables to the bird species community by CCA and I then developed species-habitat models predicting species presence. I followed the same methods for the CCA as outlined above. For developing the predictive models, I used logistic regression and I included the 19 bird species with ≥20 observations over the study period (see Appendix V for the species included in these analyses). I used the linear logistic model for binary response data with a logit link function from the Logistic Procedure of SAS/STAT software (SAS Institute Inc. 1997) for the logistic regression [logit (p)=log(p/(1-p)) where p was the probability of occurrence]. For variable selection, I used the best subset selection method, which is based on the likelihood chi-square score statistic, since it allowed the comparison of all possible models based on all variable combinations. To limit computation time, I restrained the model size to eight variables maximum. In addition, I specified only a subset of models as output, i.e., the top two models for each variable size class. These models were then compared by the following statistics: (1) the Akaike Information Criterion, which adjusts for the number of variables; (2) concordance; (3) the Hosmer-Lemeshow goodness-of-fit test; and (4) the significance of each variable (alpha level for significance was set at 0.2 for variables in a model). Typically, the top five models based on the above criteria shared a similar set of variables. The overall best model from the top five was chosen by comparing residual and influence diagnostics and checking for overdispersion (i.e., variance >> mean) (Collett 1991).

To discern the variables with the most influence for predicting the probability of occurrence for a species, the standardized estimates of the slopes for each variable within

a species-habitat model were compared. These standardized estimates also were used to compare the importance of each variable for habitat relationships among species (Saab 1999).

RESULTS

Microhabitat Patterns

Appendix VI shows the mean values of the microhabitat variables. Figure 1 shows the ordination for the first two community variation axes of the CCA of the 31 breeding bird species and its association with 27 microhabitat variables. Appendix IV lists the summary statistics and correlations of the ordination axes with the microhabitat variables and bird species. Based on correlations of axis one to the microhabitat variables (Appendix IV), this main axis of avian community variation is correlated with a vegetation gradient from open longleaf pine forests to denser, more speciose mixed pine-hardwood forests. High values for the number of longleaf pine trees and percent grass cover are at one end of the gradient, and high values for percent canopy cover, percent shrub cover, percent leaf litter, the number of trees 8-23 cm dbh, the number of other pine (non-longleaf) species trees, the number of other species (non-pine) trees, and shrub, sapling, and tree species richness are at the opposite end of the gradient. Axis two is associated with a further separation between many of these variables. This axis appears to separate the understory characteristics of drains, such as greater green cover, shrub cover, and shrub species richness, from the mid- and overstory components of mixed pine-hardwood forests, i.e., greater number of trees 8-23 cm dbh, number of other pine species trees, and number of other species trees.

Similar to the findings of Chapter 2 (*this manuscript*), the CCA groups many bird species together into species assemblages. The first axis separates the longleaf pine bird species assemblage from two other groups, fire suppressed and drain bird species assemblages. The longleaf pine assemblage includes the Red-cockaded Woodpecker (see Chapter 2, Appendix I for scientific names of avifauna), Red-headed Woodpecker, Eastern Wood Pewee, Brown-headed Nuthatch, Pine Warbler, Prairie Warbler, Bachman's Sparrow, and Chipping Sparrow. On the ordination plot, Mourning Dove also appears to belong to this species assemblage, but its abundance is not correlated with the first axis (Appendix IV). Abundances of members of the longleaf pine assemblage are not strongly correlated with the second axis of avian community variation except for the Prairie Warbler, whose abundance is positively influenced by a shrubby, speciose understory.

The second ordination axis serves to separate the drain bird species assemblage from the fire suppressed assemblage. The fire suppressed bird species assemblage includes the Acadian Flycatcher, Wood Thrush, Red-eyed Vireo, Black-and-white Warbler, Ovenbird, and possibly the Yellow-throated Warbler (Figure 1). The drain bird species assemblage includes Carolina Wren, White-eyed Vireo, Common Yellowthroat, Hooded Warbler, Northern Cardinal, Eastern Towhee, and possibly the Yellow-throated

Vireo. Almost all of the drain and fire suppressed birds are correlated with the first ordination axis, but only the drain species show a strong positive correlation with the second axis. The fire suppressed birds either show a mild negative correlation or no association with the second axis (Figure 1).

The abundance of the Blue-gray Gnatcatcher is highly correlated with the first ordination axis and has a weaker correlation with the second axis. Thus this species is associated with the mixed pine-hardwood forests similar to the fire suppressed assemblage, but it also has a weak association with shrubby understory characteristics, similar to the drain species assemblage. Although somewhat unique, the Blue-gray Gnatcatcher can still be classified with the fire suppressed species assemblage. The Tufted Titmouse exhibits a mild association with the first ordination axis, indicating that it may be more abundant in mixed pine-hardwood forest. However, this association is not strong, suggesting the Tufted Titmouse could be classified with the fire suppressed birds or as a forest generalist.

Several species are either not associated with either ordination axes or only slightly correlated with one. These species are grouped loosely together in the generalist bird species assemblage. Three species are not associated with the main axes of community variation, the Northern Flicker, Brown-headed Cowbird, and Summer Tanager. The abundance pattern for the Carolina Chickadee is similar to that of the Tufted Titmouse in that it is weakly correlated with speciose forested areas along the first axis. Abundances of the Blue Jay, Red-bellied Woodpecker, and Great Crested Flycatcher have slight negative correlations with the second axis, indicating that these species may be mildly associated with a more open understory layer than what is characteristic of drains. Conversely, the Mourning Dove may have a mild association with denser, speciose understory layers.

Landscape Patterns

Appendix III contains the descriptive statistics (mean, standard error, and range) for the landscape attributes characterizing the three landscape scales. Figure 2 shows a comparison of the mean values for each variable across the three scales. For most landscape attributes, only slight trends can be detected as the landscape scale increases. The percentages of young open and young dense cover types increase noticeably with scale, whereas the cover types pine/mix open and upland hardwood increase only slightly with scale. Pine/pine open, pine/pine dense, pine/mix dense, and drain cover types decrease with increasing scale. Patch richness density greatly decreases as the scale increases and the Simpson's Evenness Index has a slight increasing trend. Patch density has a noticeable decreasing trend, patch size coefficient of variation an increasing trend, contrast-weighted edge density a decreasing trend, and the interspersion and juxtaposition index slightly increasing trend with increasing landscape scale.

The Wilcoxon rank sum analyses comparing landscape structure at sites where a bird species was present to the average landscape structure across the study area revealed

significant results for 14 bird species (Figure 3). A large number of landscape attributes were related to distributions for several species, namely the Brown-headed Nuthatch (12), Red-eyed Vireo (9), Ovenbird (14), and Prairie Warbler (8). Regardless of scale, patch richness density was the most common attribute that was significantly related to a species' presence. Yet, for most species there was a small difference in mean patch richness density across the study area and where a species was present. The occurrences of Brown-headed Nuthatch, Prairie Warbler, Bachman's Sparrow, White-eyed Vireo, and Eastern Towhee were associated with less patch richness density, and the occurrences of Red-eyed Vireo, Ovenbird, and Northern Cardinal were associated with more patch richness density.

Three other attributes were significantly related to the presence of several species, the percentages of mix/mix dense, pine/pine open, and upland hardwood cover types in the landscape (Figure 3). The presence of seven species was influenced by mix/mix dense: Blue Jay (+), Brown-headed Nuthatch (-), Prairie Warbler (-), Bachman's Sparrow (-), Red-eyed Vireo (+), Ovenbird (+), and Black-and-white Warbler (+). Five species were influenced by pine/pine open: Blue Jay (-), Brown-headed Nuthatch (+), Prairie Warbler (+), Bachman's Sparrow (+), and Red-eyed Vireo (-). The occurrences of five species were associated with upland hardwood in the landscape: Brown-headed Nuthatch (-), Prairie Warbler (-), Red-eyed Vireo (+), Ovenbird (+), and Carolina Wren (+).

The occurrence of several species in a landscape was associated with the percentage of particular cover types (Figure 1). For example, the Bachman's Sparrow and Prairie Warbler, both members of the longleaf pine assemblage, were positively associated with pine/pine cover types (i.e., open longleaf pine woodlands and savannas) and negatively with mix/mix cover types (i.e., mixed pine-hardwood forests). The Red-eyed Vireo, Ovenbird, and Black-and-white Warbler, members of the fire suppressed assemblage, had a positive association with mix/mix dense cover, and the Ovenbird and vireo were both more likely to be present in landscapes composed of greater upland hardwood cover and lower amounts of pine/pine cover types. In contrast, within the drain assemblage, only two species were more likely to be present in landscapes with higher amounts of drain cover and only at the 300-m scale, the White-eyed Vireo and the Hooded Warbler. Further, the Blue Jay was the only generalist species with any landscape influence on species presence. Two cover types were greater where jays were present, mix/mix dense at the 300-m scale and pine/mix dense at the 1500-m scale, and one cover type had a lower value, pine/pine open at the 900-m scale (Figure 3).

In general, the presence of most species was influenced by landscape composition attributes, such as patch richness density or the cover types described above, more than landscape configuration attributes. Notable exceptions were that three species were associated with the configuration index patch density, the Brown-headed Nuthatch (-), Ovenbird (+), and Northern Cardinal (+). Also, the presence of two species was associated with the index contrast-weighted edge density (Figure 3). The Eastern Wood Pewee was associated with a lower amount of edge at the 900-m and 1500-m scales and the Carolina Wren was associated with a greater amount of edge at the 1500-m scale.

Bird-Habitat Relationships at Multiple Scales

Results of the principal components analyses on the microhabitat, landscape composition, and landscape configuration variables are shown in Tables 2, 3, and 4 respectively. Table 5 shows my interpretation of each principal component. For the microhabitat PCA, seven components were retained, which together explained 69% of the variance in the microhabitat data set (Table 2). The loaded variables of the first microhabitat component (M1) mainly represent tree species richness and density, or in other words, the fire suppression gradient, and this component explained 25% of the variance. The second component (M2) accounted for 13% of the variation in the microhabitat data set and it represents the drain habitat, or the drain-upland gradient. The components M3-M7 reflected habitat characteristics not accounted for by the main patterns of vegetation variation (M1 and M2) or defined specific attributes within these main vegetation patterns. M3 represents the ground leaf litter characteristics and M4 represents stand age and height based on high loadings for the variables canopy height and the number of trees >38 cm dbh. The fifth microhabitat component (M5) is loaded on the following variables: (+) number of saplings 2.5-8 cm, (+) longleaf pine saplings, and (-) trees 23-38 cm dbh. This variable may represent the degree of forest openness since a more open forest may allow higher sapling establishment. M6 represents variation in forb cover, which reaches its highest values in burned areas and in drains (Appendix VI). M7 represents percent downed logs and number of other pine trees (non-longleaf), and it appears to represent habitat variation within fire suppressed habitats or even within drains that experience lower fire intensities. I base this interpretation on the fact that infrequent fires or less intense burns would allow more woody fuels to remain on the ground and may enhance the establishment of other pine species, such as loblolly.

Ten principal component variables were retained for the PCA of landscape composition variables, explaining 83% of the variance in this data set (Table 3). Each component variable loaded on the same landscape composition variable (e.g., pine/mix dense) for all three landscape scales. This result implies that landscape composition attributes may be correlated across these hierarchical scales even though strong correlations were not indicated by the Pearson's correlation coefficient tests (see above). All but one of these components represents a particular cover type. The first three landscape composition components, LCP1, LCP2, and LCP3, loaded on the variables pine/mix dense, mix/mix dense, and mix/mix open cover types, respectively, and accounted for a total of 43% of the variance explained. The remaining components loaded on the variables pine/pine open (LCP4), upland hardwood (LCP5), young open (LCP6), pine/mix open (LCP7), young dense (LCP8), and drain (LCP9) cover types and Simpson's Evenness Index (LCP10).

Four principal components were retained from the PCA of the landscape configuration variables and these components explained 74% of the variance in this data set (Table 4). The first component (LCF1) loaded on the patch density variables for the 900 m and 1500 m scales. LCF2 represents contrast-weighted edge density at the 300 and 900 m scales and LCF3 represents this edge metric at the 1500 m scale. LCF4

represents the patch size coefficient of variation at the 1500 m scale.

The ordination plot resulting from the CCA of 31 breeding bird species and its association with the 21 microhabitat and landscape composition and configuration component variables is shown in Figure 4. Appendix VII shows the summary statistics and correlations of the ordination axes with the microhabitat and landscape component variables. The first two axes account for 18.2% of the variance in the bird species community structure. M1 (tree species richness and density), M2 (drain habitat), and LCP5 (upland hardwoods) are the only component variables strongly associated with species distribution patterns in this analysis. This ordination is similar to the CCA of the bird species and microhabitat variables shown in Figure 1. M1 and M2 represent the main patterns of vegetation variation, i.e., the fire suppression vegetation gradient and the drain-upland vegetation gradient, so these component variables summarize most of the microhabitat variables that were important in the bird species-microhabitat CCA (Figure 1). The addition of LCP5 (upland hardwoods) is the only novel addition associated with the ordination of these 31 breeding bird species.

The predictor variables for each of the logistic regression models predicting species occurrence are listed in Table 6 and the complete models with coefficients and significance values are shown in Appendix V. Microhabitat component variables were selected 47 times and landscape variables were selected on 41 occasions, with landscape composition and configuration variables selected 26 and 15 times, respectively (Figures 5, 6, and 7). Two microhabitat component variables, M2 (drain-upland gradient) and M1 (fire suppressed gradient), were selected most frequently (Figure 5). One or both of these variables were included in 17 of the 19 models. LCP2, the percentage of mix/mix dense cover type in the landscape, was selected the least frequently: it was only included in the Blue Jay model (Figure 7). Species occurrences of the Brown-headed Nuthatch, Black-and-white Warbler, Blue-gray Gnatcatcher, and Red-eyed Vireo were influenced by the largest number of model variables (7-8). Presence of the Bachman's Sparrow was related to the least number of variables, one (M1: fire suppression gradient).

The majority of the 19 species responded most strongly to microhabitat features (Table 6). The occurrences of two species, Brown-headed Nuthatch and Great Crested Flycatcher, were more strongly associated with landscape features than microhabitat features. It was unclear whether the occurrences of the Tufted Titmouse, Ovenbird, Blue Jay, and possibly the Summer Tanager were more closely associated with features measured at the landscape or microhabitat scale. The Bachman's Sparrow and Carolina Chickadee only responded to microhabitat features and the Great Crested Flycatcher only responded to landscape features. The occurrences of several species (Prairie Warbler, Tufted Titmouse, Ovenbird, Eastern Towhee, Blue Jay, and Summer Tanager) were not associated with any landscape configuration component variables. Eastern Wood Pewee and Common Yellowthroat did not respond to any landscape composition components.

The drain-upland gradient, M2, was a significant predictor for 12 species-habitat models, with 11 species being moderate to strong drain associates (Figure 5). The Common Yellowthroat had the strongest association with drain habitat and the Blue Jay

had a negative association with it, meaning that the jay selected upland habitats more frequently. The fire suppression gradient (M1) of dense mixed pine-hardwood forests to longleaf pine woodlands and savannas was associated with nine species, of which five were fire suppressed associates and four were longleaf pine associates. The Red-eyed Vireo had the strongest relationship with fire suppressed habitats, which have higher tree species richness and density, and the Bachman's Sparrow had the strongest association with the open longleaf pine end of this gradient.

The influence of the remaining microhabitat variables, M3-M7, was not as strong or uniformly significant as M1 and M2, but each variable was an important predictor of occurrence for two or more species (Figure 5). Seven species were more likely to occur in stands of greater age and height (M4), with the Red-eyed Vireo and Common Yellowthroat exhibiting the strongest relationships. Several species (e.g., Red-eyed Vireo and Black-and-white Warbler) occurred more frequently in microhabitats with greater leaf litter (M3) and the Brown-headed Nuthatch occurred less frequently. This association could be related to whether a species prefers structurally complex forests (e.g., Red-eyed Vireo) or simple forests (e.g., Brown-headed Nuthatch) or whether a species often forages or nests on the ground (e.g., Eastern Towhee and Blue Jay). Four species (e.g., Prairie Warbler and Black-and-white Warbler) were present more often in microhabitats containing higher numbers of saplings 2.5-8 cm and longleaf pine saplings and fewer trees 23-38 cm dbh (M5), and the Carolina Chickadee and Carolina Wren occurred less often. The component M7, the percent of downed logs and the number of other pine trees, was associated with the occurrence of five species. Four species (e.g., Prairie Warbler and Red-eyed Vireo) may select habitats with a higher percentage of downed logs and a higher number of other pine trees, suggesting they prefer longer fire cycles or less intense fires, and the Eastern Towhee may avoid these habitat characteristics. The White-eyed Vireo had higher occurrences in microhabitats of greater forb cover (M6) and the Summer Tanager had lower occurrences.

Individual landscape composition and configuration component variables were included in models less often than the microhabitat components (Figures 6 and 7). Among the landscape composition variables, LCP1 (percent of pine/mix dense cover type) was selected the most frequently (4 models) and LCP2 (percent of mix/mix dense cover type) was selected the least frequently (1 model) (Figure 7). In many cases, selected composition variables were indicative of earlier-described habitat associations related to fire treatment and the riparian-upland gradient. For example, the Brown-headed Nuthatch, a member of the longleaf pine assemblage, was less common in landscapes with a greater proportion of mix/mix open cover (LCP3), pine/mix open cover (LCP7), and upland hardwood cover (LCP5). Some members of the fire suppressed and drain assemblages had higher occurrences in cover types indicative of fire suppression or lower fire intensity. The Hooded Warbler and Tufted Titmouse were more common in landscapes with greater pine/mix dense cover (LCP1) and the Blue-gray Gnatcatcher and Red-eyed Vireo occurred more in landscapes with greater mix/mix open cover (LCP3). The gnatcatcher and the Hooded Warbler also occurred more frequently in landscapes with less pine/pine dense cover (LCP4), which typically represented longleaf pine woodlands. Surprisingly, no members of the drain assemblage had higher occurrences in

landscapes with a larger proportion of drain habitat, and it appears that this landscape composition variable was negatively associated with the Carolina Wren's occurrence. The Blue-gray Gnatcatcher was the only species that benefited from an increasing amount of drain habitat in the landscape. Three species, Summer Tanager, White-eyed Vireo, and Eastern Towhee, were more common in landscapes with lower evenness among cover types (LCP10: Simpson's evenness index), or in other words, less spatial diversity.

Each of the landscape configuration variables was selected for three to four species-habitat models (Figure 6). Three species, Brown-headed Nuthatch, Black-and-white Warbler, and Hooded Warbler, were less common in landscapes with higher patch density at the 900-m and 1500-m scales (LCF1), whereas the Northern Cardinal was more common indicating that it may benefit from greater landscape heterogeneity. The Great Crested Flycatcher and Eastern Wood Pewee both occurred less frequently when landscapes had greater contrast-weighted edge density at all scales (LCF2 and LCF3). Three members of the drain assemblage were more common in landscapes with greater edge, i.e., White-eyed Vireos at the 300-m and 900-m scales and Common Yellowthroats and Carolina Wrens at the 1500-m scale. Four species, Red-eyed Vireo, Black-and-white Warbler, Blue-gray Gnatcatcher, and Northern Cardinal, occurred more often when landscapes contained greater variation in mean patch size (i.e., LCF4: patch size coefficient of variation).

All four species of the longleaf pine assemblage had a strong significant negative association with M1, the fire suppression gradient (Table 6). Other than this similarity, the models of this assemblage were distinctive from one another. The Bachman's Sparrow model had only the variable M1, the fire suppression gradient. The Prairie Warbler model included a positive association with M2 (drain habitat) and M5 ((+) longleaf pine saplings and (-) trees 23-38 cm dbh) and a negative association with M7 (percent downed logs and number of other pine trees) and LCP1 (percentage of pine/mix dense cover). The Eastern Wood Pewee model included (+)M5 and two landscape configuration variables, (-)LCF2 and (-)LCF3, referring to the amount of contrast-weighted edge density at the 300 and 900-m scales and then 1500-m scale, respectively. Seven additional variables were included in the Brown-headed Nuthatch model, (-)M3 (leaf litter cover and depth), (+)M4 (stand age/height), (-)LCP3 (percent of mix/mix open cover), (-)LCP5 (percent of upland hardwood cover), (-)LCP7 (percent of pine/mix open cover), (+)LCP8 (percent of young dense cover), and (-)LCF1 (patch density at 900 and 1500-m scales).

Within the fire suppressed assemblage, models for the Blue-gray Gnatcatcher and Red-eyed Vireo and for the vireo and Black-and-white Warbler shared five variables between each species pair, suggesting that habitat preferences of these species may greatly overlap (Table 6). The three species shared three variables, revealing that these species occurred more often in stands of greater age and height (M4), greater numbers of other pine (non-longleaf) trees (M7), and greater variation in mean patch size (LCF4). M1, the fire suppression gradient, was a strong positive predictor for three species of the fire suppressed assemblage, the Red-eyed Vireo, Black-and-white Warbler, and

Ovenbird, but it was not a component of the Tufted Titmouse and Blue-gray Gnatcatcher models. M2, the variable representing vegetation characteristics of drains, was important in predicting the occurrence of three species, Tufted Titmouse, Blue-gray Gnatcatcher, and Red-eyed Vireo.

The drain habitat variable, M2, was a ubiquitous positive and relatively important predictor of occurrence for each species in the drain assemblage (Table 6). M4, stand age/height, was also an important positive predictor for three of these species, the Common Yellowthroat, Hooded Warbler, and Eastern Towhee. Conversely, stand age/height was not a predictor for the Carolina Wren and White-eyed Vireo but instead, the fire suppression gradient (M1) was a positive predictor of presence, suggesting these two species benefit from lower fire intensities within or near drains. These results suggest some degree of separation of habitat selection within the drain assemblage. LCP10, Simpson's evenness index, was the only landscape predictor shared between species of this assemblage, specifically the White-eyed Vireo and Eastern Towhee. These two species both were more common in landscapes of lower spatial heterogeneity, or lower evenness between cover types.

The four models for the generalist bird species assemblage do not share any similarities (Table 6). Furthermore, few predictor variables were relatively important based on standardized coefficients and statistical significance.

DISCUSSION

Breeding bird distributions in this fire-influenced system were associated with attributes at both microhabitat and landscape spatial scales. Two microhabitat components, M1 and M2, generally were of greater importance than any landscape feature in influencing bird community composition and species distributions. M1 and M2 represent the main patterns of vegetation variation at the study sites, i.e., a fire suppression gradient and a drain-upland gradient. Similarly, other studies have documented that microhabitat features were more influential than landscape features for common birds in a naturally patchy landscape (Berry and Bock 1998) and migratory species in a forest-dominated landscape (Jokimaki and Huhta 1996). Additional studies showed that landscape structure probably was not the dominant factor influencing bird abundance in watersheds managed for timber (McGarigal and McComb 1995) and other forest-dominated landscapes (Penhollow 1996). Several researchers have documented that the importance of landscape features for bird distribution patterns is dependent upon landscape context (McGarigal and McComb 1995; Jokimaki and Huhta 1996; Estades and Temple 1999). Microhabitat characteristics may be of greater importance in relatively natural, or forest-dominated, landscapes. Conversely, in agricultural-dominated or urbanized landscapes, landscape features greatly influence the bird communities of remnant habitat patches (e.g., Whitcomb et al. 1981; Lynch and Whigham 1984; Freemark and Merriam 1986; Hinsley et al. 1995; Saab 1999). My results from Fort Bragg are comparable to those from studies conducted in naturally patchy landscapes or landscapes managed for timber (e.g., Lehmkuhl et al. 1991; Keller

and Anderson 1992; McGarigal and McComb 1995; Berry and Bock 1998; Estades and Temple 1999).

Microhabitat Associations

The bird species distribution patterns found at the microhabitat scale are similar to the patterns documented in a previous study comparing breeding bird abundances at Fort Bragg between fire suppressed and fire intense habitats and across a drain-upland gradient (see Krieger 1997; Chapter 2, *this manuscript*). In all of the analyses, the two microhabitat gradients associated with fire treatment and the drain to upland transition were consistently more important than any other microhabitat or landscape feature in influencing the bird assemblages and species distributions. In Chapter 2 (*this manuscript*), I was able to define four bird species assemblages based on individual species abundance patterns in relation to fire treatment and distance from drain habitat, i.e., longleaf pine species, fire suppressed species, drain species, and generalist species assemblages. For the most part, these classifications were supported by the species-microhabitat relationships found in this study. Additionally, microhabitat associations for the breeding birds of this longleaf pine system were consistent with other studies conducted elsewhere.

Not surprisingly, the species grouped into the longleaf pine assemblage (Red-cockaded Woodpecker, Red-headed Woodpecker, Eastern Wood Pewee, Brown-headed Nuthatch, Pine Warbler, Prairie Warbler, Bachman's Sparrow, and Chipping Sparrow) were associated with vegetation structure and floristics characteristic of open longleaf pine communities. These attributes, such as a longleaf pine-dominated overstory, a relatively open canopy, no or sparse midstory, and a grass-dominated ground layer, were accounted for within the fire suppression gradient identified by the principal component and canonical correspondence analyses. Furthermore, for species from this assemblage that were further examined by regressing species occurrence against microhabitat and landscape variables (Eastern Wood Pewee, Brown-headed Nuthatch, Prairie Warbler, and Bachman's Sparrow), the microhabitat component representing a habitat gradient from fire suppressed habitats to pine woodlands was the most important factor affecting species' occurrences. After accounting for the fire suppression habitat gradient in these species-habitat models, the influence of other microhabitat features was species-specific. The Brown-headed Nuthatch model revealed a weak association with stand age/height, which supports earlier findings that the nuthatch prefers mature pine-dominated forests (Conner and Dickson 1997). The Prairie Warbler is the only longleaf pine associate that also is associated, albeit weakly, with drains. In the West Gulf coastal plain, Conner and Dickson (1997) report that the abundance of this species is directly correlated with deciduous foliage in the understory and midstory, and that this species disappears when a closed canopy develops within mixed pine-hardwood forests. At Fort Bragg, Prairie Warblers may select open pinelands adjacent to drains.

For the species in the fire suppressed assemblage (Acadian Flycatcher, Blue-gray Gnatcatcher, Wood Thrush, Red-eyed Vireo, Black-and-white Warbler, Ovenbird, and

Tufted Titmouse), several studies reveal an association of these species with characteristics indicative of fire suppressed pinewoods and structurally diverse mixed pine-hardwood or hardwood stands (Engstrom et al. 1984; Wilson et al. 1995; Conner and Dickson 1997). The canonical correspondence analysis in this study supports the assemblage's association with these characteristic. Also, a strong association with the variable representing the fire suppressed habitat gradient was included in the species-habitat models for three of the five species examined by regression analyses, the Red-eyed Vireo, Black-and-white Warbler, and Ovenbird, but not for the Tufted Titmouse or Blue-gray Gnatcatcher. In a previous study, the Tufted Titmouse and Blue-gray Gnatcatcher were most abundant in fire suppressed habitats, but also were fairly common in other forested habitats causing their distributions to somewhat resemble forest generalists (Chapter 2, *this manuscript*). These species may have wider niches than the vireo, warbler, and Ovenbird, which would agree with some studies that have recorded the titmouse or gnatcatcher as common mature forest species (Smith 1977; Dickson and Sequelquist 1979; Murray and Stauffer 1995). Although the models did not suggest an association with vegetation characteristic of fire suppression at the microhabitat scale, both species were associated with landscape composition variables that may be indicative of fire suppressed habitats. Thus, fire suppression practices may have some impact on these two species. In a fire exclusion study in pinelands by Engstrom et al. (1984), the Tufted Titmouse became more abundant after several years of fire suppression.

Three species of the fire suppressed assemblage (Tufted Titmouse, Blue-gray Gnatcatcher, and Red-eyed Vireo) were associated with drain habitat. In a study of bird habitat use along a riparian-upland gradient in the Appalachians, Murray and Stauffer (1995) did not find any evidence that distance from riparian habitats influenced the relative abundances of the gnatcatcher and titmouse, but found a riparian influence for the vireo. Along a forest moisture gradient in Arkansas, Smith (1977) found the titmouse exhibited an affinity for dry forests but occurred equally in both moist and dry forests, whereas the gnatcatcher and vireo were found in both forest types but had higher occurrences in moist forests. At Fort Bragg, the drain association for the titmouse may be related to cavity availability since snag abundance tended to be greater within 75 m of a drain (Chapter 2, *this manuscript*). These three species likely will continue to occur in or near drain habitats on Fort Bragg, even if their overall abundance is reduced by conversion of fire suppressed areas to longleaf pine woodlands and savannas.

Three fire suppressed bird species, Blue-gray Gnatcatcher, Red-eyed Vireo, and Black-and-white Warbler, may be positively influenced by a forest's age and height at Fort Bragg. Murray and Stauffer (1995) classify the warbler and gnatcatcher as mature hardwood generalists. Anderson and Shugart (1974) found that the gnatcatcher was most frequently found in areas with an open understory and large trees, and the vireo was associated with large subcanopy trees and a well-developed canopy, both of these descriptions possibly referring to mature forest characteristics. Smith (1977) reported that the gnatcatcher and vireo had high positive correlations with tree height.

The species of the drain assemblage (Carolina Wren, White-eyed Vireo, Common Yellowthroat, Hooded Warbler, Northern Cardinal, Eastern Towhee) are all shrub or

ground nesters (Erhlich et al. 1988) and several studies support the use of shrubby understory habitats by these species (Kilgore 1971; Cody 1974; Engstrom et al. 1984; Wilson et al. 1995; Conner and Dickson 1997; Krieger 1997). On Fort Bragg these species are confined to drain habitats because it provides shrubby characteristics that are otherwise lacking in pine forests. In other locations these shrub-nesters, except perhaps for the Hooded Warbler, do not necessarily depend on moist soil conditions that are characteristic of these drains. They often are found along abrupt edges, such as forest-field ecotones, that provide shrubby understory vegetation (e.g., see appendix E of Whitcomb 1981). For instance, Haggerty and Morton (1995) call the Carolina Wren a habitat generalist since it was abundant across many different habitat types from early successional fields to mature forests. The Northern Cardinal and the Eastern Towhee were classified as forest interior/edge species by Whitcomb et al. (1981) since they were common to both forest edges and interior forests. The Hooded Warbler has been described as an obligatory moist forest species (Smith 1977) and is associated with "well-watered mature deciduous forests, especially in ravines" (Erhlich et al. 1988). Both the soil moisture gradient and the shrubby vegetation at drains may be important to Hooded Warblers. Conversely, the distribution of the other drain species may be directly related to the shrubby drain vegetation, but only indirectly associated with the moisture gradient. Regardless, the continued presence of these species at Fort Bragg is dependent on the availability of shrub-dominated drain habitat.

Beyond the strong association with drain vegetation, a few additional similarities in microhabitat associations existed among species of the drain assemblage. The Hooded Warbler and Eastern Towhee both were positively associated with the percent leaf litter cover and litter depth, which may be related to the fact that both often forage on the ground (Ehrlich et al. 1988). Three species, Common Yellowthroat, Hooded Warbler, and Eastern Towhee, appear to be positively influenced by forest stand age and height. At Fort Bragg, canopy height and the number of large trees (>38 cm dbh) generally are greatest in the drain habitats (Chapter 2, *this manuscript*), so the association of these three species with stand age/height could be an incidental byproduct of their association with drains. However, Hooded Warblers were classified as mature hardwood generalists in the Appalachians (Murray and Stauffer 1995), and they were more abundant in older stands in the West Gulf Coastal Plain (Conner and Dickson 1997). Robinson and Wilcove (1994) suggested that older forests were more important to Hooded Warblers because these forests provide more forest gaps. Johnston and Odum (1956) found that the towhee had the highest density in 60 to 100-year old pine forests as compared to younger pine forests. Engstrom (*in prep*) classified the towhee and yellowthroat as more abundant in old-growth longleaf pine forests than in younger longleaf pine forests. Thus all these species may have an affinity for mature forests.

The occurrence of two drain species, Carolina Wren and White-eyed Vireo, was also associated with habitats indicative of fire suppressed conditions. This result is not consistent with an earlier study of fire treatment effects on the relative abundance of these species at Fort Bragg (Chapter 2, *this manuscript*). Based on a 4-year study (n=65), the White-eyed Vireo had higher abundance in fire intense drain habitats, not fire suppressed areas, although no effect was detected in an independent 1-year study (n=156). No

significant fire treatment effect was found for the Carolina Wren for either the 4-year or 1-year study.

Associations of forest generalists with microhabitat attributes were weak or absent in both the canonical correspondence analyses (Mourning Dove, Northern Flicker, Red-bellied Woodpecker, Great Crested Flycatcher, Blue Jay, Carolina Chickadee, Brown-headed Cowbird, Summer Tanager) and the regression models (Great Crested Flycatcher, Blue Jay, Carolina Chickadee, and Summer Tanager). All of these species have a relatively wide distribution at Fort Bragg in that they were commonly observed in several forest types. These species are common birds of many habitat types and wooded surburban/rural environments, and thus may be tolerant of a wide variety of forest structural changes. Anderson and Shugart (1974) reported that Carolina Chickadees used a wide range of habitats in forests of Tennessee. Similarly, Stauffer and Best (1980) found that the Great Crested Flycatcher and the Blue Jay had relatively large niche breadths in Iowa and predicted that they may be tolerant of habitat alterations.

Landscape Scale

Most other published studies of landscape influence on bird distributions have only addressed one spatial scale in quantifying landscape characteristics (e.g., Lehmkuhl et al. 1991; McGarigal and McComb 1995; Penhollow 1996; Berry and Bock 1998; Estades and Temple 1999; Saab 1999). Yet it is often suggested that multiple landscape scales should be examined since the appropriate scale is not always known, it may vary by species, landscape attributes may operate independently at different spatial scales, and not all attributes may be meaningful at the same spatial scale (Addicott et al. 1987; Wiens 1989). On Fort Bragg, and perhaps other landscapes with similar structure, the landscape composition attributes and some landscape configuration attributes may not operate independently from the 300-m to 1500-m radius scales (approximately 28 to 707 hectares). For example, principal components of the landscape composition variables typically represented the same landscape variable across all three scales. Similarly, in a study of landscape influence on wintering birds in Georgia, Pearson (1993) found that several landscape attributes were correlated across multiple scales when the data were analyzed by principal components analysis. Pearson attributes these correlations to the inclusion of large habitat patches in several spatial scales. Habitat patches sufficiently large to produce such an effect were present on Fort Bragg.

Principal components analysis also revealed correlations across scales for two landscape configuration variables, patch density at the 900-m and 1500-m scales and contrast-weighted edge density at the 300-m and 900-m scales, but contrast-weighted edge density at the 1500-m radius scale was independent of the two smaller scales. This result suggests that some landscape configuration attributes may operate independently at different scales. For this study, contrast-weighted edge density declined with increasing scale, probably because larger scales were more likely to include parachute drop zones or artillery-impact areas. These areas are relatively large, homogenous features.

Overall, examining multiple landscape scales rather than a single scale may not be necessary within this forest-dominated system for most landscape attributes, but a few landscape configuration attributes may need to be considered separately at different scales. The appropriate landscape scale and the need for examining multiple landscape scales may be dependent upon landscape context. To determine landscape influence on bird distributions, one landscape scale may suffice in most forest-dominated systems or naturally patchy mosaics. If this premise holds true, then comparisons between landscape studies conducted within forest-dominated systems or naturally patchy mosaics may be acceptable even if landscape scales differed between studies. Conversely, it is unclear whether a single spatial scale would be appropriate to address landscape influence on birds of forest patches embedded in an agricultural or urbanized matrix. Perhaps one method to assess whether multiple scales should be examined is to quantify landscape attributes at several scales and then compare across scales to determine if distinctive spatial patterns exist (Pearson 1993). Alternatively, Addicott et al. (1987) advocate that appropriate spatial scales should be identified based on the ecological neighborhood of an organism, defined by an ecological process, a time scale appropriate to that process, and an organism's activity or influence during that time period.

Landscape Associations

Although several similarities existed within the species assemblages at the microhabitat scale, only a few patterns could be related to assemblage at the landscape scale. In particular, the birds of the longleaf pine assemblage generally were associated with landscapes dominated by longleaf pine woodlands, and the birds of the fire suppressed assemblage occurred more frequently in landscapes dominated by fire suppressed habitats, such as mixed pine-hardwood forests. It appears that variation in landscape composition, i.e., the proportion of a landscape composed of specific cover types, is more important than landscape configuration for most species, except for a few species that respond to high-contrast edge density (see below). In a study of landscape structure and bird associations in Oregon, McGarigal and McComb (1995) reported similar findings, though they stress that an association between birds and landscape configuration attributes is difficult to assess because configuration can be quantified by a variety of approaches. No relationships of landscape effects to migratory, foraging, or nesting guild were detected. The influence of landscape attributes on species distributions was individualistic, except for the relationships to species assemblages noted above.

Many species were sensitive to changes in the proportion of certain forest cover types, indicated by variation in species occurrence, which suggests a sensitivity to forest fragmentation. Traditionally, forest fragmentation effects have been tested for in forest patches embedded in a non-forested matrix created by unnatural processes. Changes in forest area and degree of forest patch isolation have been implicated as the key factors impacting forest bird communities in these type of landscapes (e.g., Askins et al. 1987; Loyn 1987; Robinson et al. 1995; Flather and Sauer 1996). For species sensitive to fragmentation, changes in forest area and patch isolation cause lower survival, lower

productivity or disrupt dispersal, especially when fragmentation causes increased contrast between patch types (Walters 1998). In addition to these mechanisms, reduced species abundance related to changes in landscape structure, such as forest fragmentation, may be caused by the habitat selection behavior of a species. If a species selects habitat hierarchically from a large spatial scale to a fine scale, then certain landscape structural changes may reduce the likelihood that an individual will select any habitats defined at a smaller spatial scale.

Although forest fragmentation effects could not be directly tested in the traditional sense in this study, a sensitivity to changes in the proportion of a specific cover type embedded in a forested landscape may be analogous to forest fragmentation effects. For example, in a study of bird communities in a forest-dominated landscape in Chile, Estades and Temple (1999) reported that three species were sensitive to area of remnant hualo (*Nothofagus glauca*) forest fragments even though this native forest mostly was embedded within another forest type, i.e., exotic pine plantations. Based on the univariate tests conducted in this study, three members of the longleaf pine assemblage, Brown-headed Nuthatch, Prairie Warbler, and Bachman's Sparrow, may be sensitive to changes in the proportion of open longleaf pine habitats available in the landscape. Although the regression analyses for the Prairie Warbler and Bachman's Sparrow do not appear to support this postulate since few, if any, landscape attributes are included in their models, there is one important difference between the univariate and regression model approaches. The models include variation due to microhabitat attributes but the univariate tests do not. Thus, these two analytical approaches yielded different information, and this information is not necessarily conflicting. For instance, based on the univariate tests one can surmise that the Prairie Warbler and Bachman's Sparrow may benefit from future increases in the proportion of pine/pine open and pine/pine dense cover types (longleaf pine woodlands/savannas) in the landscape, but based on the predictive models, changes in microhabitat vegetation attributes probably will have the strongest relative impact on species occurrence.

For members of the longleaf pine assemblage, sensitivity to the proportion of longleaf pine habitat in the landscape may indicate sensitivity to forest fragmentation. This hypothesis that species of the longleaf pine assemblage may be sensitive to forest fragmentation is supported by the association of the Brown-headed Nuthatch, Prairie Warbler, and Bachman's Sparrow with landscapes having lower patch richness based on the unvariate tests. Since patch richness is a measure of landscape diversity, this result suggests that these species may fare better in more homogenous landscapes. Penhollow (1996) suggests that habitat specialists, but not habitat generalists, may be negatively impacted by higher patch richness. Indeed, the Bachman's Sparrow is a habitat specialist at Fort Bragg in that it is restricted to longleaf pine woodlands and savannas (Krieger 1997; Chapter 2, this manuscript). The Prairie Warbler had its highest abundance in the same habitat (Krieger 1997; Chapter 2, this manuscript) but it has a somewhat wider habitat range than the sparrow (Nolan 1978; Whitcomb et al. 1981; Jackson 1988). The relative importance of several landscape variables in its predictive model suggests that the Brown-headed Nuthatch may be particularly sensitive to forest fragmentation. Correspondingly, Jackson (1988) concludes that Brown-headed Nuthatch populations

have been declining due to forest fragmentation. Along its northern distribution limit, the nuthatch inhabits maritime pinewoods (Meanley 1975). In recent years, nuthatch populations have declined due to the fragmentation and loss of this habitat caused by fire suppression practices and the development of coastal areas (Watts 1999).

Another bird of the longleaf assemblage, the Eastern Wood Pewee, also may be negatively impacted by fragmentation if the density of high-contrast edge increases. An increasing amount of edge habitat is another factor, besides decreasing forest area and increasing isolation, that is often invoked as a cause of fragmentation effects (Robbins et al. 1989; Saunders et al. 1991; McGarigal and Marks 1995). Edges can function as a reproductive sink for some species by providing suboptimal habitat characterized by increased nest predation and nest parasitism (Wilcove 1985; Saunders et al. 1991; Robinson and Wilcove 1994).

Several species of the fire suppressed assemblage, namely the Blue-gray Gnatcatcher, Red-eyed Vireo, Black-and-white Warbler, and Ovenbird, may benefit from a certain level of landscape diversity. This is based on the association of higher densities of the Black-and-white Warbler, Red-eyed Vireo, and Blue-gray Gnatcatcher with greater variation in mean patch size, and higher densities of the Red-eyed Vireo and Ovenbird with greater patch richness. This association with landscape diversity cannot be interpreted as a general tolerance of forest fragmentation without further information. Other results from this study suggest that these species will benefit from increases in the proportion of mixed pine-hardwood and hardwood forests in the landscape, which is consistent with sensitivity to traditionally-defined forest fragmentation effects (i.e., a decrease in forest area). Accordingly, Robinson et al. (1995) found that nest parasitism and daily nest mortality rates both increased for the Red-eyed Vireo and Ovenbird as the percent forest cover in a landscape decreased. Similarly, abundances of these two species decreased with decreasing forest or patch area (Askins et al. 1987; Robbins et al. 1989), and Whitcomb et al. (1981) calculated a relatively low tolerance to forest fragmentation for both. Clearly, these two species are impacted by changes in forest cover in other large scale studies.

Some members of the drain assemblage may benefit from forest fragmentation if contrast-weighted edge density, patch density, and variation in mean patch size increase. These species are the Common Yellowthroat, Carolina Wren, and Northern Cardinal. Several studies support the premise that the yellowthroat may benefit from forest fragmentation: the yellowthroat declined with greater forest cover in one study (Robbins et al. 1989) and its abundance was negatively related to increased forest area in another study (Askins et al. 1987). This potential tolerance of fragmentation is probably related to the yellowthroat's preference for shrubby habitat along forest edges and in early successional habitats (Whitcomb et al. 1981). Similar to the Common Yellowthroat, Whitcomb et al. (1981) reported that the Carolina Wren was tolerant of fragmentation in Maryland, and Penhollow (1996) found that the wren's abundance in northern Virginia was positively associated with the density of high-contrast edges.

Postulating that the White-eyed Vireo is tolerant of forest fragmentation based on a positive relationship with edge density is precluded by the finding that the vireo is associated with homogeneous landscapes (i.e., lower patch richness and lower Simpson's evenness values). As discussed earlier, the vireo is associated with shrubby understory and midstory vegetation (Johnston and Odum 1956; Johnson and Landers 1982; Robbins et al. 1989; Conner and Dickson 1997), which can occur at high-contrast edges. Perhaps White-eyed Vireos have an affinity for landscapes that are dominated mostly by a few cover types but also provide ample shrub and midstory vegetation.

The last two species of the drain assemblage, the Eastern Towhee and Hooded Warbler, may be more abundant in landscapes dominated by a few cover types (i.e., lower Simpson's evenness index) or having lower patch density, respectively, suggesting that these species may be associated with more homogenous landscapes. Furthermore, the Hooded Warbler may benefit from future increases in pine/mix dense cover in the landscape and the Eastern Towhee may benefit from an increase in early successional habitats (i.e., young open cover type).

Univariate tests suggest that some members of the generalist assemblage (Great Crested Flycatcher, Carolina Chickadee, and Summer Tanager) may be tolerant of changes in landscape structure since their presence was not associated with any landscape attributes. This conclusion appears to be contradicted by the regression models for the flycatcher and the tanager since their models do include landscape variables. These contradictions could be caused by interactions between predictor variables within the models that cannot be accounted for by the univariate analytical method. The flycatcher's model reveals a negative association with high contrast-edge at all the landscape scales considered, which may indicate sensitivity to forest fragmentation. The Summer Tanager may occur more often in more homogenous landscapes, or those dominated by a few cover types. Robbins et al. (1989) found that Great Crested Flycatcher and Summer Tanager were positively associated with greater forested area (at least to a minimum threshold area), and McIntyre (1995) reported that the Carolina Chickadee and Summer Tanager were negatively impacted by decreasing forest patch size. All of the above species can be described on a regional basis as forest generalists since they are relatively common members of the avifauna if enough forest cover is available. Most of these species at Fort Bragg may be tolerant of landscape structural changes, although the degree of tolerance is unknown, and may not perceive the landscape as fragmented if the matrix continues to be dominated by forested habitats.

Scope and Limitations

This study was constrained to some extent because the distribution of count stations was designed to address species' relative abundance between fire suppressed and fire-maintained habitats and across a riparian-upland gradient (see Chapter 2, *this manuscript*), rather than effects of landscape structure. A more appropriate method for studying effects of microhabitat and landscape simultaneously would be to randomly place stations across accessible areas of Fort Bragg while limiting the overlap of

landscapes associated with the count stations. Still, associations between landscape structure and the probability of occurrence for several species were detected, such as the negative relationship with edge density for the Eastern Wood Pewee and the apparent sensitivity of Brown-headed Nuthatches to landscape structure. Further research based on more powerful methodology may reveal more landcape associations for the breeding birds of Fort Bragg.

The utility of this study for discerning species-habitat relationships also was restricted by the spatial scales considered (Wiens 1986). First, the microhabitat scale, a 50-m radius, was chosen to address habitat selection at the level of an individual bird's territory. The 50-m radius point count method is a common technique in bird-habitat studies, therefore the species-microhabitat relationships detected can be compared readily to results of many other studies. For quantifying the landscape pattern, grain (the minimum mapping resolution or patch size) and extent (the maximum area studied) can greatly affect the observed patterns (Turner et al. 1989). In this study, the grain of the landscape analyses was 10 acres (4.05 hectares), so I was unable to discern patchiness in the landscape at a finer resolution. The perceived heterogeneity of a landscape is dependent on this minimum resolution, and thus changes in the grain ultimately can affect conclusions about species-habitat relationships (Kotliar and Wiens 1990; Pickett and Cadenasso 1995). The extent ranged from a 300-m to a 1500-m radius area. It is well established that habitat relationships should not be extrapolated to larger landscape scales since a species may exhibit distinctive associations for different spatial scales (Addicott et al. 1987; Wiens 1989). It may be difficult to compare the landscape patterns associated with the breeding birds of Fort Bragg to other landscape-level studies since the grain often varies across studies (Wiens 1989). However, because I quantified attributes at multiple landscape scales in this study, it may be possible to compare my results to other studies of varying landscape extents in forest-dominated systems (see Landscape Scale section).

CONCLUSIONS

One of the major implications of my results is that changes in microhabitat and landscape attributes resulting from alternative fire management practices can be expected to impact two distinct bird assemblages, the fire suppressed assemblage and longleaf pine assemblage. If land managers continue to restore the forested landscape of Fort Bragg to longleaf pine savannas and woodlands through growing season prescribed fire, the probability of occurrence for species such as the Red-cockaded Woodpecker, Brown-headed Nuthatch, Prairie Warbler, and Bachman's Sparrow will increase, and the occurrence of species such as the Red-eyed Vireo, Black-and-white Warbler and Ovenbird will decline. Several studies have shown that the birds of the longleaf pine assemblage are highly sensitive to fire suppression and other land management activities that allow open pine forests to succeed to denser mixed pine-hardwood forests (Nolan 1978; Engstrom et al. 1984; Dunning 1993; Carter et al. 1995; Wilson et al. 1995; Krieger 1997; Chapter 2, *this manuscript*). Of this assemblage, the Bachman's Sparrow may be ultra-sensitive to fire suppression practices that induce successional changes in its

preferred open habitat. Engstrom et al. (1984) found that this sparrow was one of the first species to disappear from open pinelands after fire exclusion. Continued existence of the longleaf pine assemblage depends on periodic prescribed fires to maintain the open pinelands preferred by these birds. Although birds of the fire suppressed assemblage will be negatively impacted by continued restoration of longleaf pine, conservation of these species can be best accomplished through efforts in other regions where longleaf pine woodlands and savannas were not the predominant habitats prior to European settlement.

Another implication of this study is that large scale changes to landscape structure, especially the relative composition of various cover types, also may impact certain species. Species associated with longleaf pine woodlands and savannas, such as the Brown-headed Nuthatch, Bachman's Sparrow, and Prairie Warbler, may be sensitive not only to the loss of these habitats, but also to fragmentation of the remaining habitat. These longleaf pine associates appear to do best in relatively homogenous landscapes dominated by longleaf pine habitats. Though less important than relative availability of different habitat types, other landscape attributes, such as patch richness density or contrast-weighted edge density, may influence the occurrence of at least some species. For instance, a few species of the drain assemblage, such as the Common Yellowthroat, Carolina Wren, and Northern Cardinal, would most likely benefit from forest fragmentation if it caused an increase in the availability of high-contrast edge habitat.

The most significant conclusion of this study is that the microhabitat scale may be of greater importance than the landscape scale for many breeding bird species within a forest-dominated landscape. At Fort Bragg, the vegetation characteristics associated with fire management and the drain-upland gradient within this longleaf pine ecosystem greatly influence species assemblages and the occurrences of individual species. Therefore, future land management that directly impacts vegetation structure and floristics will affect the occurrence of most breeding birds considered in this study. While landscape attributes were typically of secondary importance for most species, management activities such as prescribed burning will not only impact microhabitat characteristics but most likely, burning will cause large-scale changes in landscape structure. Hence the main patterns of variation in vegetation structure and floristics at the microhabitat scale should be directly correlated with certain landscape structure attributes. Consequently, the probability of occurrence of various species may be coarsely predicted by examining landscape structure if an appropriate GIS database is available. Although there is substantial evidence that the microhabitat scale is the most important scale for determining bird distributions at Fort Bragg, Morris (1987) suggested that the spatial scale related to the greatest amount of variation in fitness may be the most important scale for a particular species. Thus to detect the most influential spatial scale, studies of species occurrence, relative abundance or density should be followed by studies of demography to make the strongest inferences about potential impacts of management.

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Table 1: List of FRAGSTATS metrics used in quantifying landscape composition and configuration around n=87 count stations at Fort Bragg, NC (1996-1997).

FRAGSTATS Metric	Metric Description
Landscape Composition	
• %LAND	• % of landscape of particular class – one for each cover type
(1) Young open	(1) Early successional fields – no midstory/overstory; ground cover of grasses/forbs (parachute drop zones, wildlife food fields)
(2) Young dense	(2) Later successional fields – scrub/shrub and young pine stands
(3) Pine/pine open	(3) Open longleaf pine stands (fire intense areas)
(4) Pine/pine dense	(4) Dense longleaf pine stands (fire intense areas)
(5) Pine/mix open	(5) Open pine overstory and mixed pine and hardwood midstory (fire suppressed areas)
(6) Pine/mix dense	(6) Dense pine overstory and mixed pine and hardwood midstory (fire suppressed areas)
(7) Mix/mix open	(7) Open mixed pine and hardwood overstory and midstory (fire suppressed areas)
(8) Mix/mix dense	(8) Dense mixed pine and hardwood overstory and midstory (fire suppressed areas)
(9) Drain	(9) Dense, shrubby vegetation of drains
(10) Upland hardwood	(10) Upland soils, primarily hardwood species
• PRD (#/100 ha)	• Patch Richness Density – density allows comparison across scales
• SIEI	• Simpson's Evenness Index
Landscape Configuration	
• PD (#/100 ha)	• Patch Density; at landscape scale yields heterogeneity index; density allows comparison across scales
• MPS (ha)	• Mean Patch Size
• PSCV (%)	• Patch Size Coefficient of Variation – allows consideration of mean and standard deviation (measures relative variability about the mean)
• CWED (m/ha)	• Contrast-Weighted Edge Density – contrast weights 0 to 1; density allows comparison across scales
• IJI	• Interspersion and Juxtaposition Index – extent that cover types are interspersed (high values indicate patch types are equally adjacent to another)

Table 2: Results of the principal components analysis for the microhabitat variables collected at n=87 count stations at Fort Bragg, NC. Variables with relatively high loadings are in bold.

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Eigenvalue	6.79	3.58	2.47	2.01	1.66	1.26	1.17
Variance Explained (proportion)	0.25	0.13	0.09	0.07	0.06	0.05	0.04
Variables:							
% Slope	0.09	0.23	0.01	-0.01	-0.11	-0.19	0.03
% Canopy Cover	**0.66**	0.03	0.50	0.28	-0.08	-0.03	0.17
Canopy Height	-0.06	0.29	0.36	**0.68**	-0.22	0.01	0.16
Litter Depth	0.31	0.09	**0.64**	0.08	-0.06	0.12	-0.22
% Green Cover	-0.29	**0.84**	0.16	0.14	0.06	0.30	-0.02
% Grass Cover	**-0.73**	-0.03	-0.09	0.05	0.22	0.31	-0.06
% Shrub Cover	0.03	**0.88**	0.22	-0.02	-0.04	-0.07	0.14
% Forb Cover	0.02	0.05	-0.03	0.16	0.09	**0.86**	-0.08
% Fern Cover	0.11	**0.62**	-0.01	0.07	-0.17	-0.13	-0.27
% Downed Logs	0.31	0.08	0.06	0.10	0.01	-0.30	**0.66**
% Leaf Litter	0.16	0.19	**0.81**	0.05	-0.10	-0.30	0.10
% Bare Ground	0.01	-0.30	**-0.81**	-0.17	0.07	-0.13	-0.19
Shrubs 2.5-8 cm	0.10	0.30	0.10	-0.01	0.01	-0.12	0.05
Saplings <2.5 cm	-0.05	0.31	0.39	-0.57	0.09	-0.26	-0.11
Saplings 2.5-8 cm	0.38	-0.10	0.18	-0.31	**0.63**	0.07	-0.03
# Trees 8-23 cm dbh	**0.77**	-0.09	0.15	-0.30	-0.06	0.17	0.28
# Trees >23-38 cm dbh	0.04	-0.21	0.31	-0.01	**-0.70**	-0.06	0.11
# Trees >38 cm dbh	-0.02	0.18	0.19	**0.85**	-0.01	0.12	-0.07
# Longleaf Pine Saplings	-0.10	-0.09	-0.03	-0.06	**0.84**	0.04	0.04
# Other Pine Species Saplings [a]	0.13	0.14	0.07	-0.05	0.12	-0.02	0.08
# Longleaf Pine Trees	-0.52	-0.38	0.12	-0.19	-0.30	-0.01	-0.37
# Other Pine Species Trees [a]	0.45	0.09	0.26	-0.05	-0.24	0.24	**0.60**
# Other Species Trees [b]	**0.91**	-0.04	-0.02	-0.06	0.09	0.01	-0.01
Shrub Species Richness	0.29	**0.80**	0.11	0.24	-0.08	-0.08	0.07
Sapling Species Richness	0.35	**0.66**	0.33	0.05	0.24	-0.06	0.08
Tree Species Richness	**0.80**	0.39	0.16	0.11	0.07	0.01	0.14
# Snags >12 cm dbh	0.16	0.37	0.01	-0.11	-0.11	-0.38	0.31

[a] excludes Longleaf Pine
[b] non-pine species

Table 3: Results of the principal components analysis for the landscape composition variables for n=87 count stations at Fort Bragg, NC. Variables are identified first by landscape scale (m) and then by the landscape composition attribute. Variables with relatively high loadings are in bold.

	PC 1	PC 2	PC 3	PC 4	PC 5	PC6	PC 7	PC 8	PC 9	PC 10
Eigenvalue	7.12	4.82	3.57	3.14	2.53	2.27	1.96	1.61	1.35	1.03
Variance Explained (proportion)	0.20	0.13	0.10	0.09	0.07	0.06	0.05	0.04	0.04	0.03
Variables										
300_Young Open	-0.10	-0.13	-0.01	-0.21	-0.27	**0.75**	-0.19	0.10	-0.09	-0.09
300_Young Dense	-0.06	0.13	-0.16	0.03	0.02	0.19	0.17	**0.73**	-0.06	0.09
300_Pine/Pine Open	-0.56	-0.32	-0.28	-0.29	-0.34	-0.10	-0.11	-0.17	-0.27	-0.13
300_Pine/Pine Dense	-0.21	-0.04	-0.02	**0.86**	-0.21	-0.05	-0.14	0.03	-0.09	-0.03
300_Pine/Mix Open	0.23	-0.12	-0.12	-0.04	0.08	0.07	**0.81**	0.21	-0.02	0.18
300_Pine/Mix Dense	**0.87**	0.01	0.14	-0.17	-0.06	0.01	0.02	-0.08	-0.02	0.06
300_Mix/Mix Open	-0.04	-0.13	**0.86**	-0.04	0.04	-0.12	0.01	0.07	-0.01	0.08
300_Mix/Mix Dense	0.03	**0.78**	-0.10	-0.22	0.37	-0.11	-0.02	-0.03	-0.02	-0.01
300_Drain/Riparian	0.01	-0.23	0.01	-0.03	0.26	-0.17	-0.09	0.07	**0.79**	0.05
300_Upland Hardwood	-0.01	0.06	-0.05	-0.16	**0.88**	0.06	-0.07	-0.02	0.05	0.07
300_Patch Richness Density	0.31	0.16	0.28	-0.06	0.05	-0.02	0.14	0.05	-0.12	0.35
300_Simpson's Evenness Index	0.16	-0.29	-0.19	-0.09	0.08	0.10	-0.05	0.23	0.19	**0.67**
900_Young Open	-0.09	-0.11	0.01	-0.11	-0.04	**0.91**	-0.09	0.11	-0.15	-0.04
900_Young Dense	0.01	0.11	0.06	-0.03	-0.14	0.23	0.01	**0.83**	0.03	0.02
900_Pine/Pine Open	-0.53	-0.50	-0.25	-0.38	-0.12	-0.02	-0.29	-0.14	-0.27	0.01
900_Pine/Pine Dense	-0.08	-0.19	-0.05	**0.84**	-0.26	-0.30	-0.09	-0.10	0.06	-0.14
900_Pine/Mix Open	0.14	0.05	-0.03	-0.12	-0.11	-0.13	**0.90**	0.07	-0.06	0.14
900_Pine/Mix Dense	**0.92**	0.04	-0.08	-0.08	0.01	-0.12	0.09	-0.09	-0.12	0.06
900_Mix/Mix Open	0.04	-0.05	**0.93**	-0.02	-0.03	0.04	0.06	0.02	0.05	0.02
900_Mix/Mix Dense	0.05	**0.85**	-0.05	-0.19	0.29	-0.13	0.05	0.14	-0.07	0.03
900_Drain/Riparian	-0.17	-0.03	0.04	-0.01	-0.03	-0.19	-0.06	-0.02	**0.93**	0.01
900_Upland Hardwood	-0.04	0.33	-0.05	-0.25	**0.82**	-0.04	-0.13	-0.01	-0.03	0.02
900_Patch Richness Density	0.31	0.32	0.45	-0.21	0.26	-0.08	0.30	0.42	-0.04	0.07
900_Simpson's Evenness Index	0.09	0.07	0.22	-0.15	0.04	-0.04	0.37	-0.07	-0.01	**0.78**

Table 3 continued.

Variables:	PC 1	PC 2	PC 3	PC 4	PC 5	PC6	PC 7	PC 8	PC 9	PC 10
1500_Young Open	-0.07	-0.11	-0.03	-0.11	0.27	**0.82**	-0.02	0.04	-0.20	0.05
1500_Young Dense	-0.11	-0.02	0.41	-0.08	0.10	-0.16	0.05	**0.74**	-0.07	0.04
1500_Pine/Pine Open	-0.53	-0.62	-0.12	-0.37	0.11	-0.04	-0.24	-0.03	-0.15	-0.05
1500_Pine/Pine Dense	0.03	-0.25	-0.16	**0.73**	-0.24	-0.33	0.01	-0.22	0.18	-0.10
1500_Pine/Mix Open	-0.09	0.20	0.09	-0.01	-0.24	-0.27	**0.73**	-0.04	-0.05	0.19
1500_Pine/Mix Dense	**0.83**	0.16	-0.19	-0.09	-0.07	-0.16	0.06	0.07	-0.12	0.02
1500_Mix/Mix Open	-0.02	0.17	**0.77**	-0.01	-0.19	0.15	-0.20	0.08	0.14	0.19
1500_Mix/Mix Dense	0.22	**0.84**	0.04	-0.13	0.02	-0.15	0.01	0.20	-0.08	0.07
1500_Drain/Riparian	-0.02	0.16	0.08	0.15	-0.29	-0.08	0.02	-0.20	**0.75**	-0.03
1500_Upland Hardwood	-0.04	0.39	0.08	-0.43	**0.69**	-0.05	-0.05	0.07	-0.16	-0.17
1500_Patch Richness Density	0.33	0.15	0.41	-0.31	0.17	-0.13	-0.08	0.54	-0.12	-0.08
1500_Simpson's Evenness Index	-0.07	0.20	0.28	0.06	-0.09	-0.13	0.33	0.03	-0.07	**0.70**

Table 4: Results of the principal components analysis for the land configuration variables for n=87 count stations at Fort Bragg, NC. Variables are identified first by landscape scale (m) and then by the landscape configuration attribute. Variables with relatively high loadings are in bold.

	PC 1	PC 2	PC 3	PC 4
Eigenvalue	3.66	2.33	1.57	1.46
Variance Explained (proportion)	0.30	0.19	0.13	0.12
Variables:				
300_Patch Density	0.43	0.16	0.13	0.01
300_Patch Size Coefficient of Variation	0.05	-0.06	0.01	-0.02
300_Contrast-Weighted Edge Density	0.06	**0.96**	0.16	0.12
300_Interspersion/Juxtaposition Index	-0.07	0.09	0.02	-0.06
900_Patch Density	**0.84**	0.12	0.13	-0.21
900_Patch Size Coefficient of Variation	-0.07	-0.02	0.06	0.34
900_Contrast-Weighted Edge Density	0.17	**0.74**	0.51	-0.03
900_Interspersion/Juxtaposition Index	0.09	0.02	0.02	-0.06
1500_Patch Density	**0.94**	0.07	0.19	-0.04
1500_Patch Size Coefficient of Variation	-0.14	0.11	0.06	**0.94**
1500_Contrast-Weighted Edge Density	0.28	0.36	**0.87**	0.08
1500_Interspersion/Juxtaposition Index	0.21	-0.08	0.02	-0.08

Table 5: Interpretations of principal components analyses of the microhabitat, landscape composition, and landscape configuration variables quantified during 1996-1997 at n=87 count stations at Fort Bragg, NC.

Principal Component[a]	Loaded Variables[b]	Interpretation
M1	% Canopy Cover, (–) % Grass Cover, # Trees 8-23 cm dbh, # Other Species Trees[c], Tree Species Richness	Tree Species Richness and Density (Fire Suppression Gradient)
M2	% Green Cover, % Shrub Cover, % Fern Cover, Shrub Species Richness, Sapling Species Richness	Drain Habitat (Drain-Upland Gradient)
M3	Litter Depth, % Leaf Litter, (–) % Bare Ground	Leaf Litter
M4	Canopy Height, # Trees >38 cm dbh	Stand Age/Height
M5	# Saplings 2.5-8 cm, # Longleaf Pine Saplings, (–) # Trees 23-38 cm dbh	# Saplings 2.5-8 cm, # Longleaf Pine Saplings, (–) # Trees 23-38 cm dbh[d]
M6	% Forb Cover	% Forb Cover[d]
M7	% Downed Logs, # Other Pine Trees[e]	% Downed Logs, # Other Pine Trees[de]
LCP1	300_Pine/Mix Dense, 900_Pine/Mix Dense, 1500_Pine/Mix Dense	Pine/Mix Dense
LCP2	300_Mix/Mix Dense, 900_Mix/Mix Dense, 1500_Mix/Mix Dense	Mix/Mix Dense
LCP3	300_Mix/Mix Open, 900_Mix/Mix Open, 1500_Mix/Mix Open	Mix/Mix Open
LCP4	300_Pine/Pine Dense, 900_Pine/Pine Dense, 1500_Pine/Pine Dense	Pine/Pine Dense
LCP5	300_Upland Hardwood, 900_Upland Hardwood, 1500_Upland Hardwood	Upland Hardwood
LCP6	300_Young Open, 900_Young Open, 1500_Young Open	Young Open
LCP7	300_Pine/Mix Open, 900_Pine/Mix Open, 1500_Pine/Mix Open	Pine/Mix Open
LCP8	300_Young Dense, 900_Young Dense, 1500_Young Dense	Young Dense
LCP9	300_Drain, 900_Drain, 1500_Drain	Drain
LCP10	300_Simpson's Evenness Index, 900_Simpson's Evenness Index, 1500_Simpson's Evenness Index	Simpson's Evenness Index
LCF1	900_Patch Density, 1500_Patch Density	Patch Density at 900 and 1500 m scales[e]
LCF2	300_Contrast-Weighted Edge Density, 900_Contrast-Weighted Edge Density	Contrast-Weighted Edge Density at 300 and 900 m scales[e]
LCF3	1500_Contrast-Weighted Edge Density	Contrast-Weighted Edge Density at 1500 m scale[e]
LCF4	1500_Patch Size Coefficient of Variation	Patch Size Coefficient of Variation at 1500 m scale[e]

[a] Codes are: M=microhabitat, LCP=landscape composition, LCF=landscape configuration.
[b] Variables are positively related to the principal component unless otherwise noted.
[c] Non-pine species
[d] No interpretation in addition of variable(s)
[e] Excludes Longleaf Pine

Table 6: Predictor variables of probability of occurrence (presence/absence) by logistic regression for 19 breeding bird species assemblage at Fort Bragg, NC (n=87, 1996-1997). Model variables are indicated by standardized slope parameter estimates.

	Longleaf Pine Bird Species[c]			
	EAWP	BHNU	PRAW	BACS
Concordant (%) [a]	81.3	89.7	85.3	91.1
Principal Component Variable[b]:				
M1: Tree Species Richness and Density (Fire Suppressed Habitat)	-0.50[3]	-0.53[3]	-0.97[4]	-1.97[4]
M2: Drain Habitat			0.26[2]	
M3: %Leaf Litter Cover and Depth		-0.30[2]		
M4: Stand Age/Height		0.25[1]		
M5: (+)Longleaf Pine Saplings and (-)# Trees 23-38 cm dbh	0.31[3]		0.48[3]	
M6: %Forb Cover				
M7: %Downed Logs and # Other Pine Trees[d]			0.68[3]	
LCP1: Pine/Mix Dense			-0.36[3]	
LCP2: Mix/Mix Dense				
LCP3: Mix/Mix Open		-0.66[3]		
LCP4: Pine/Pine Dense				
LCP5: Upland Hardwood		-0.61[2]		
LCP6: Young Open				
LCP7: Pine/Mix Open		-0.34[2]		
LCP8: Young Dense		0.36[2]		
LCP9: Drain				
LCP10: Simpson's Evenness Index				
LCF1: Patch Density at 900 and 1500 m scales		-0.69[3]		
LCF2: Contrast-Weighted Edge Density at 300 and 900 m scales	-0.30[2]			
LCF3: Contrast-Weighted Edge Density at 1500 m scale	-0.38[3]			
LCF4: Patch Size Coefficient of Variation at 1500 m scale				

Table 6 continued.

	Fire Suppressed Bird Species[c]				
	TUTI	BGGN	REVI	BAWW	OVEN
Concordant[a]	69.6	90.0	92.6	91.8	83.7
Principal Component Variable[b]:					
M1: Tree Species Richness and Density (Fire Suppressed Habitat)			1.09[4]	0.87[4]	0.50[3]
M2: Drain Habitat	0.31[3]	0.93[4]	0.72[3]		
M3: %Leaf Litter Cover and Depth			0.53[1]	0.49[3]	
M4: Stand Age/Height		0.52[3]	0.84[3]	0.53[3]	
M5: (+)Longleaf Pine Saplings and (-)# Trees 23-38 cm dbh				0.45[3]	
M6: %Forb Cover					
M7: %Downed Logs and # Other Pine Trees[d]		0.34[2]	0.56[3]	0.36[2]	
LCP1: Pine/Mix Dense	0.29[3]				
LCP2: Mix/Mix Dense					
LCP3: Mix/Mix Open		0.72[3]	0.33[2]		
LCP4: Pine/Pine Dense		-0.30[2]			
LCP5: Upland Hardwood					0.49[3]
LCP6: Young Open					
LCP7: Pine/Mix Open					
LCP8: Young Dense				-0.62[3]	
LCP9: Drain		0.35[2]			
LCP10: Simpson's Evenness Index					
LCF1: Patch Density at 900 and 1500 m scales				-0.50[3]	
LCF2: Contrast-Weighted Edge Density at 300 and 900 m scales					
LCF3: Contrast-Weighted Edge Density at 1500 m scale					
LCF4: Patch Size Coefficient of variation at 1500 m scale		0.33[1]	0.62[3]	0.45[3]	

Table 6 continued.

	Drain Bird Species[c]					
	CARW	WEVI	COYE	HOWA	NOCA	EATO
Concordant[a]	83.3	95.7	93.9	89.6	76.7	92.2
Principal Component Variable[b]:						
M1: Tree Species Richness and Density (Fire Suppressed Habitat)	0.45[3]	0.65[3]				
M2: Drain Habitat	0.66[4]	1.36[4]	1.47[4]	0.74[4]	0.52[3]	1.33[4]
M3: %Leaf Litter Cover and Depth				0.33[1]		0.45[3]
M4: Stand Age/Height			0.75[4]	0.58[3]		0.61[3]
M5: (+)Longleaf Pine Saplings and (-)# Trees 23-38 cm dbh	-0.30[1]					
M6: %Forb Cover		0.66[3]				
M7: %Downed Logs and # Other Pine Trees[d]						-0.73[3]
LCP1: Pine/Mix Dense				0.53[3]		
LCP2: Mix/Mix Dense						
LCP3: Mix/Mix Open						
LCP4: Pine/Pine Dense				-0.34[1]		
LCP5: Upland Hardwood						
LCP6: Young Open						0.47[3]
LCP7: Pine/Mix Open						
LCP8: Young Dense					0.19[1]	
LCP9: Drain	-0.29[2]					
LCP10: Simpson's Evenness Index		-0.45[2]				-0.77[3]
LCF1: Patch Density at 900 and 1500 m scales				-0.50[3]	0.33[2]	
LCF2: Contrast-Weighted Edge Density at 300 and 900 m scales		0.56[2]				
LCF3: Contrast-Weighted Edge Density at 1500 m scale	0.29[2]		0.48[3]			
LCF4: Patch Size Coefficient of variation at 1500 m scale					0.26[2]	

Table 6 continued.

	Generalist Bird Species[c]			
	GCFL	BLJA	CACH	SUTA
Concordant[a]	74.7	80.3	63.9	72.1
Principal Component Variable[b]:				
M1: Tree Species Richness and Density (Fire Suppressed Habitat)				
M2: Drain Habitat		-0.38[1]	0.17[1]	
M3: %Leaf Litter Cover and Depth		0.38[2]		
M4: Stand Age/Height				
M5: (+)Longleaf Pine Saplings and (-)# Trees 23-38 cm dbh		0.28[2]	-0.26[2]	
M6: %Forb Cover				-0.42[3]
M7: %Downed Logs and # Other Pine Trees[d]				
LCP1: Pine/Mix Dense		0.29[2]		
LCP2: Mix/Mix Dense		0.34[3]		
LCP3: Mix/Mix Open				
LCP4: Pine/Pine Dense	-0.37[3]			
LCP5: Upland Hardwood				
LCP6: Young Open	0.33[3]			
LCP7: Pine/Mix Open				0.31[3]
LCP8: Young Dense				
LCP9: Drain	-0.22[1]			
LCP10: Simpson's Evenness Index				-0.21[1]
LCF1: Patch Density at 900 and 1500 m scales				
LCF2: Contrast-Weighted Edge Density at 300 and 900 m scales	-0.28[3]			
LCF3: Contrast-Weighted Edge Density at 1500 m scale	-0.23[2]			
LCF4: Patch Size Coefficient of Variation at 1500 m scale				

[a] Concordant: percent concordance between predictions and observations

[b] Description of principal component variables reflect positive relationship unless otherwise noted. Codes are: M=microhabitat, LCP=landscape composition, LCF=landscape configuration. For landscape variables, description of component variables applies across all three landscape scales unless specific scales are identified.

[c] Mnemonic codes for bird species in Appendix III. Statistical significance indicated by superscripts: [1]=p<0.2, [2]=p<0.1, [3]=p<0.05, [4]=p<0.001.

[d] Excludes Longleaf Pine trees.

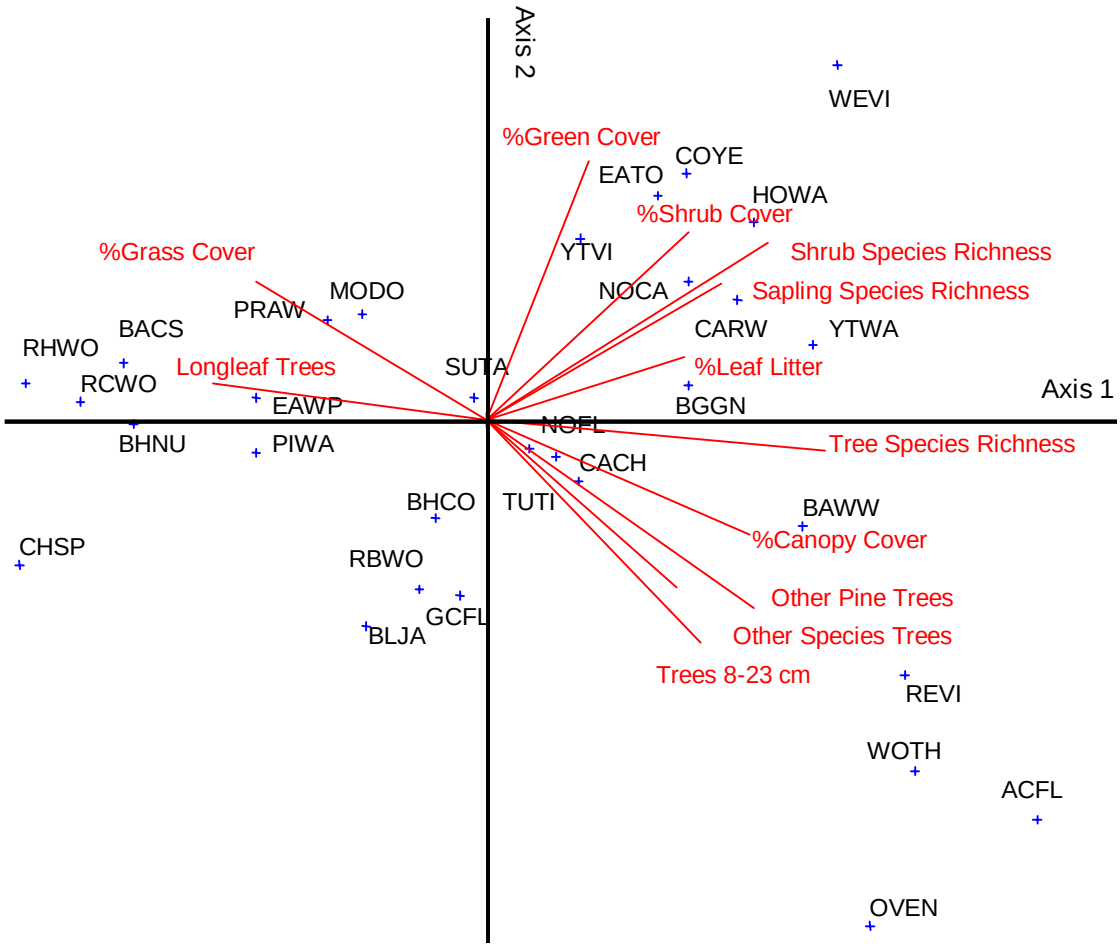

Figure 1: Bi-plot of canonical correspondence analysis for the ordination of the breeding bird community of Fort Bragg, NC for 1996-1997 (n=87) in relation to microhabitat variables. Species codes for birds are given in Appendix I, Chapter 2.

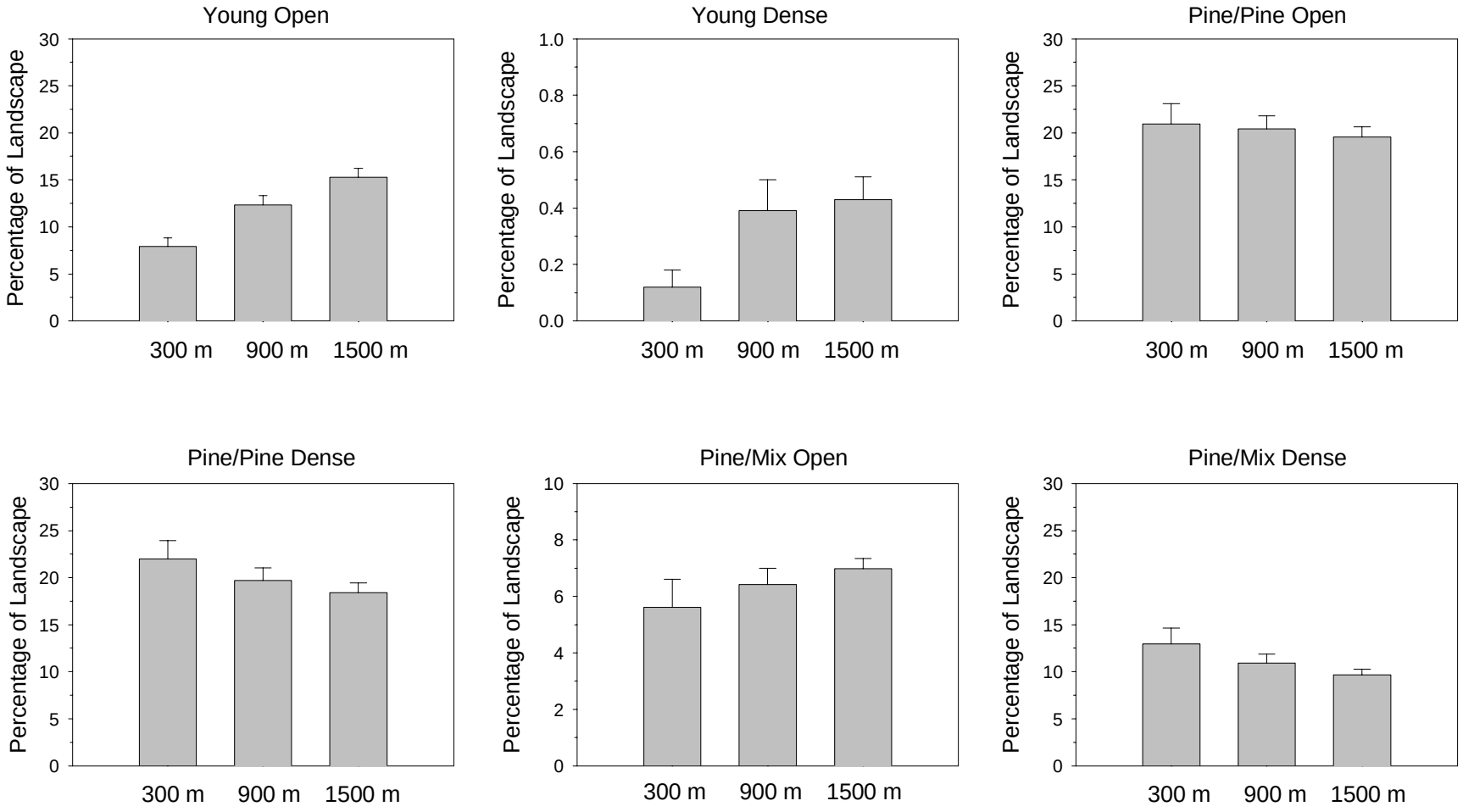

Figure 2: Comparison of the mean values (with standard error bars) of the landscape variables across the three landscape scales for n=87 count stations at Fort Bragg, NC (1996-1997).

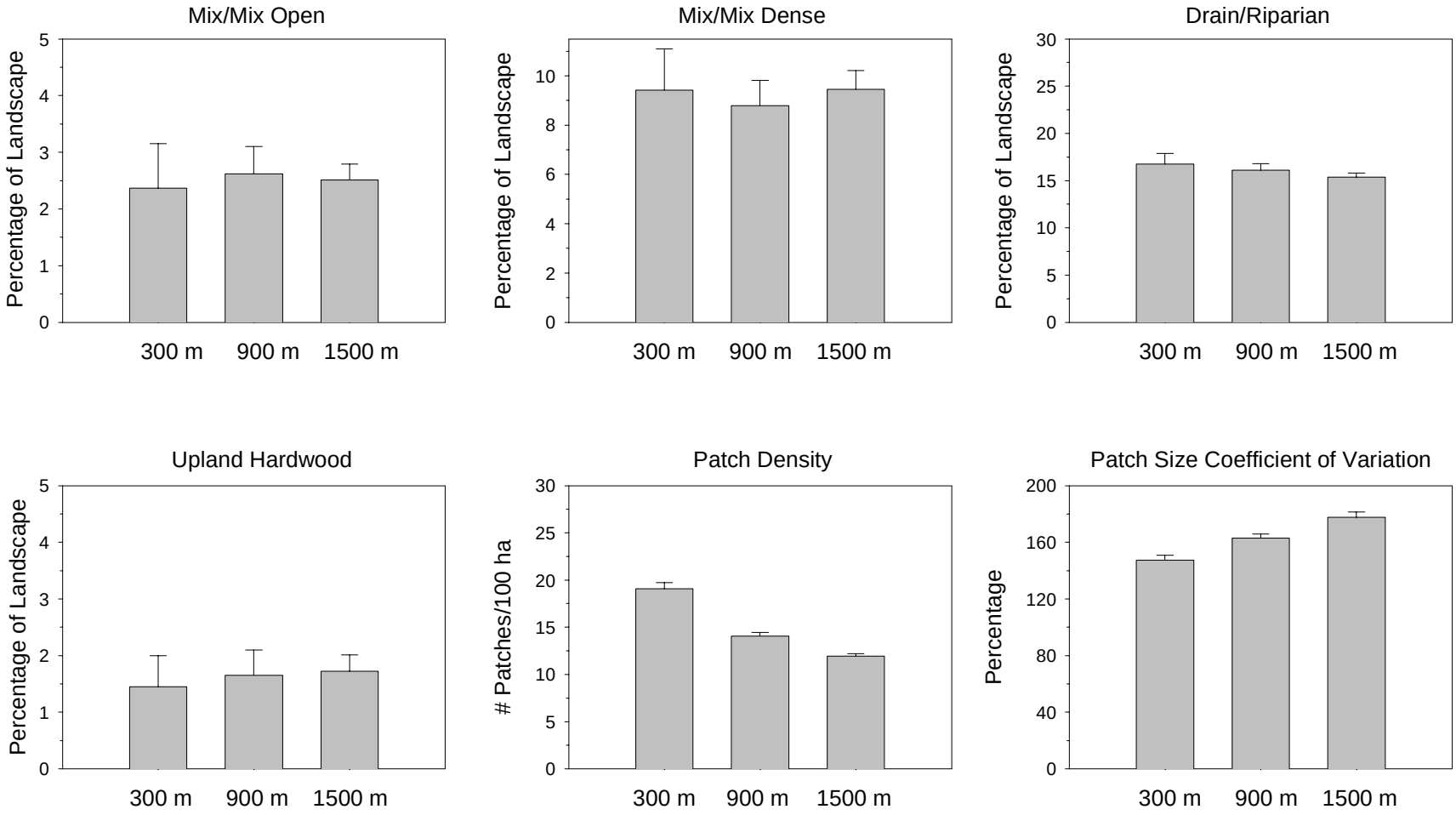

Figure 2 continued.

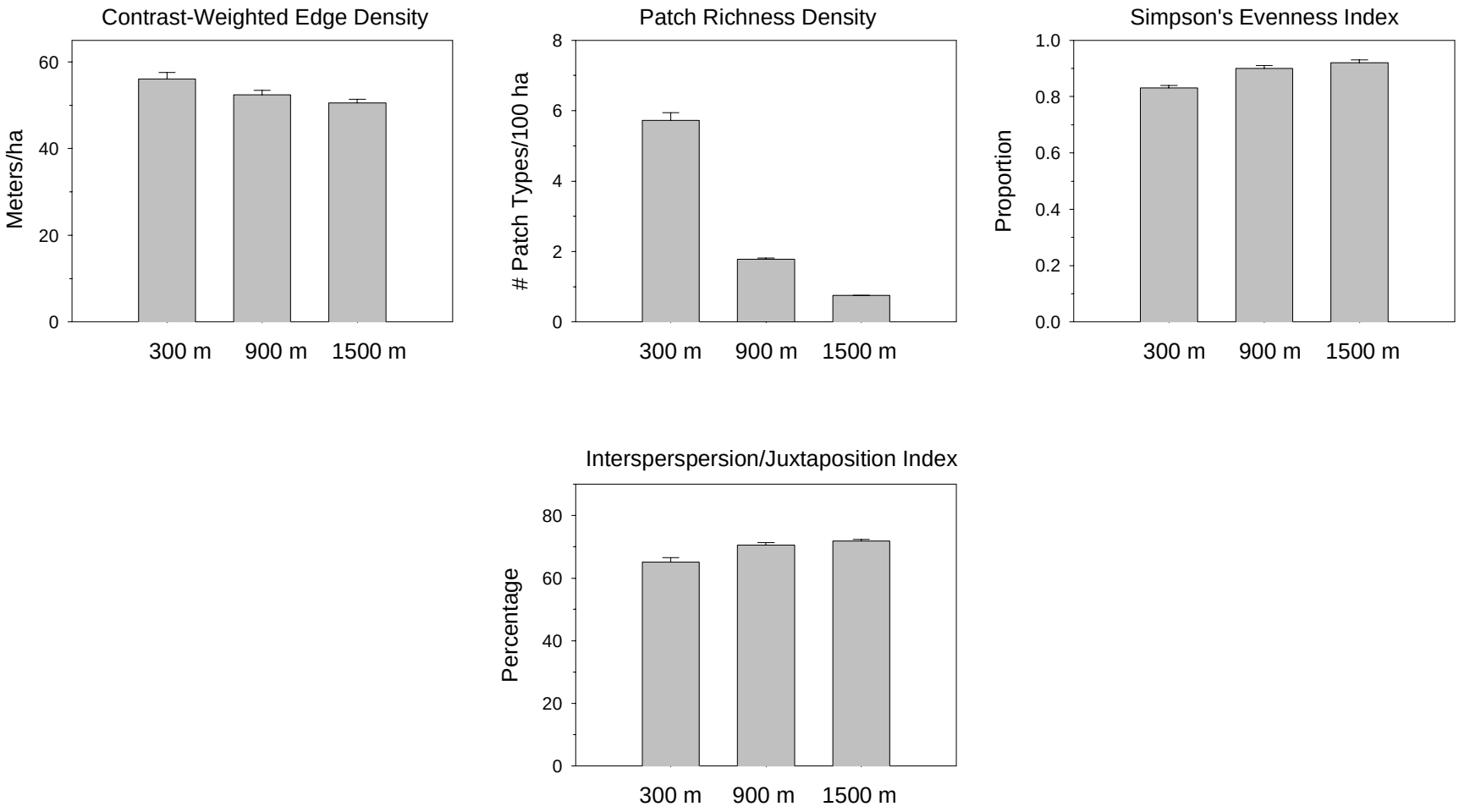

Figure 2 continued.

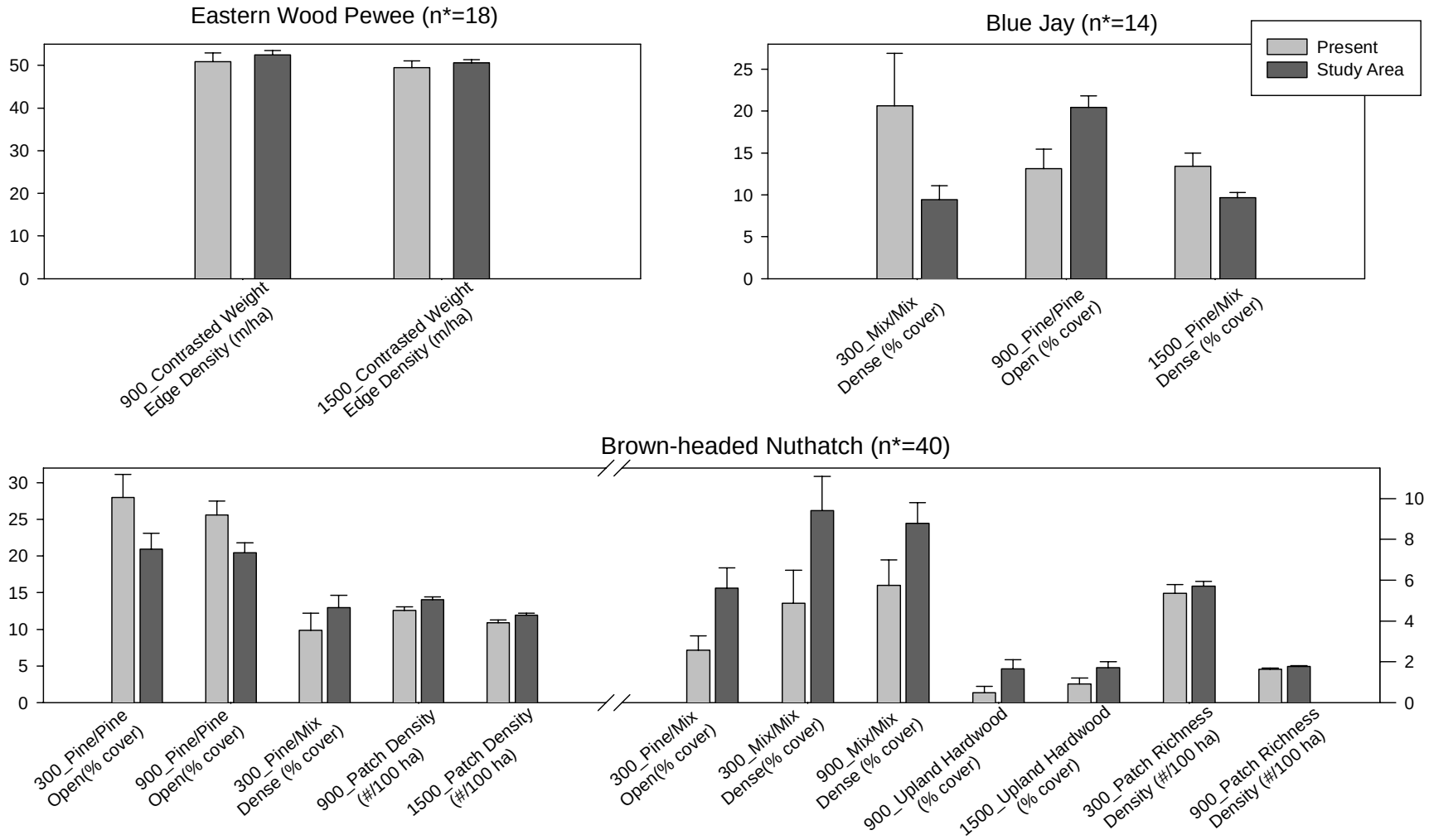

Figure 3: Results of Wilcoxon tests for breeding bird species of Fort Bragg, NC (1996-1997) comparing landscape structure for count stations where a bird species was present (n* is the sample size for each species) to the landscape structure for the entire study area (n=87). In the graphs, only species with significant results are shown and only the landscape variables that differed significantly are included.

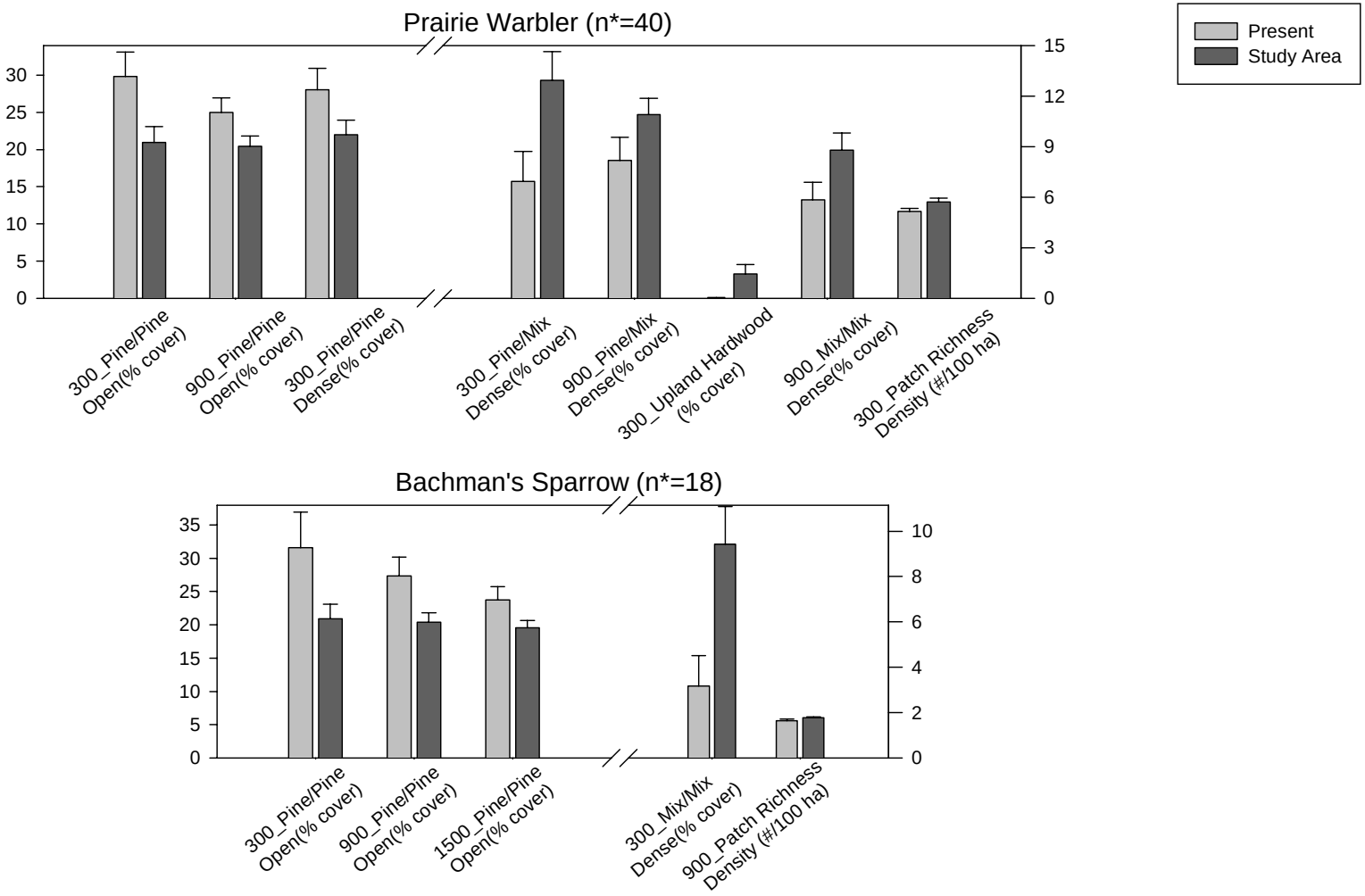

Figure 3 continued.

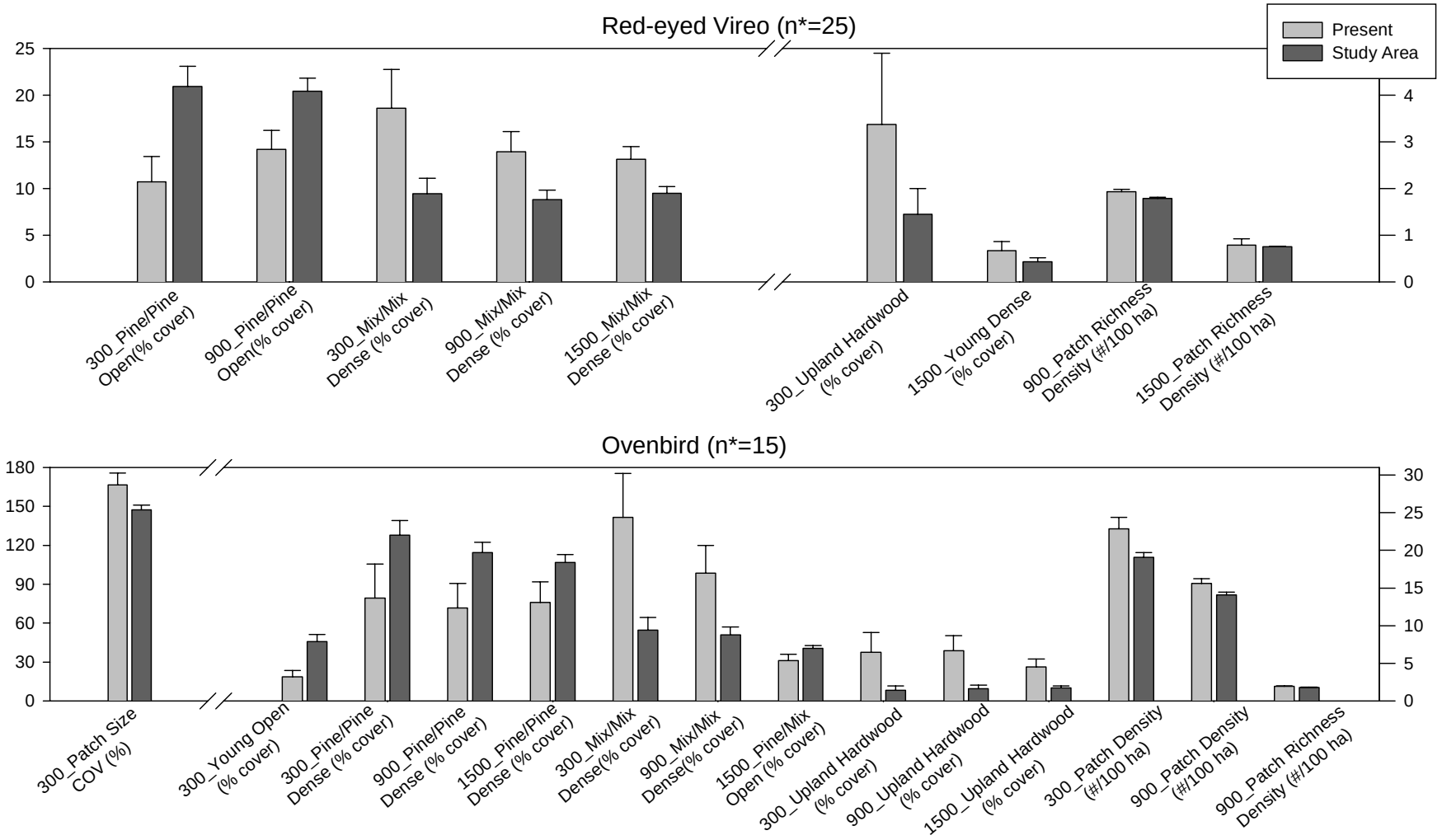

Figure 3 continued.

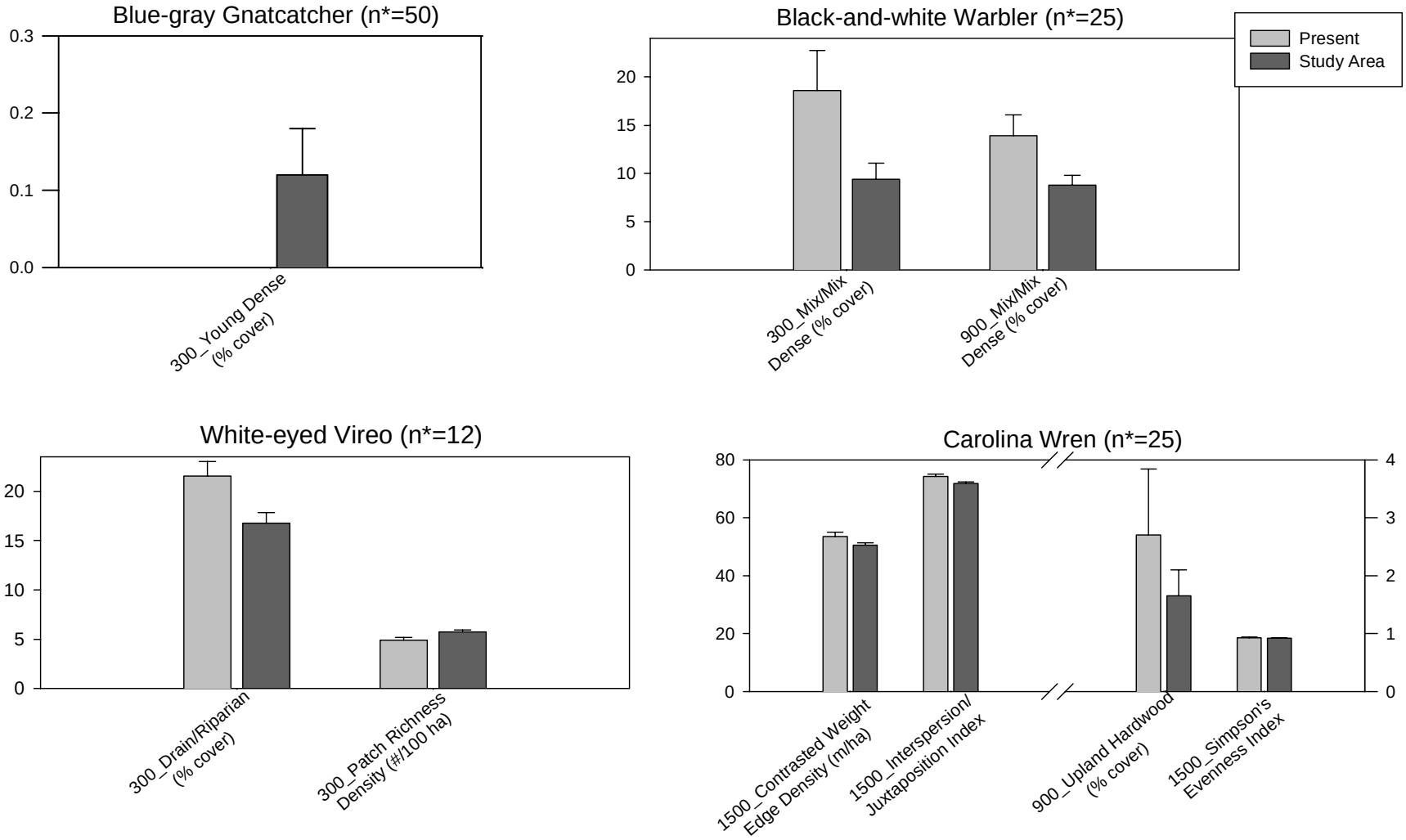

Figure 3 continued.

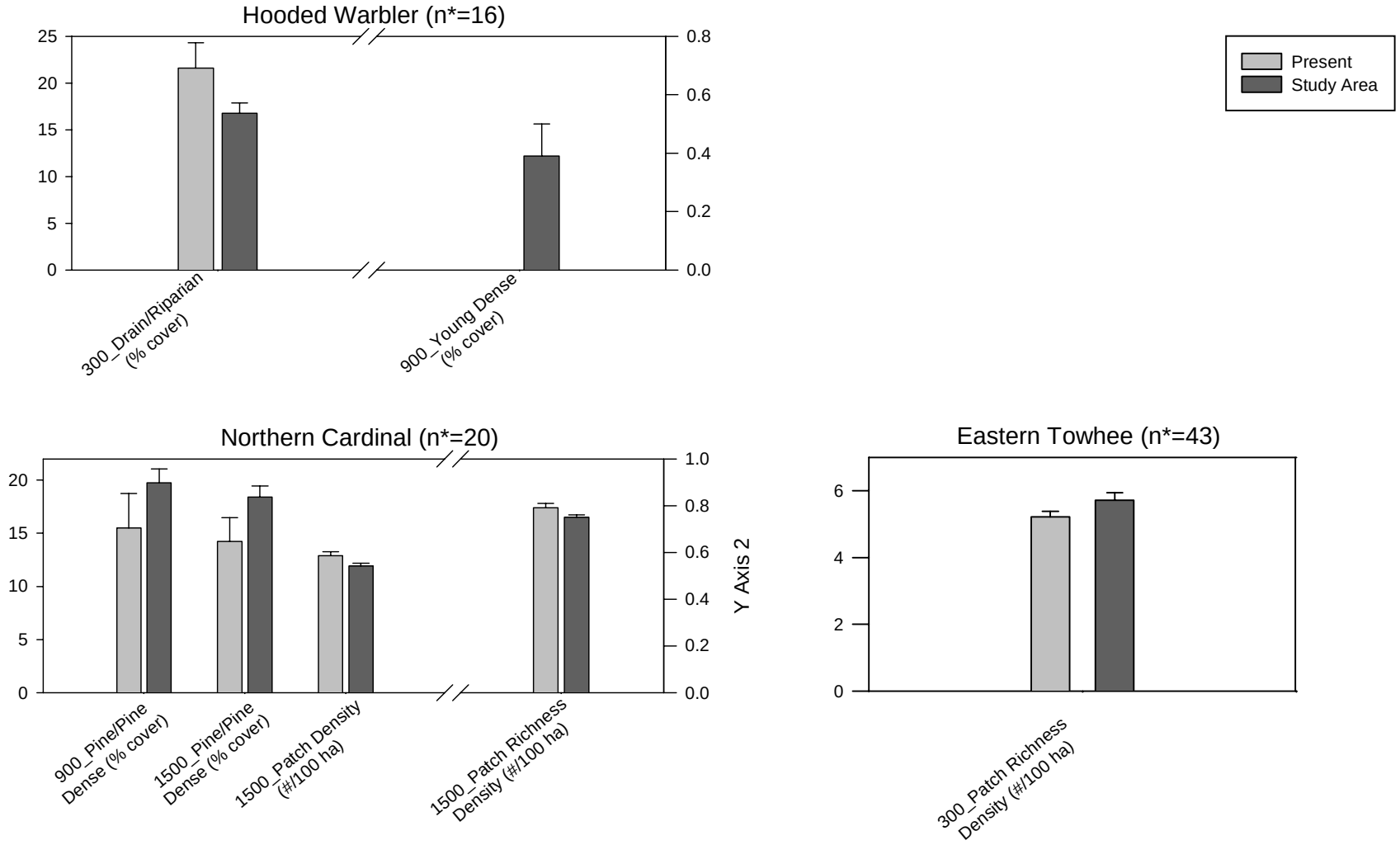

Figure 3 continued.

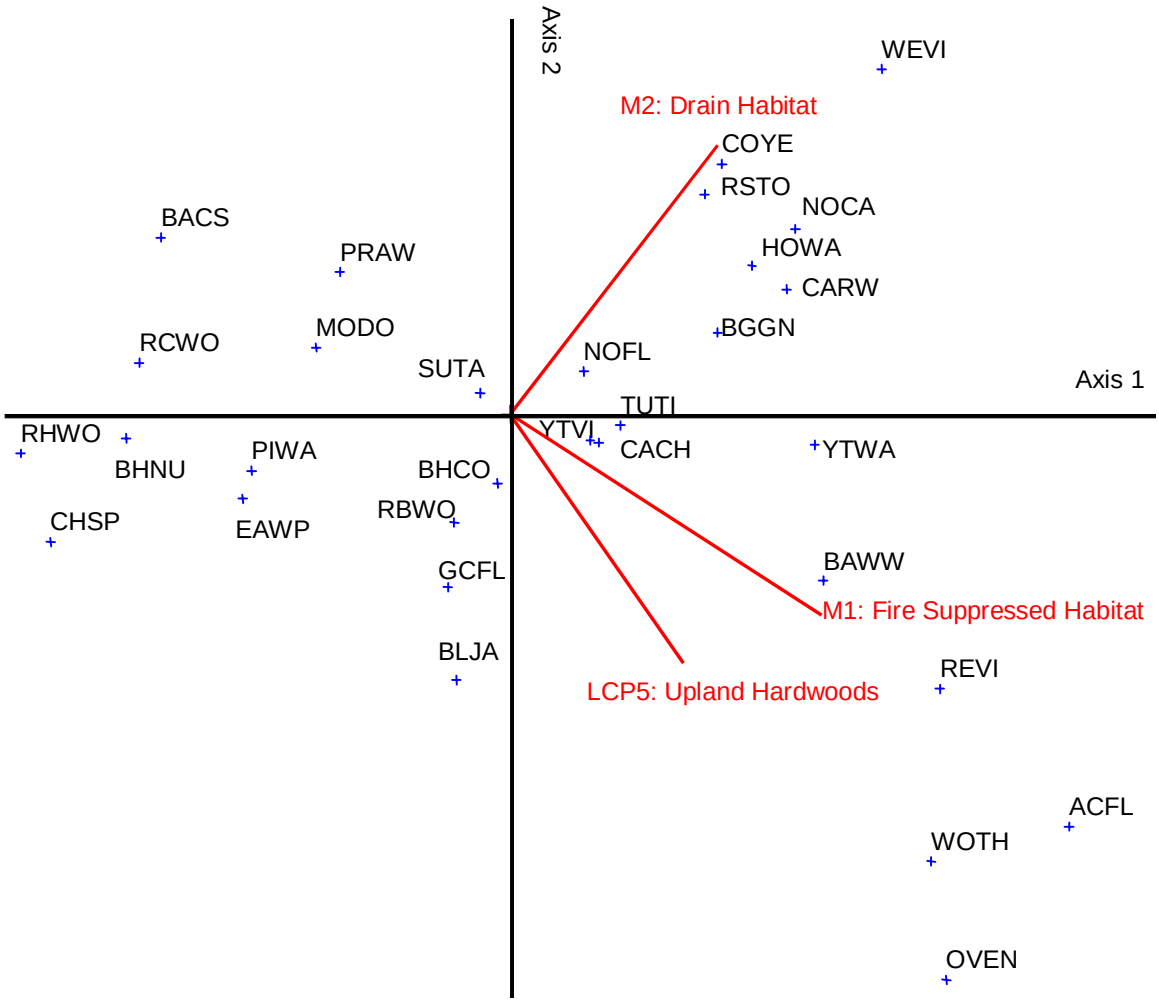

Figure 4 : Bi-plot of canonical correspondence analysis for the ordination of the breeding bird community of Fort Bragg, NC in relation to microhabitat and landscape principal component variables for n=87 count stations (1996-1997). Species codes for birds are given in Appendix I, Chapter 2.

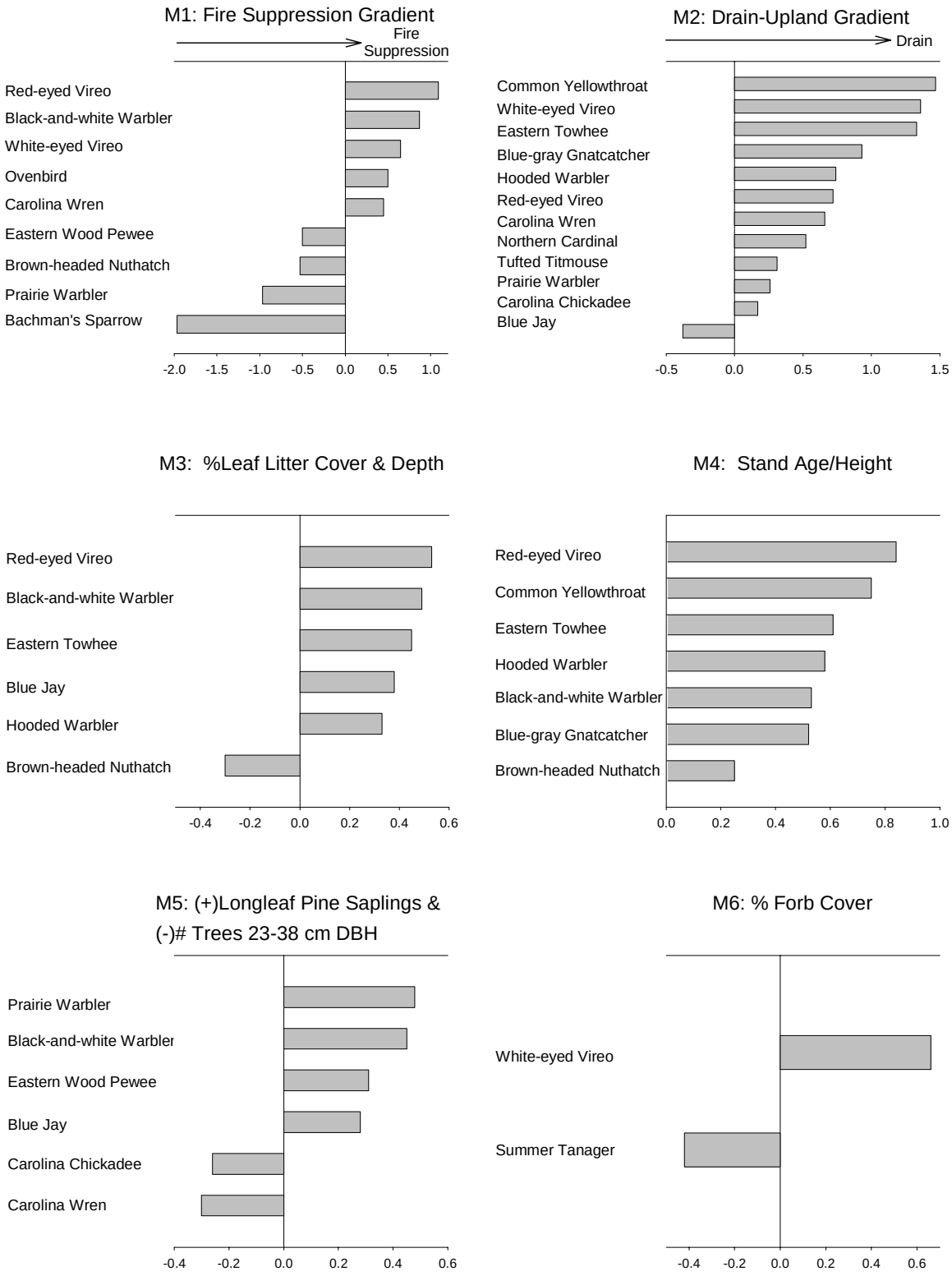

Figure 5: The relative importance (i.e., standardized slopes for each model variable) of each microhabitat variable from the models predicting occurrence for the breeding bird species of Fort Bragg, NC (1996-1997; n=87). The relationship between each variable and occurrence of each species is relative to the other variables included in the full model.

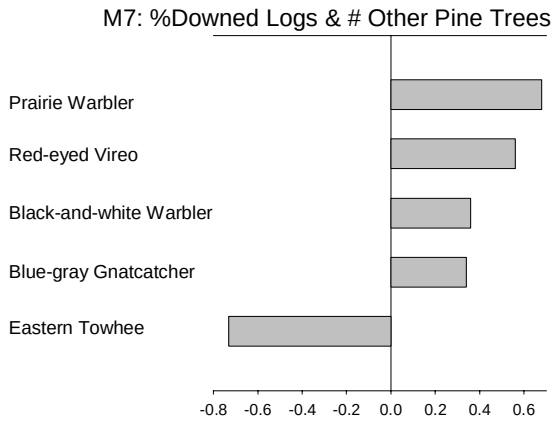

Figure 5 continued.

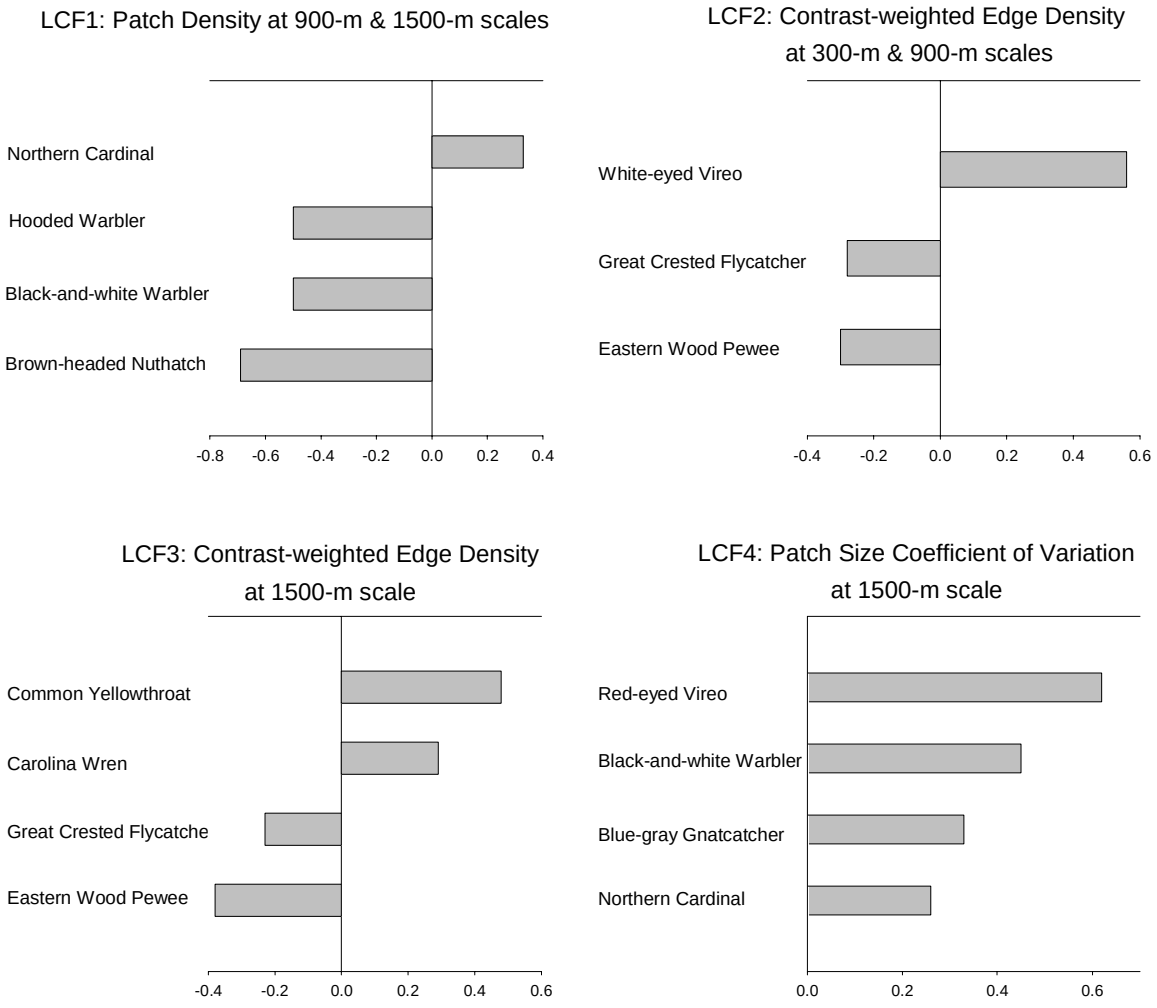

Figure 6: The relative importance (i.e., standardized slopes for model variables) of each landscape configuration variable from the models predicting occurrence for the breeding bird species of Fort Bragg, NC (1996-1997; n=87). The relationshup between each variable and occurrence of each species is relative to the other variables included in the full model.

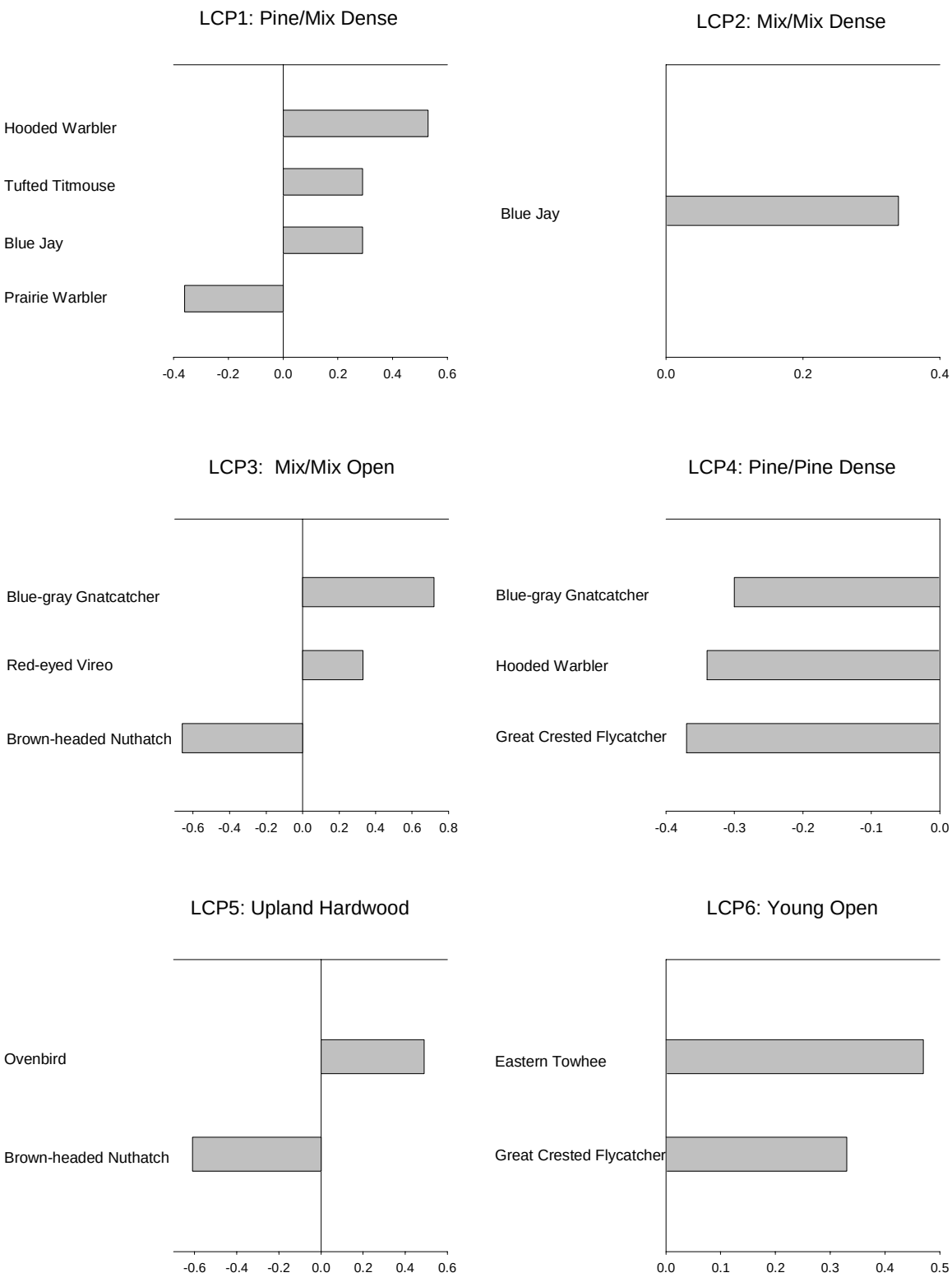

Figure 7: The relative importance (i.e., standardized slopes for model variables) of each landscape composition variable from the models predicting occurrence for the breeding bird species of Fort Bragg, NC (1996-1997; n=87). The relationship between each variable and occurrence of each species is relative to the other variables included in the full model.

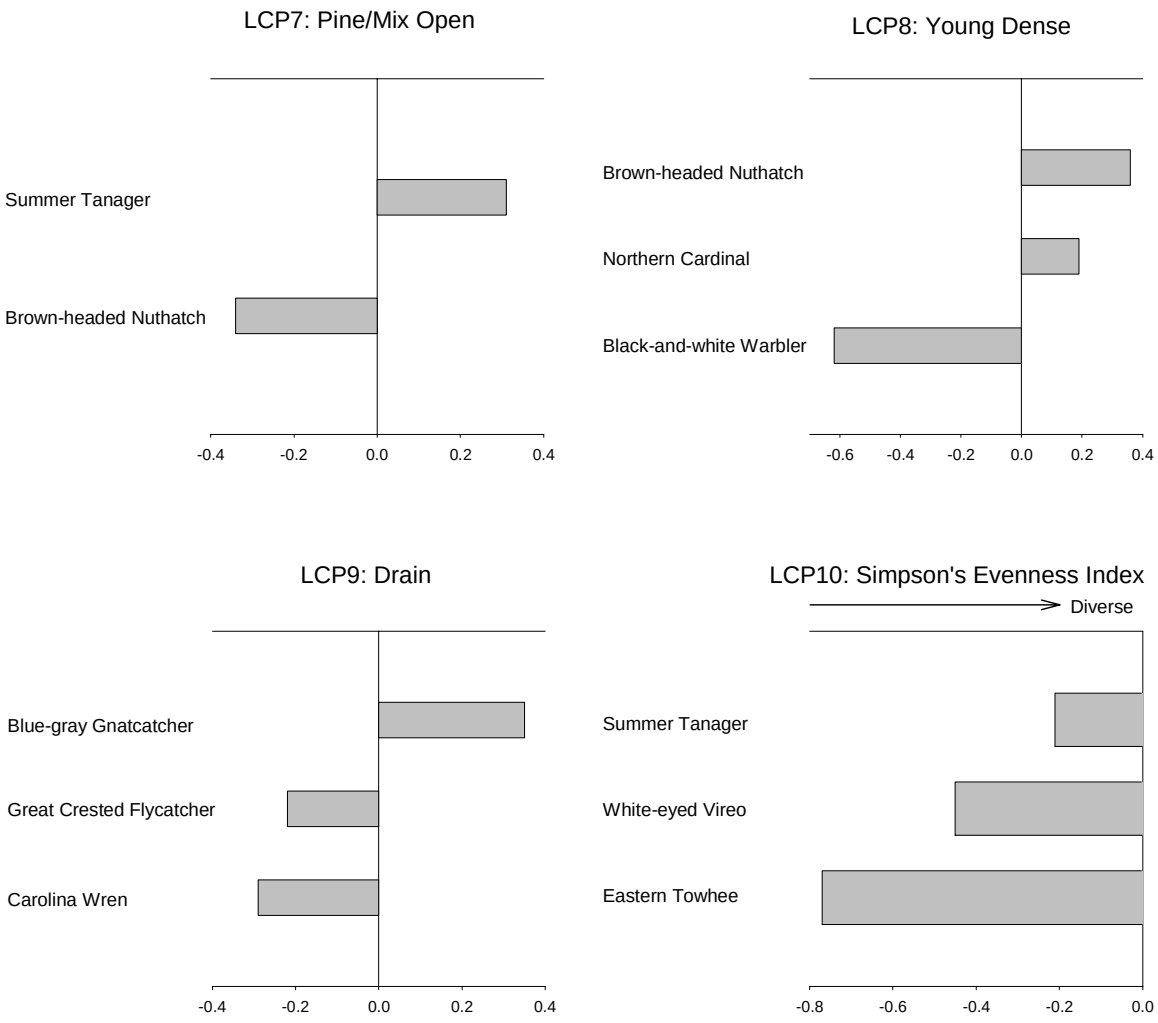

Figure 7 continued.

Appendix I. Contrast weights for landscape cover type edges.

Cover Types	Yg open	Yg dense	P/p open	P/p dense	P/m open	P/m dense	M/m open	M/m dense	Drain	Upld hdwd	Lake	Back-ground
Yg open	0	0.9	1	1	1	1	1	1	1	1	0	0
Yg dense		0	1	1	1	1	1	1	1	1	0.9	0
P/p open			0	0.2	0	0.2	0	0.2	1	0.4	1	0
P/p dense				0	0.2	0	0.2	0	0.5	0.2	1	0
P/m open					0	0.2	0	0.2	1	0.2	1	0
P/m dense						0	0.2	0	0.5	0	1	0
M/m open							0	0.2	1	0.2	1	0
M/m dense								0	0.5	0	1	0
Drain									0	0.5	1	0
Upld hdwd										0	1	0
Lake											0	0
Background												0

Appendix II. List of microhabitat variables available for statistical analyses.

Variables
% Slope
% Canopy Cover
Canopy Height
Litter Depth
% Green Cover
% Grass Cover
% Shrub Cover
% Forb Cover
% Fern Cover
% Downed Logs
% Leaf Litter
% Bare Ground
Shrubs <2.5 cm
Shrubs 2.5-8 cm
Saplings <2.5 cm
Saplings 2.5-8 cm
Trees 8-23 cm dbh
Trees >23-38 cm dbh
Trees >38 cm dbh
Longleaf Pine Saplings
Other Pine Species Saplings
Other Species Saplings (non-pine)
Longleaf Pine Trees
Other Pine Species Trees
Other Species Trees (non-pine)
Shrub Species Richness
Sapling Species Richness
Tree Species Richness
Snags >12 cm dbh

Appendix III: Descriptive statistics for landscape variables characterizing three landscape scales (300-m, 900-m, and 1500-m) centered around avian point count stations (n=87) at Fort Bragg, NC.

Scale(m)_Variable	Mean	Standard Error	Minimum Value	Maximum Value
300_Young Open	7.89	0.92	0	31.39
300_Young Dense	0.12	0.06	0	3.69
300_Pine/Pine Open	20.94	2.16	0	71.64
300_Pine/Pine Dense	21.99	1.96	0	76.92
300_Pine/Mix Open	5.62	0.99	0	48.22
300_Pine/Mix Dense	12.94	1.70	0	63.01
300_Mix/Mix Open	2.37	0.78	0	41.43
300_Mix/Mix Dense	9.42	1.67	0	68.08
300_Drain/Riparian	16.76	1.10	0	44.37
300_Upland Hardwood	1.45	0.55	0	29.94
300_Patch Density	19.10	0.62	8.00	37.56
300_Patch Size Coefficient of Variation	147.40	3.47	77.76	256.03
300_Contrast-Weighted Edge Density	56.05	1.49	19.67	96.90
300_Patch Richness Density	5.72	0.22	2.67	21.33
300_Simpson's Evenness Index	0.83	0.01	0.53	0.96
300_Interspersion/Juxtaposition Index	65.19	1.34	15.81	88.23
900_Young Open	12.31	1.00	0.86	42.85
900_Young Dense	0.39	0.11	0	5.14
900_Pine/Pine Open	20.43	1.38	0	53.05
900_Pine/Pine Dense	19.72	1.32	0	64.00
900_Pine/Mix Open	6.43	0.57	0	23.32
900_Pine/Mix Dense	10.90	0.96	0	32.81
900_Mix/Mix Open	2.62	0.48	0	21.89
900_Mix/Mix Dense	8.80	1.01	0	44.47
900_Drain/Riparian	16.12	0.68	0.33	32.04
900_Upland Hardwood	1.65	0.45	0	21.39
900_Patch Density	14.08	0.35	7.33	23.47
900_Patch Size Coefficient of Variation	163.04	2.74	113.12	224.58
900_Contrast-Weighted Edge Density	52.42	1.07	33.87	76.68
900_Patch Richness Density	1.78	0.03	1.12	2.28
900_Simpson's Evenness Index	0.90	0.01	0.65	0.97
900_Interspersion/Juxtaposition Index	70.55	0.77	39.88	83.71
1500_Young Open	15.28	0.93	1.78	35.31
1500_Young Dense	0.43	0.08	0	3.54
1500_Pine/Pine Open	19.56	1.07	2.27	42.71
1500_Pine/Pine Dense	18.41	1.03	1.49	43.99
1500_Pine/Mix Open	6.98	0.37	1.67	16.25
1500_Pine/Mix Dense	9.65	0.63	0	24.38
1500_Mix/Mix Open	2.51	0.28	0	9.44
1500_Mix/Mix Dense	9.46	0.75	0	35.65
1500_Drain/Riparian	15.35	0.46	3.30	27.36
1500_Upland Hardwood	1.72	0.29	0	11.20
1500_Patch Density	11.93	0.26	6.40	18.27
1500_Patch Size Coefficient of Variation	177.68	3.84	123.89	294.36
1500_Contrast-Weighted Edge Density	50.53	0.82	36.41	69.78
1500_Patch Richness Density	0.75	0.01	0.49	0.91
1500_Simpson's Evenness Index	0.92	0.01	0.73	0.97
1500_Interspersion/Juxtaposition Index	71.85	0.53	61.29	84.91

Appendix IV. Summary statistics and correlations for the first three axes of the canonical correspondence analysis with the microhabitat variables and bird species for n=87 count stations at Fort Bragg, NC (1996-1997).

Summary Statistics

Statistic	Axis 1	Axis 2	Axis 3
Eigenvalue	0.38	0.15	0.11
% Variance accounted for in species data	13.0	4.9	3.8
Kendall Correlation[a]	0.77	0.62	0.49

[a] Rank correlation coefficients between sample scores for an axis derived from the species data and sample scores that are linear combinations of the microhabitat variables (McCune and Mefford 1997).

	Intraset Correlations[a]			Interset Correlations[b]		
Variable	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
% Slope	-0.28	-0.29	-0.16	-0.26	-0.24	-0.12
% Canopy Cover	-0.65	0.28	0.21	-0.61	0.24	0.16
Canopy Height	-0.31	-0.11	0.34	-0.29	-0.09	0.26
Litter Depth	-0.42	-0.05	-0.04	-0.39	-0.04	-0.03
% Green Cover	-0.25	-0.64	0.20	-0.24	-0.55	0.16
% Grass Cover	0.57	0.34	0.30	0.54	-0.29	0.23
% Shrub Cover	-0.50	-0.46	-0.17	-0.47	-0.40	-0.13
% Forb Cover	-0.04	0.09	0.50	-0.04	0.07	0.38
% Fern Cover	-0.32	-0.39	-0.11	-0.30	-0.34	-0.09
% Downed Logs	-0.26	0.31	-0.05	-0.24	0.26	-0.04
% Leaf Litter	-0.50	-0.16	-0.22	-0.46	-0.14	-0.17
% Bare Ground	0.45	0.15	-0.24	0.42	0.13	-0.19
Shrubs 2.5-8 cm	-0.29	-0.32	-0.04	-0.27	-0.27	-0.03
Saplings <2.5 cm	-0.09	-0.16	-0.34	-0.09	-0.14	-0.26
Saplings 2.5-8 cm	-0.24	0.23	-0.22	-0.23	0.20	-0.17
# Trees 8-23 cm dbh	-0.53	0.55	-0.14	-0.49	0.47	-0.11
# Trees >23-38 cm dbh	-0.11	0.37	0.15	-0.10	0.32	0.12
# Trees >38 cm dbh	-0.21	-0.14	0.47	-0.20	-0.12	0.36
# Longleaf Pine Saplings	-0.24	0.01	-0.19	0.22	0.01	-0.14
# Other Pine Species Saplings	-0.18	-0.05	-0.22	-0.17	-0.04	-0.17
# Longleaf Pine Trees	0.68	-0.09	-0.12	0.63	-0.08	-0.09
# Other Pine Species Trees	-0.47	0.41	-0.01	-0.44	0.35	-0.01
# Other Species Trees	-0.66	0.46	0.04	-0.62	0.40	0.03
Shrub Species Richness	-0.70	-0.44	-0.04	-0.65	-0.38	-0.03
Sapling Species Richness	-0.58	-0.34	-0.01	-0.54	-0.29	-0.01
Tree Species Richness	-0.84	0.07	0.06	-0.79	0.06	0.04
# Snags >12 cm dbh	-0.36	-0.03	-0.12	-0.34	-0.03	0.09

[a] Intraset correlations are the correlations of the microhabitat variables with the ordination scores that are derived by linear combinations of the microhabitat variables (i.e., LC scores). Intraset correlations are not strictly independent measures of the relationship between communities and the microhabitat variables since the LC scores are dependent on the microhabitat variables (McCune and Mefford 1997).

[b] Interset correlations are the correlations of the microhabitat variables with the ordination scores that are obtained by weighted averaging of the bird species scores (i.e., WA scores). These correlations are also not independent measures since the ordination axes were constrained by regression to the microhabitat variables (McCune and Mefford 1997).

Appendix IV continued.

Kendall tau correlations with axes.

Species	Axis 1	Axis 2	Axis 3
Mourning Dove	-0.03	0.16	0.15
Northern Flicker	0.03	0.08	0.25
Red-bellied Woodpecker	0.01	-0.08	0.16
Red-cockaded Woodpecker	-0.31	0.04	0.08
Red-headed Woodpecker	-0.24	0.03	0.23
Great Crested Flycatcher	-0.01	-0.13	-0.15
Acadian Flycatcher	0.43	-0.15	0.18
Eastern Wood Pewee	-0.20	0.08	-0.14
Blue Jay	-0.01	-0.14	-0.04
Carolina Chickadee	0.14	0.02	-0.05
Tufted Titmouse	0.16	0.05	-0.08
Brown-headed Nuthatch	-0.38	0.10	0.11
Carolina Wren	0.35	0.17	0.10
Wood Thrush	0.30	-0.16	0.12
Blue-gray Gnatcatcher	0.39	0.18	0.06
Red-eyed Vireo	0.51	-0.07	0.22
White-eyed Vireo	0.31	0.28	0.07
Yellow-throated Vireo	0.09	0.18	0.12
Black-and-white Warbler	0.35	-0.07	0.27
Common Yellowthroat	0.32	0.43	0.10
Hooded Warbler	0.26	0.20	0.08
Ovenbird	0.31	-0.28	0.05
Pine Warbler	-0.38	-0.01	0.05
Prairie Warbler	-0.23	0.21	0.03
Yellow-throated Warbler	0.25	0.08	0.09
Brown-headed Cowbird	0.03	-0.10	0.01
Summer Tanager	0.05	0.08	-0.23
Northern Cardinal	0.26	0.16	0.08
Eastern Towhee	0.32	0.43	0.11
Bachman’s Sparrow	-0.32	0.12	0.15
Chipping Sparrow	-0.34	-0.13	-0.06

Appendix V: Species-habitat models predicting the probability of occurrence by logistic regression for 19 breeding bird species at Fort Bragg, NC. Models based on presence/absence data collected at n=87 count stations from 1996-1997. Variables are derived from principal components analyses on microhabitat, landscape composition, and landscape configuration variables. See text for descriptions of bird assemblages.

Species	C [a]	Model Pr>X^2 [b]	Intercept	Full Model Variables[c]	Coefficient	Pr>X^2
Longleaf Pine Assemblage						
Eastern Wood Pewee	81.3	0.0013	-1.54	M1: Tree Species Richness and Density (Fire Suppression Gradient)	-0.90	0.0124
				M5: # Saplings 2.5-8 cm, # Longleaf Pine Saplings, (–) # Trees 23-38 cm dbh	0.56	0.0445
				LCF2: Contrast-Weighted Edge Density at 300 and 900 m scales	-0.55	0.0993
				LCF3: Contrast-Weighted Edge Density at 1500 m scale	-0.69	0.0199
Brown-headed Nuthatch	89.7	0.0001	-0.62	M1: Tree Species Richness and Density (Fire Suppression Gradient)	-0.97	0.0061
				M3: Leaf Litter	-0.54	0.0822
				M4: Stand Age/Height	0.45	0.1415
				LCP3: Mix/Mix Open	-0.20	0.0260
				LCP5: Upland Hardwood	-1.10	0.0754
				LCP7: Pine/Mix Open	-0.62	0.1076
				LCP8: Young Dense	0.65	0.1002
				LCF1: Patch Density	-1.26	0.0022
Prairie Warbler	85.3	0.0001	-0.65	M1: Tree Species Richness and Density (Fire Suppression Gradient)	-1.76	0.0003
				M2: Drain Habitat	0.47	0.0948
				M5: # Saplings 2.5-8 cm, # Longleaf Pine Saplings, (–) # Trees 23-38 cm dbh	0.88	0.0168
				M7: % Downed Logs, # Other Pine Trees[d]	-1.23	0.0205
				LCP1: Pine/Mix Dense	-0.66	0.0402
Bachman's Sparrow	91.1	0.0001	-3.42	M1: Tree Species Richness and Density	-3.57	0.0002
Fire Suppressed Assemblage						
Tufted Titmouse	69.6	0.0100	-0.38	M2: Drain Habitat	0.56	0.0177
				LCP1: Pine/Mix Dense	0.52	0.0302

Appendix V continued.

Species	C [a]	Model Pr>X^2 [b]	Intercept	Full Model Variables[c]	Coefficient	Pr>X^2
Blue-gray Gnatcatcher	90.0	0.0001	0.71	M2: Drain Habitat	1.69	0.0002
				M4: Stand Age/Height	0.94	0.0085
				M7: % Downed Logs, # Other Pine Trees[d]	0.61	0.0639
				LCP3: Mix/Mix Open	1.31	0.0128
				LCP4: Pine/Pine Dense	-0.54	0.0996
				LCP9: Drain	0.64	0.0566
				LCF4: Patch Size Coefficient of Variation at 1500 m scale	0.60	0.1173
Red-eyed Vireo	92.6	0.0001	-2.16	M1: Tree Species Richness and Density (Fire Suppression Gradient)	1.98	0.0001
				M2: Drain Habitat	1.31	0.0098
				M3: Leaf Litter	0.96	0.1274
				M4: Stand Age/Height	1.53	0.0050
				M7: % Downed Logs, # Other Pine Trees[d]	1.01	0.0136
				LCP3: Mix/Mix Open	0.60	0.0690
				LCF4: Patch Size Coefficient of Variation at 1500 m scale	1.11	0.0435
Black-and-white Warbler	91.8	0.0001	-2.15	M1: Tree Species Richness and Density (Fire Suppression Gradient)	1.58	0.0005
				M3: Leaf Litter	0.89	0.0306
				M4: Stand Age/Height	0.95	0.0211
				M5: # Saplings 2.5-8 cm, # Longleaf Pine Saplings, (–) # Trees 23-38 cm dbh	0.81	0.0268
				M7: % Downed Logs, # Other Pine Trees[d]	0.66	0.0704
				LCP8: Young Dense	-1.13	0.0226
				LCF1: Patch Density	-0.91	0.0438
				LCF4: Patch Size Coefficient of Variation at 1500 m scale	0.82	0.0207
Ovenbird	83.7	0.0001	-2.03	M1: Tree Species Richness and Density (Fire Suppression Gradient)	0.91	0.0149
				LCP5: Upland Hardwood	0.89	0.0175

Appendix V continued.

Species	C [a]	Model Pr>X^2 [b]	Intercept	Full Model Variables[c]	Coefficient	Pr>X^2
Drain Assemblage						
Carolina Wren	83.3	0.0001	-1.31	M1: Tree Species Richness and Density (Fire Suppression Gradient)	0.82	0.0092
				M2: Drain Habitat	1.20	0.0001
				M5: # Saplings 2.5-8 cm, # Longleaf Pine Saplings, (–) # Trees 23-38 cm dbh	-0.54	0.1255
				LCP9: Drain	-0.52	0.0965
				LCF3: Contrast-Weighted Edge Density at 1500 m scale	0.53	0.0848
White-eyed Vireo	95.7	0.0001	-4.24	M1: Tree Species Richness and Density (Fire Suppression Gradient)	1.19	0.0459
				M2: Drain Habitat	2.47	0.0006
				M6: % Forb Cover	1.20	0.0275
				LCP10: Simpson's Evenness Index	-0.81	0.0566
				LCF2: Contrast-Weighted Edge Density at 300 and 900 m scales	1.02	0.0683
Common Yellowthroat	93.9	0.0001	-0.97	M2: Drain Habitat	2.67	0.0001
				M4: Stand Age/Height	1.36	0.0013
				LCF3: Contrast-Weighted Edge Density at 1500 m scales	0.88	0.0220
Hooded Warbler	89.6	0.0001	-2.40	M2: Drain Habitat	1.34	0.0008
				M3: Leaf Litter	0.59	0.1856
				M4: Stand Age/Height	1.05	0.0086
				LCP1: Pine/Mix Dense	0.96	0.0161
				LCP4: Pine/Pine Dense	-0.62	0.1548
				LCF1: Patch Density at 900 and 1500 m scales	-0.90	0.0409
Northern Cardinal	76.7	0.0017	-1.55	M2: Drain Habitat	0.94	0.0019
				LCP8: Young Dense	0.34	0.1894
				LCF1: Patch Density at 900 and 1500 m scales	0.59	0.0829
				LCF4: Patch Size Coefficient of Variation at 1500 m scale	0.46	0.0882

Appendix V continued.

Species	C [a]	Model Pr>X^2 [b]	Intercept	Full Model Variables[c]	Coefficient	Pr>X^2
Eastern Towhee	92.2	0.0001	0.08	M2: Drain Habitat	2.42	0.0001
				M3: Leaf Litter	0.81	0.0404
				M4: Stand Age/Height	1.11	0.0029
				M7: % Downed Logs, # Other Pine Trees[d]	-1.32	0.0342
				LCP6: Young Open	0.84	0.0265
				LCP10: Simpson's Evenness Index	-1.39	0.0021
Generalist						
Great Crested Flycatcher	74.7	0.0080	0.10	LCP4: Pine/Pine Dense	-0.68	0.0136
				LCP6: Young Open	0.60	0.0233
				LCP9: Drain	-0.40	0.1404
				LCF2: Contrast-Weighted Edge Density at 300 and 900 m scales	-0.51	0.0536
				LCF3: Contrast-Weighted Edge Density at 1500 m scale	-0.42	0.0870
Blue Jay	80.3	0.0142	-2.17	M2: Drain Habitat	-0.69	0.1171
				M3: Leaf Litter	0.69	0.0569
				M5: # Saplings 2.5-8 cm, # Longleaf Pine Saplings, (–) # Trees 23-38 cm dbh	0.51	0.0852
				LCP1: Pine/Mix Dense	0.53	0.0916
				LCP2: Mix/Mix Dense	0.61	0.0295
Carolina Chickadee	63.9	0.0728	-0.33	M2: Drain Habitat	0.30	0.1831
				M5: # Saplings 2.5-8 cm, # Longleaf Pine Saplings, (–) # Trees 23-38 cm dbh	-0.47	0.0640
Summer Tanager	72.1	0.0024	0.59	M6: % Forb cover	-0.76	0.0043
				LCP7: Pine/Mix Open	0.55	0.0568
				LCP10: Simpson's Evenness Index	-0.39	0.1245

[a] Concordant (%)

[b] Wald $\mathscr{X}^2$ value

[c] Description of principal component variables reflect positive relationship unless otherwise noted; For landscape variables, description applies across all scales unless specific scales are identified; Codes are: M=Microhabitat, LCP=Landscape Composition, LCF=Landscape Configuration

[d] Excludes Longleaf Pine

Appendix VI: Mean values and standard errors for microhabitat variables by fire treatment and location collected in 1996 (n=87) at Fort Bragg, NC. Results of two-way factorial tests for treatment, location, and interaction effects are shown.

	Fire Intense						Fire Suppressed						
	Drain n=17		Intermediate n=18		Upland n=17		Drain n=12		Intermediate n=12		Upland n=11		Significant
Microhabitat Variable	x	se	x	se	x	se	x	se	x	se	x	se	Effects[a]
Slope	6.72	0.57	6.85	0.52	3.97	0.63	6.56	1.56	5.21	0.54	5.16	1.11	L*
% Canopy Cover	71.20	2.47	67.37	2.51	60.22	2.40	86.50	3.04	74.28	5.12	77.75	5.64	T**** L**
Canopy Height (m)	21.51	1.22	18.57	0.70	18.13	0.80	20.27	0.83	16.78	1.12	16.47	0.92	L***
Litter Depth (cm)	3.70	0.41	2.68	0.26	1.95	0.24	3.59	0.34	2.93	0.32	3.72	0.49	T** L** I*
% Grass Cover	16.00	1.66	23.92	2.58	25.55	2.26	8.85	1.90	11.17	2.49	11.08	2.45	T**** L*
% Shrub Cover	42.95	3.59	18.36	1.87	13.44	1.61	35.59	4.16	16.64	2.79	18.00	1.63	L****
% Forb Cover	7.40	2.03	6.92	1.16	6.45	1.50	7.20	2.78	4.06	0.97	3.05	0.90	T*
% Fern Cover	9.48	2.25	0.72	0.34	0.48	0.29	5.16	1.76	1.16	0.59	0.80	0.64	L****
% Downed Logs	2.63	0.47	1.83	0.32	1.48	0.20	4.53	0.79	5.74	2.43	4.13	0.88	T****
% Leaf Litter	83.51	3.05	77.88	3.28	66.13	3.87	83.27	4.87	76.94	6.63	80.68	4.93	L*
% Bare Ground	5.28	1.57	8.68	1.27	17.84	2.67	5.73	2.25	17.36	6.49	9.46	3.48	L**
# Shrubs (>2.5-8 cm)	1.06	0.48	0.00	0.00	0.00	0.00	2.04	0.92	0.04	0.04	0.02	0.02	L****
# Saplings (<2.5 cm)	41.13	4.81	47.03	5.79	29.32	6.79	40.73	5.68	32.08	7.45	39.00	8.11	
# Saplings (>2.5-8 cm)	2.79	0.59	3.15	1.06	1.40	0.48	4.29	1.00	4.35	1.11	6.14	1.13	T***
# Trees (8-23 cm)	4.76	0.60	3.83	0.71	2.19	0.50	13.65	2.24	12.65	1.64	16.30	2.57	T****
# Trees (>23-38 cm)	3.09	0.30	3.69	0.49	3.96	0.37	4.44	0.61	3.83	0.59	3.64	0.64	
# Trees (>38 cm)	1.81	0.19	1.40	0.17	1.35	0.26	1.71	0.27	1.08	0.33	0.57	0.14	T* L**
# Longleaf Pine Saplings	0.22	0.11	0.65	0.23	0.46	0.21	0.15	0.10	0.29	0.17	0.50	0.30	
# Other Pine Saplings	1.16	0.68	0.22	0.22	0.00	0.00	0.67	0.37	0.58	0.50	1.23	0.75	T***
# Longleaf Pine Trees	3.21	0.42	6.67	0.59	6.88	0.65	1.63	0.51	4.67	1.51	3.75	1.45	T**** L****
# Other Pine Trees	2.96	0.52	0.36	0.15	0.03	0.03	6.92	1.95	3.33	1.76	8.07	3.19	T**** L****
# Other Species Trees (non-pine)	3.28	0.64	1.86	0.66	0.53	0.20	10.71	1.57	9.40	1.31	8.52	1.81	T**** L***
Sapling Species Richness	10.06	0.85	5.67	0.48	3.76	0.38	10.67	1.18	5.50	1.06	6.64	0.77	T* L**** I*
Tree Species Richness	6.12	0.45	3.00	0.47	1.88	0.28	8.67	0.38	6.42	0.86	5.55	0.77	T**** L****

Appendix VI continued.

	Fire Intense						Fire Suppressed						
	Drain n=17		Intermediate n=18		Upland n=17		Drain n=12		Intermediate n=12		Upland n=11		
Microhabitat Variable	x	se	x	se	x	se	x	se	x	se	x	se	Significant Effects[a]
# Snag (≥12 cm)	0.25	0.13	0.04	0.03	0.10	0.05	0.46	0.13	0.19	0.09	0.23	0.06	T** L*

[a] Codes and asterisks indicate significance: T=fire treatment effect, L=location effect, I=interaction effect, *=p<0.05, **= p<0.01, ***=p<0.001, ****=p<0.0001

Appendix VII. Summary statistics and correlations for the first three axes of the canonical correspondence analysis with the microhabitat and landscape variables, derived from principal components analyses, and bird species for n=87 count stations at Fort Bragg, NC (1996-1997).

Summary Statistics

Statistic	Axis 1	Axis 2	Axis 3
Eigenvalue	0.38	0.15	0.11
% Variance accounted for in species data	13.0	5.2	3.7
Kendall Correlation[a]	0.74	0.64	0.52

[a] Rank correlation coefficients between sample scores for an axis derived from the species data and sample scores that are linear combinations of the microhabitat and landscape principal component variables (McCune and Mefford 1997).

	Intraset Correlations[b]			Interset Correlations[c]		
Principal Component Variable[a]	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
M1: Tree Species Richness and Density (Fire Suppressed Habitat)	-0.73	0.47	0.03	-0.68	0.41	0.02
M2: Drain Habitat	-0.49	-0.64	0.04	-0.46	-0.55	0.03
M3: %Leaf Litter Cover and Depth	-0.26	0.02	-0.06	-0.25	0.01	-0.05
M4: Stand Age/Height	-0.14	-0.05	-0.34	-0.13	-0.04	-0.26
M5: (+)Longleaf Pine Saplings and (-)# Trees 23-38 cm dbh	0.10	-0.11	0.06	0.10	-0.09	0.05
M6: %Forb Cover	-0.01	0.12	-0.58	-0.01	0.11	-0.43
M7: %Downed Logs and # Other Pine Trees[d]	-0.09	0.35	0.02	-0.08	0.30	0.01
LCP1: Pine/Mix Dense	-0.11	0.08	-0.13	-0.11	0.07	-0.10
LCP2: Mix/Mix Dense	-0.22	0.41	0.05	-0.21	0.35	0.03
LCP3: Mix/Mix Open	-0.25	-0.12	0.27	-0.23	-0.11	0.20
LCP4: Pine/Pine Dense	0.19	-0.18	-0.39	0.18	-0.15	-0.29
LCP5: Upland Hardwood	-0.40	0.58	-0.23	-0.38	0.50	-0.17
LCP6: Young Open	0.19	0.09	0.31	0.18	0.07	0.23
LCP7: Pine/Mix Open	0.04	0.05	0.27	0.03	0.04	0.20
LCP8: Young Dense	-0.08	-0.06	0.18	-0.07	-0.05	0.13
LCP9: Drain	-0.15	0.01	0.10	-0.14	0.01	0.07
LCP10: Simpson's Evenness Index	0.06	0.08	0.02	0.06	0.07	0.02
LCF1: Patch Density at 900 and 1500 m scales	-0.32	0.03	-0.02	-0.30	0.03	-0.02
LCF2: Contrast-Weighted Edge Density at 300 and 900 m scales	-0.06	-0.39	0.09	-0.06	-0.33	0.07
LCF3: Contrast-Weighted Edge Density at 1500 m scale	-0.11	-0.01	-0.14	-0.11	-0.01	-0.10
LCF4: Patch Size Coefficient of Variation at 1500 m scale	0.01	0.03	0.05	0.01	0.03	0.04

[a] Description of principal component variables reflect positive relationship unless otherwise noted. Codes are: M=microhabitat, LCP=landscape composition, LCF=landscape configuration. For landscape variables, description of component variables applies across all three landscape scales unless specific scales are identified.

[b] Intraset correlations are the correlations of the variables with the ordination scores that are derived by linear combinations of the variables (i.e., LC scores). Intraset correlations are not strictly independent

measures of the relationship between communities and the variables since the LC scores are dependent on the variables (McCune and Mefford 1997).

[c] Interset correlations are the correlations of the variables with the ordination scores that are obtained by weighted averaging of the bird species scores (i.e., WA scores). These correlations are also not independent measures since the ordination axes were constrained by regression to the variables (McCune and Mefford 1997).

[d] Exclude Longleaf Pine trees

Kendall tau correlations with axes.

Species	Axis 1	Axis 2	Axis 3
Mourning Dove	-0.29	0.20	-0.20
Northern Flicker	0.31	-0.14	-0.03
Red-bellied Woodpecker	0.40	0.25	0.12
Red-cockaded Woodpecker	-0.40	0.07	-0.01
Red-headed Woodpecker	0.33	0.19	-0.07
Great Crested Flycatcher	-0.36	-0.15	0.21
Acadian Flycatcher	-0.21	-0.09	0.10
Eastern Wood Pewee	-0.02	-0.11	0.06
Blue Jay	0.21	0.20	-0.13
Carolina Chickadee	0.34	-0.24	-0.24
Tufted Titmouse	-0.35	-0.02	-0.02
Brown-headed Nuthatch	-0.22	0.26	0.02
Carolina Wren	0.04	-0.07	-0.06
Wood Thrush	-0.30	0.01	-0.22
Blue-gray Gnatcatcher	-0.24	-0.06	-0.14
Red-eyed Vireo	0.34	0.41	-0.01
White-eyed Vireo	0.03	0.07	0.22
Yellow-throated Vireo	0.29	0.30	-0.17
Black-and-white Warbler	0.28	-0.19	-0.06
Common Yellowthroat	0.07	0.03	0.01
Hooded Warbler	0.22	0.00	0.15
Ovenbird	0.40	-0.14	-0.03
Pine Warbler	0.08	-0.09	0.11
Prairie Warbler	0.17	0.007	0.02
Yellow-throated Warbler	0.32	0.46	-0.12
Brown-headed Cowbird	0.27	0.16	0.01
Summer Tanager	0.47	-0.08	0.04
Northern Cardinal	0.18	0.12	0.02
Eastern Towhee	0.07	-0.16	-0.09
Bachman's Sparrow	-0.06	0.10	0.01
Chipping Sparrow	0.07	0.13	-0.26

CHAPTER 4

THE USEFULNESS OF PREDICTIVE SPECIES-HABITAT MODELS FOR THE BREEDING BIRDS OF A LONGLEAF PINE ECOSYSTEM

INTRODUCTION

Around the turn of the 20th century, many biologists began shifting focus from describing the natural history of organisms to understanding ecological relationships that influenced their distribution and abundance (Morrison et al. 1992). Early on, models were recognized as an important tool for assessing these ecological relationships (Van Horne and Wiens 1991). Simply defined, a model is a hypothesis representing some system of interest (Marcot et al. 1983; Starfield 1997). With respect to species-habitat relationships, models have been useful in describing the *niche gestalt* of a species, or the vegetation characteristic of the habitat of a species (James 1971), with habitat defined as the resources and environmental conditions that support occupancy, survival and reproduction (Morrison et al. 1992; Hall et al. 1997). The rationale for developing these models is diverse: increase the understanding of species-habitat relationships, describe ecological patterns, generate hypotheses about the underlying processes supporting these patterns, detect habitat preferences, improve the capacity to manage a population, and predict a species' response to potential land management decisions. Typically, we cannot conclude that a model describing a species-habitat relationship is any more than a correlation between observed patterns, but assessing this relationship is the first step in understanding patterns of life history, adaptation, and evolution of a species (Rotenberry 1981).

Many species-habitat models are based on a statistical relationship between species occurrence or abundance and habitat characteristics, such as vegetation structure and composition. An inherent assumption of species-habitat models is that if a habitat is characterized as suitable for a particular species, i.e., able to provide life requisites (food, cover, reproduction) (Lancia et al. 1986), then that species will occur (Schamberger and O'Neil 1986). However, species-habitat models may have limited predictive ability because habitat suitability is influenced by factors other than the characteristic vegetation, such as predation, inter- and intraspecific competition (current and past), biogeographic influences on species distribution, and environmental and human disturbances (Farmer et al. 1982; Diehl 1986; Hejl and Beedy 1986; Van Horne and Wiens 1991; Morrison et al. 1992). Further, local populations can fluctuate independently of habitat suitability because of environmental and demographic stochasticity. The predictive ability of models additionally can be limited by other biological and statistical concerns, such as: (1) nonlinear or nonmonotonic (sign of slope changes) species-habitat relationships; (2) incomplete sampling along a habitat gradient causing extrapolated or interpolated predictions; (3) unequal detectability of a species across habitat types; (4) ability to measure habitat parameters that are "perceived" by a species or correlated with life requisites; and (5) observer error (Best and Stauffer 1986; Maurer 1986; Rotenberry

1986; Schamberger and O'Neil 1986; Morrison et al. 1987; Morrison et al. 1992; Bibby et al. 2000). Because species-habitat models can be imperfect for the reasons outlined above, it is imperative to test models to assess their predictability, or degree of unreliability, before the models are used to direct management and conservation actions (Farmer et al. 1982; Lancia and Adams 1985).

To assess the predictive ability of species-habitat models, a common method is to test the models with an independent data set, a process called validation (Van Horne and Wiens 1991). Model validation is simply matching the observed results in a new data set with the model predictions. Testing models in this manner can provide information on whether models are inaccurate, biased and/or imprecise (Morrison et al. 1992). A model lacks accuracy if predictions deviate from reality but it may still have precision if predictions have low variance or are consistently biased in one direction. Most bird species-habitat models do not produce accurate or even precise predictions with little error since species-habitat correlations generally do not account for more than half of the natural variation in species occurrence or abundance (Farmer et al. 1982; Morrison et al. 1992). Yet, through the process of model validation, the limitations of a model can be examined, weaknesses can be identified, and models can be revised.

For several breeding bird species of the longleaf pine system at the Fort Bragg Military Installation in North Carolina, I developed species-habitat models "to assist Fort Bragg personnel in the preparation of comprehensive management plans (Collazo and Walters 1994)." In this study, I assumed that species occurrence and relative abundance reflect potentially suitable habitat, but not necessarily habitat of optimal quality, since the reproductive viability of populations was not simultaneously sampled (Van Horne 1983; Pulliam 1988). To detect correlative species-habitat relationships, I used statistical models to regress species occurrence and then relative abundance within occupied sites against vegetation variables measured at a microhabitat scale (i.e., 50-m radius area). The rationale for this approach was that relative abundance within occupied sites may operate partially independently from species occurrence. Thus, I examined these models to determine whether a difference existed between the floristic and structural features of vegetation associated with species occupancy patterns and with species relative abundance. To validate these empirical models and similar models developed by another researcher (Krieger 1997), I used independent data sets to examine their ability to predict species occurrence and relative abundance. Since the models were developed from multiple years of data, they predict responses for an "average" year. The models were tested by generating predictions based on a 1-year data set and a 2-year ("average" year) data set to evaluate whether model performance differed for a single year versus multiple years.

STUDY AREA DESCRIPTION

The Fort Bragg Military Installation is located in the Sandhills physiographic region of North Carolina and encompasses 63,143 hectares, with approximately 40,000 hectares forested (Cantrell et al. 1995). Fort Bragg is a heterogeneous landscape of

upland pine, successional communities of mixed pine-hardwood and hardwood stands, and streamhead pocosins (i.e., drains) influenced greatly by fire and land management history and soil moisture gradients (i.e., a drain to upland gradient). Currently, mostly second- and third-growth stands exist on the base. Prior to 1989, the Natural Resources Branch conducted dormant season burns on a 5-year rotation. Since 1989, Fort Bragg has adopted a three-year growing season rotation for prescribed burns to enhance and conserve this longleaf pine (Scientific names of flora are listed in Chapter 2, Appendix II) ecosystem.

Many areas have been actively managed with prescribed fire, and in some cases, mechanical thinning of trees to restore the longleaf pine/scrub oak community. These areas are classified as fire intense for this study. Longleaf pine dominates the canopy, the ground layer is highly diverse, and there is virtually no vertical structural diversity. These areas are often described as open park-like savannas or woodlands. Areas that have lacked periodic growing season fires until recently, though dormant season burns may have occurred, are classified as fire suppressed. They are dominated by longleaf pine and/or loblolly pine and hardwoods in the overstory, have a hardwood or mixed pine and hardwood midstory, and have low ground cover diversity.

Throughout the base, plant community composition is also influenced by the soil-moisture gradient. Drains, the riparian habitat of streamhead pocosins, are features common to both fire intense and fire suppressed stands. The vegetation, especially the shrub layer, is more speciose and dense than in the nearby upland habitats. Drains that had experienced a recent intense fire that removed the shrub layer were not included in this study.

A more detailed study area description is provided in Chapter 2.

STUDY SITE SELECTION

Since fire history and a soil-moisture gradient were hypothesized to influence vegetation composition and structure within the study area (see Chapter 2, *this manuscript*), bird point count stations were positioned in areas classified by fire treatment, either fire intense or fire suppressed, at one of three locations (i.e., distances from) relative to a drain, drain (0 m), intermediate (75 m), and upland (≥150 m). Sixty-five point count stations were established in 1994 and 156 stations were added in 1996. Krieger (1997) selected the 65 points for count stations in 1994 based on fire history, timber stocking levels, military activity, and location relative to drains. Fire history was determined from 1978 onward with documentation provided by the Fort Bragg Natural Resources Office, and the latter three criteria and current vegetation conditions were determined by field inspections. In 1996, I selected potential sites with the aid of a geographic information system developed by Fort Bragg biologists depicting habitat cover types. For this GIS, the spatial cover type layer was generated based on forest inventory stand data containing stocking rates of overstory and midstory trees. This GIS cover type layer depicted various habitats across the base thought to influence bird

populations, and to reasonably represent the influence of fire history, soil-moisture gradient, and timber stocking levels on the current vegetative conditions. This spatial database has a 10 acre (4.05 hectare) minimum resolution, i.e., no polygons were mapped that were smaller than 10 acres (Schultz and Howell, pers. comm.). Criteria for final site selection were the patch cover type, military activity, and presence of drains. I verified these site selection criteria and the GIS cover type map in March and April of 1996 by conducting field inspections across most accessible areas of Fort Bragg (i.e., artillery-impact areas were inaccessible).

All count stations were ≥200 m apart for sampling independence and ≥200 m from the following edges to reduce possible edge effects: forest-forest ecotones, paved roads, parachute drop zones and other fields.

FIELD METHODS

Vegetation Sampling

I collected vegetation structure and floristic data at each count station on four subplots based on the sampling protocol of BBIRD (Martin 1994). The first subplot was centered on the count station and the second subplot was 30 m away at a random azimuth. The third and fourth subplots were 120 degrees in opposite directions from the random azimuth and 30 m from the first subplot center. Each subplot consisted of nested 5-m and 11.3-m radius plots. Within the 5-m radius plots, I measured shrubs, saplings, litter depth and ground cover. I quantified shrub and sapling species ≥50 cm above ground by counting number of stems, and I counted stems separately if they branched at <10 cm above the ground. I used two shrub diameter size classes, <2.5 cm and >2.5 cm, measured at 10 cm above the ground, and two sapling diameter size classes, <2.5 cm and 2.5 to 8 cm. I measured organic litter depth at twelve points, spaced 2 m apart along two 10-m transects that intersected and were centered within each 5-m radius plot. I defined ground cover as ≤50 cm above ground and quantified the following variables: % green cover, % grass cover, % shrub cover, % forb cover, % fern cover, % leaf litter, % downed logs, % bare ground, and % water. Within each 11.3 m radius plot, I tallied the number of trees >8 cm for diameter at breast height (dbh) by species and three diameter size classes: >8-23, >23-38, >38 cm dbh. Breast height for measuring tree diameters was 1.4 m. I also counted the number of snags >12 cm dbh and taller than 1.4 m. Finally, I estimated canopy cover and height, aspect, and slope for each subplot.

Bird Counts

During the breeding seasons of 1994 through 1997, S. Krieger or I used a 50-m fixed-radius point count method to census the avifauna at each count station (Hutto et al. 1986). Trees were marked at 25 m and 50 m from each point count center to aid in distance estimation. We conducted bird counts from April 19th to mid June in 1994 and from the beginning of May to mid June in 1995 through 1997, between 0545 and 1000.

We recorded the birds detected within the 50-m count station by sight and sound for 10 minutes. We excluded observations recorded as fly-overs (i.e., birds flying over the canopy without stopping in the count station). We conducted three such counts at each point count station in 1994, 1995 and 1997, but only two counts in 1996 in order to allow more stations to be sampled. The observer, order, and time of counts were varied to minimize systematic detection biases. In addition, observers practiced bird identification skills and distance estimation for three to four weeks prior to the first survey in 1996 and 1997.

ANALYTICAL METHODS

I developed and tested statistical species-habitat models using SAS/STAT software (SAS Institute Inc. 1997). All models follow the same format, with a bird index as the dependent variable (i.e., species relative abundance or species occurrence) and microhabitat variables (mainly vegetation variables) as independent variables or predictors. Before conducting the analyses, I averaged the bird census data by survey within each sampling season and again averaged the data by sampling season (i.e., year) when appropriate, to calculate a relative abundance index for each species. To develop species occurrence data, I converted the count data to presence and absence data. The bird and vegetation data obtained from each point count station in 1996 and 1997 were split into two data sets, one for model development and one for model validation. Data points were chosen for model development randomly, with the restriction that sample sizes were balanced as much as possible across locations within each fire treatment to minimize possible confounding effects of treatment and location.

Model Development

I developed both logistic and multiple linear regression models based on microhabitat variables for 19 species from data collected in 1996 and 1997. The logistic regression models predicted species occurrence (i.e., presence or absence) and the multiple linear regression models predicted species relative abundance for locations where a species was present. Thus, the MLR models excluded all zero count data.

Since species occurrence or abundance can be correlated with structural habitat and/or floristic features, and since I wanted to develop models with high predictive potential, I examined a spectrum of narrowly defined floristic variables (e.g., number of turkey oaks in the small tree diameter size class, 8-23 cm dbh), floristic composite variables (e.g., number of non-pine trees) and habitat structural variables (e.g., % canopy cover) for model inclusion. I used nine variables, litter depth and cover percentages for the categories of green, grass, shrub, forb, fern, downed logs, leaf litter, and bare ground, to characterize ground cover attributes. I also retained the variables slope, canopy cover, canopy height, and number of snags ≥12 cm dbh. To characterize the under-, mid-, and overstory structure, I pooled the shrub, sapling, and tree species data into seven composite variables: number of shrubs <2.5 cm and >2.5 cm, number of saplings <2.5

cm and >2.5-8 cm, and number of trees 8-23 cm, >23-38 cm, and >38 cm dbh. To reflect major floristic differences in the mid- and overstory species composition, I combined the tree and sapling species data into six composite variables: number of longleaf pine saplings, number of other pine (i.e., not longleaf) saplings, number of other species (i.e., non-pine) saplings, number of longleaf pine trees, number of other pine trees, and number of other species trees. I then created three species richness variables: shrub, sapling, and tree species richness. To detect responses to finer floristic and structural features than is captured by the above composite variables, I also included numerous variables that specified a shrub, sapling, or tree species by a diameter size class. For a full list of microhabitat variables used for model development, see Appendix I.

Logistic regression models (LR) predicting the probability of occurrence were developed for 19 species using the entire data set for presence and absence data (n=87). To construct these models, I first performed Pearson's correlation coefficient tests between all habitat variables to test for multicollinearity. Correlations of ≥0.8 resulted in one variable from the pair being dropped. When possible, I excluded the variable that was harder to interpret or harder to estimate in the field. Next, I conducted simple logistic regressions between each bird species and each habitat variable and excluded any variables with a statistical significance value (p-value) greater than 0.5. In the Logistic Procedure of SAS/STAT software (SAS Institute Inc. 1997), I used the linear logistic model for binary response data with a logit link function for the logistic regression (logit (p)=log(p/(1-p)) where p is the probability of occurrence). For variable selection, I used both forward stepwise and the best subset selection methods. The best subset method is based on the likelihood chi-square score statistic and it allows the comparison of all possible models based on all variable combinations. To limit computation time for the best subset method, I limited the model size to eight variables maximum. In addition, I specified only a subset of models as output, i.e., the top two models for each variable size class from two to eight. The top models from the stepwise and the best subset selection methods were compared by the following statistics: (1) the Akaike Information Criterion, which adjusts for the number of variables; (2) concordance; (3) the Hosmer-Lemeshow goodness-of-fit test; and (4) the significance of each variable (alpha level was set at 0.2 for model variable inclusion). Typically, the top five models based on the above criteria shared a similar set of variables. The overall best model was chosen by comparing residual and influence diagnostics and checking for overdispersion (i.e., variance >> mean) (Collett 1991).

For developing multiple linear regression (MLR) models that predicted species relative abundance, I first dropped zero count data for each species, so the sample size varies by species. I then examined the abundance data for each species to determine whether their distribution was normal. As needed, the data were square-root or power transformed to meet the assumption of a normal distribution of the error term (i.e., residuals). After model development, I examined the distribution of model residuals to ensure that the transformation was appropriate (Eric Smith, pers. comm.). Prior to the MLR modeling procedures, I performed simple linear regressions between each species' abundance index and each habitat variable. Variables with a statistical significance value (p-value) > 0.5 were dropped. I performed Pearson's correlation coefficient tests

between the remaining habitat variables and dropped one variable from each highly correlated ($r \geq 0.8$) pair of variables to reduce multicollinearity. Additionally, for some species models, I had to exclude more variables from the modeling process because the number of variables was greater than the sample size. I made these further deletions by eliminating variables with the highest probability values from the simple linear regression analyses.

I used the C_p variable selection method available in the Regression Procedure of SAS/STAT (SAS Institute Inc. 1997) to develop the MLR models since this method allows all possible regressions to be compared and ranked. The C_p statistic expresses both model variance and bias and it can be used to discriminate between models (Myers 1990). The maximum number of variables allowed to enter a model was contingent upon the sample size for each species, with the maximum set at one variable per five sampling units. From the top five models, I chose the overall best model by comparing the PRESS (prediction error sum of squares) statistic, the variance inflation factors and the residual analyses (Myers 1990). To represent the quality of fit for each model to the data, I calculated the adjusted R^2 value, and to reflect the prediction potential of each model, I calculated an R^2-like statistic, R^2_{pred} (Myers 1990). This statistic is calculated by using the PRESS statistic and the total variability in the response variable (SS_{Total}), i.e., $R^2_{pred} = 1 - (PRESS / SS_{Total})$. In effect, the R^2_{pred} values summarize a true validation test conducted by repetitively refitting the model for n-1 observations and predicting the final observation, i.e., an observation is not simultaneously used for model fit and validation. An R^2_{pred} value close to the adjusted R^2 value for a model indicates a relatively good predictive ability (Gaudette and Stauffer 1988). To indicate both the fit of the data to the regression line and the spread of the data around it, I calculated the coefficient of variation, i.e., $CV = (s / \bar{y}) * 100$. This statistic depicts the natural dispersion around the regression line as a percentage of the average response value (Myers 1990).

Model Validation

Logistic Regression Models (1996-1997)

The LR models were validated by generating predicted occurrence values with an independent data set and then comparing the predictions to the observed values (Van Horne and Wiens 1991). To examine the predictive ability of the LR models, I first conducted cross-validation tests by comparing predicted values to observed values for the data set used to develop these models. This cross-validation step was necessary to develop a table of classification probabilities based on five summary rates: % correct; % sensitivity (ability to predict presence); % specificity (ability to predict absence); % false presence; and % false absence (SAS Institute Inc. 1997). The formulas of these classification summary rates are provided in Appendix II. From this classification table, I chose a "cutoff value" for probability of occurrence for determining presence or absence based on the above summary rates. A cutoff value is the probability threshold that determines whether particular probabilities of occurrence that a model generates is classified as predicting occurrence or absence. For example, if the cutoff value for a

species-habitat model is 0.5, then probabilities of occurrence less than 0.5 are classified as absence and values ≥0.5 are classified as presence. The cutoff values for species-habitat models ranged from 0.4 to 0.7.

After the cross-validation tests, I tested the classification abilities of the LR models with two data sets, both independent of the data sets used for model development. The first set, 1YR, included data collected during 1996 at n=120 point count stations. The second data set, 2YR, included n=41 stations sampled in both 1996 and 1997. I calculated the predicted probability of species occurrence for each count station by inputting the vegetation data into each species model. I then classified each prediction as presence or absence based on the cutoff rate chosen during the cross-validation process described above. I transformed the observed bird count data for each data set into presence and absence. Finally, I calculated the five summary rates (% correct, % sensitivity, % specificity, % false presence and % false absence) using the predicted and observed values.

Multiple Linear Regression Models (1996-1997)

I also tested the MLR models developed from the 1996-1997 data with the two independent data sets, 1YR and 2YR, just described. I first excluded all records associated with count data of zero, and then generated model predictions at the remaining count stations by inputting the required vegetation data. I next assessed the models by pairing predicted and observed relative abundance values per station and testing if the mean difference deviated from zero by Sign or t-tests. Additionally, I tested whether predicted and observed values were positively correlated using a Spearman's rank correlation coefficient test since model predictions could be biased (i.e., over- or underestimated) and inaccurate (substantially different from the true value), yet still consistently reflect how abundance changes with vegetational changes. Lack of such correlation suggests a lack of precision in the predictive abilities of the models. Before these analyses, I back-transformed model predictions for comparison to observed species occurrence values.

Multiple Linear Regression Models (1994-1996)

Additionally, I tested 17 MLR models predicting species relative abundance developed by Krieger (1997; see Appendix III) based on data from 1994-1996. Zero count data were included in the development of these models. Also, most of these models are restricted to particular fire treatments and/or locations relative to drains (see Appendix III). For example, the Eastern Wood Pewee model only included data from count stations positioned in fire intense areas because the pewee was too rare in fire suppressed areas to assess its distribution there. These models were tested with independent data, first with a 1-year data set (1YR) of n=156 from 1996 and then with a 2-year data set (2YR) of n=63 from 1996-1997. I generated model predictions and performed statistical analyses as described earlier for testing the previous MLR models.

Sources of Variation

Since the MLR models were based on multiple sampling years, I investigated whether annual variation may have impacted the ability of these models (both MLR 1996-1997 and 1994-1996 models) to predict relative abundance for a single breeding season (1996) by applying a correction factor to predicted values. The correction factor was based on the data used to develop the models and was defined as the mean observed value (for each species) for 1996 divided by the mean observed value for the entire time span of the model development data. The following equation was used to calculate the corrected predicted value for each sample:

$c_i = (o_1/o_2) * p_i$, where

i = sample i
c = corrected predicted value
o_1 = mean observed value for 1996 from model development data
o_2 = mean observed value for time span of model development data
p = predicted value.

RESULTS

For presenting results, bird species were grouped into assemblages that were defined in a previous study (see Chapter 2, *this manuscript*). These assemblages are longleaf pine, fire suppressed, drain, and generalist species assemblages. For example, the Bachman's Sparrow, Prairie Warbler, Brown-headed Nuthatch and Eastern Wood Pewee were most abundant within longleaf pine woodlands so these species are grouped into the longleaf pine assemblage. See Table 1 for species composition of each assemblage.

Model Development: *Logistic Regression Models (1996-1997) and Multiple Linear Models (1996-1997)*

Model parameters for the LR and MLR models are listed in Table 1 and full models with parameter coefficients and probability values for testing whether each parameter equals zero are listed in Appendices V and VI. For the LR models predicting probability of occurrence, concordance between observed values and the model predicted values was greater than 78% for each bird species (Table 1). Several of these models had concordant values greater than 90% (Eastern Wood Pewee, Bachman's Sparrow, Blue-gray Gnatcatcher, Red-eyed Vireo, Black-and-white Warbler, Ovenbird, White-eyed Vireo, Common Yellowthroat, Hooded Warbler, Northern Cardinal and Eastern Towhee). The adjusted R^2 values varied from 0.42 to 0.80 for the MLR models (1996-1997) predicting relative abundance for 19 species (Table 1). Every MLR model except

for the Eastern Towhee and Summer Tanager models had an adjusted R^2 value greater than 0.50. Five models (Carolina Wren, Black-and-white Warbler, Hooded Warbler, White-eyed Vireo, and Northern Cardinal) had adjusted R^2 values > 0.70. Species of the drain and fire suppressed assemblages generally had MLR models with a tighter fit than species of the longleaf pine and generalist assemblages. The natural dispersion, or coefficient of variation, around the regression line for each MLR model was relatively low, ranging from 4.3% to 13.2% of the average response value (Appendix V). The R^2_{pred} values, indicating the predictive capability of a MLR model, varied from 0.05 to 0.75 (Table 1). Nine MLR models (Brown-headed Nuthatch, Blue-gray Gnatcatcher, Black-and-white Warbler, Ovenbird, Carolina Wren, White-eyed Vireo, Hooded Warbler, Eastern Towhee, and Blue Jay) had relatively good predictive abilities, i.e., the R^2_{pred} values were within 20% of the adjusted R^2 values. The R^2_{pred} values for the Tufted Titmouse and Great Crested Flycatcher models had particularly poor predictive capabilities.

Although the same variables were available in the beginning of the variable selection process for both LR and MLR model development, the data available for the LR and MLR models of a particular species were not identical since count stations with zero counts were excluded from MLR analysis. Most parameters included in a species' LR and MLR models were unique to one model (Table 1). In five cases, one parameter was shared between models of a species (Great Crested Flycatcher, Brown-headed Nuthatch, Common Yellowthroat, Northern Cardinal, and Eastern Towhee). Even though LR and MLR model variables rarely overlapped for a species, I could not discern whether each species' respective LR and MLR model indicated different habitat features associated with that species' occurrence and then its abundance within already occupied sites. Most variables for a species' respective LR and MLR models appeared to indicate similar fire treatment and location patterns (see Appendix I for results of two-way factorial tests for fire treatment and location effects for each variable).

The relative importance of each model parameter is indicated by the parameter coefficients listed in Appendices V and VI for LR and MLR models, respectively. For example, the LR model for Bachman's Sparrow indicated that the probability of occurrence for this species increases with greater grass and shrub cover and decreases with greater tree species richness and the abundance of cane (Table 1, Appendix IV). The sparrow's relative abundance is positively associated with longleaf pine saplings (<8 cm) and negatively associated with greater bare ground, sapling species richness and black cherry saplings (<2.5 cm) (Table 1, Appendix V). These habitat associations for species occurrence and relative abundance of the sparrow generally characterize aspects of the upland communities of longleaf pine woodlands, and this supports the previous designation of this species as a member of the longleaf pine bird species assemblage (see Chapter 2, *this manuscript*). Similarly, the models predicting probability of occurrence and relative abundance for the other species support prior decisions to classify each species as associated with the longleaf pine, fire suppressed, drain, or generalist bird species assemblage (see Chapter 2, *this manuscript*).

Model Validation

Logistic Regression Models (1996-1997)

Figure 1 shows the results of testing the LR models through cross-validation (i.e., using the same data for testing that were used for model development) and validation with the 1YR and 2YR independent data sets. For optimal model performance in presence/absence classification, high values of correct classification, sensitivity (correct presence predictions), and specificity (correct absence predictions) and low rates of false presence and false absence predictions are desired. Based on the classification summary rates, the models performed the best overall in the cross-validation tests, and generally performed better when tested with the 2YR than with the 1YR data set. Also, most models predicted absence (specificity) better than presence (sensitivity) and had lower false absence rates than false presence rates. In general, a greater proportion of species-habitat models for the drain and fire suppressed assemblage performed better than models from the longleaf pine and generalist assemblage.

The Bachman's Sparrow, White-eyed Vireo, Hooded Warbler, and Blue Jay models performed the best overall in correctly classifying presence/absence (≥80% for cross-validation model, 1YR, and 2YR tests), although the favorable performance of the jay model was due largely to a high ability to predict absence but not presence (Figure 1). In addition to these models, the Eastern Wood Pewee, Ovenbird, Red-eyed Vireo, Black-and-white Warbler, and Carolina Wren models correctly predicted presence/absence ≥70% of the time in the three tests. The Blue-gray Gnatcatcher model was the best in correctly predicting presence (sensitivity) across all tests (≥75%). For predicting absence correctly (specificity), the Eastern Wood Pewee, Black-and-white Warbler, Ovenbird, Carolina Wren, White-eyed Vireo, Hooded Warbler and Blue Jay models performed the best (≥80% specificity) across the cross-validation and validation tests. No models were able to reduce false presence rates to below 30% in all three tests, although the Blue-gray Gnatcatcher, Ovenbird, Carolina Wren and Eastern Towhee models consistently yielded false presence rates of less than 50%. All models except the Common Yellowthroat, Great Crested Flycatcher, Carolina Chickadee, and Summer Tanager models had false absence rates of less than 30%. Several models (Bachman's Sparrow, Ovenbird, Carolina Wren, White-eyed Vireo, Hooded Warbler, Northern Cardinal and Blue Jay) consistently yielded false absence predictions of less than 20%. The models for three generalist species, the Great Crested Flycatcher, Carolina Chickadee and Summer Tanager, consistently had the poorest predictive abilities.

Multiple Linear Regression Models (1996-1997)

All MLR models, except for the Brown-headed Nuthatch, Carolina Wren, White-eyed Vireo and Common Yellowthroat models, had predicted values that were significantly lower than the observed relative abundance values when tested with the 1YR data (Figure 2). Yet, when these models were tested with the 2YR data, predicted values were similar to the observed values and were not statistically different from them

(Figure 2). The predicted values for the Red-eyed Vireo and Eastern Towhee models were positively correlated with their respective observed values in the 1YR data, and the Common Yellowthroat model predicted values that were highly correlated with observed values in the 2YR data (Table 2). However, for most models predicted values were not correlated with the observed values, indicating a lack of precision.

Applying an annual variation correction factor to the 1YR predictions slightly decreased the discrepancy between predicted and observed values for five species, the Bachman's Sparrow, Black-and-white Warbler, Blue-gray Gnatcatcher, Eastern Towhee and Summer Tanager (Table 3).

Multiple Linear Regression Models (1994-1996)

The results of testing 17 MLR models developed by Krieger (1997) from relative abundance data collected during 1994-1996, including all zero count data, are shown in Figure 3. For the Eastern Wood Pewee, Prairie Warbler, Bachman's Sparrow, Acadian Flycatcher, Black-and-white Warbler, Blue-gray Gnatcatcher, Ovenbird and Great Crested Flycatcher models, predicted values differed significantly from the corresponding observed values for the 1YR data set. No models for the species of the drain assemblage predicted values significantly different for the 1YR data set. Predicted values for the Acadian Flycatcher, Black-and-white Warbler and Eastern Towhee models also were statistically different from observed values for the 2YR data set. When tested for a correlation between observed and predicted values, the Blue-gray Gnatcatcher and Ovenbird models yielded significant results for the 1YR data and the Acadian Flycatcher, Blue-gray Gnatcatcher and Eastern Towhee models had positive correlations for the 2YR data (Table 4). Overall, the lack of correlation between observed and predicted values indicated poor precision in the predictive abilities of most models.

Model predictions for the 1YR validation were improved slightly by the annual variation correction factor for the following species: Bachman's Sparrow, Tufted Titmouse, Carolina Wren, White-eyed Vireo and Eastern Towhee (Table 5).

DISCUSSION

Model Performance

Since models are hypotheses, testing them is essential to assessing their predictive ability (Farmer et al. 1982; Marcot et al. 1983; Schamberger and O'Neil 1986; Van Horne and Wiens 1991; Morrison et al. 1992; Starfield 1997). In this study, the LR models performed best in presence/absence classification when tested with the same data used in development (i.e., cross-validation). This suggests that species-habitat models may be best able to predict changes at the sites used for model development. Support for this supposition is provided by the validation results for bird-habitat models developed by Morrison et al. (1987), who found that their models performed better at predicting future

species numbers at the same sites used for model development than at different sites. Conversely, although Rotenberry (1986) reported that the predictive ability of models for shrubsteppe birds was sufficient for cross-validation tests, these models poorly predicted future densities at the same sites.

Although species-habitat models may perform best in cross-validation tests, their utility depends mostly on their performance against independent data, i.e., in validation tests (Van Horne and Wiens 1991). Almost all models, including the LR and both sets of MLR models, performed better in validation tests based on the average of multiple years of sampling rather than on a single sampling year. Assuming that observer bias was minimized across years and sampling units, these results suggest that model performance may be sensitive to annual variation. Yet, using the MLR model development data to calculate an annual variation correction did not improve MLR model predictions for most species. This latter result suggests that annual variation present in data for one set of sampled sites may not be applicable for other, independent sites. Rotenberry (1986) contends that once basic habitat associations are expressed, local populations may stochastically fluctuate spatio-temporally independent of local habitat features. Stochastic variation at the local scale could be caused by landscape or regional influences, or may be an artifact of the spatial scale used in a study (Rotenberry 1986; Wiens 1986; Haila et al. 1996). Although it is important to sample across both space and time since habitat resource use by a species can vary annually (see Keane and Morrison 1999) and to adequately assess the natural variation in species occurrence or abundance, it is unrealistic to expect species-habitat models to accurately predict annual changes in species responses caused by stochastic variation that is uncoupled from habitat variation. Instead, most models for the breeding birds at Fort Bragg are more capable of predicting "average" responses (i.e., for a multiple year period) at the scale of individual count stations for the LR models and at the scale of the study area for the MLR models (see below).

For the MLR models predicting relative abundance, an alternative explanation of why they performed better at predicting an "average" response for a multiple year period rather than response in a single year may be that the sample size was greater for the 1YR test data than for the 2YR test data. That is, greater statistical power may have enabled detection of more discrepancies between observed and predicted values. This is unlikely for the 1996-1997 MLR models (Figure 2). In these models, the 1YR predicted values were usually lower than the corresponding observed values but very similar to the 2YR observed and predicted values. That the observed values for the 1YR data were consistently greater than the observed values for the2YR data suggests temporal variation due to population fluctuations. A sample size effect does not appear to be an adequate explanation for most of the 1994-1996 MLR models either (Figure 3). The Eastern Wood Pewee 1994-1996 MLR model may be an exception, since the difference between the predicted and observed values was similar for both the 1YR test and the 2YR test (1YR: n=73, mean difference = 0.077, SE=0.032; 2YR: n=30, mean difference = 0.078, SE=0.032), but only the 1YR test resulted in significance.

Almost all LR models could predict presence or absence at individual count

stations with ≥50% accuracy, and many could predict with ≥70% accuracy. For making land use decisions, it may be more important for species-habitat models to be more proficient at correctly predicting species absence rather than presence (Stauffer, pers. comm.). For instance, if these models were used to predict the probability of occurrence for a rare species in a site proposed for development, a false absence prediction may cause the proposed development to proceed, thus negatively impacting that rare species. In contrast, a false presence prediction would either cause the proposed development to be shifted to another site or it may cause further investigations through field survey work at the site. For this study, these species occurrence models were better at predicting absence than presence, and had lower false absence rates than false presence rates. A possible reason why most species occurrence models are more capable of predicting absence than presence is that habitat avoidance patterns may be clearer than habitat preference patterns. Haila et al. (1996) found that the annual variation of territory locations for 11 out of 17 boreal bird species inhabiting a forest mosaic could be explained by avoidance constraints, and when avoided sites were removed from analyses, territory locations varied stochastically. Thus habitat selection by many species may be described more aptly by habitat avoidance patterns, not habitat preferences. To improve a model's accuracy at predicting presence and to minimize the chance of failing to find a species where it is actually present, increased sampling effort is needed, in the form of increasing sample size, count duration or number of intra-seasonal survey periods (Dedon et al. 1986; Maurer 1986; Drapeau et al. 1999). Also, it may be that a species is more often absent from suitable habitat than present in unsuitable habitat due to stochastic variation of population levels. Sampling over multiple years will reduce this problem.

Although most MLR models were not significantly biased when tested with the 2YR test data sets, most had relatively low precision, evidenced by the lack of significantly correlated predicted and observed values at individual count stations. Morrison et al. (1987) reported similar findings when testing bird species-habitat models and concluded that the relative abundance models generally could predict presence or absence at a particular count station, but could not predict abundance with much precision. Relative abundance may fluctuate more widely than species occurrence at a specific site because of numerous factors that vary independently of habitat conditions during the breeding season, such as weather patterns, predation, social interactions (i.e. intra- and interspecific competition), and non-breeding season habitat requirements (Lancia et al. 1982; Sherry and Holmes 1985; Diehl 1986; Hejl and Beedy 1986; Holmes et al. 1986; Maurer 1986; Rice et al. 1993). For instance, the variability in the relative abundance of many Neotropical and temperate migrants may be partially "decoupled" from breeding season habitat conditions if the survival and future reproductive potential of these species is tightly adapted to migratory and wintering habitat features (Van Horne 1983; Wiens 1985; Rotenberry 1986). These MLR models may be most useful at predicting mean relative abundance across the study area instead of relative abundance changes at individual count stations because of their lack of precision.

Most species-habitat models typically account for about half the variation present in species numbers (Farmer et al. 1982; Morrison et al. 1992). Accordingly, the LR and MLR modeling approaches explained at least half of the variation in species occurrence

and relative abundance respectively for most of the breeding bird species in this study. Several species, particularly members of the fire suppressed and drain species assemblages, had LR and MLR models with relatively good fit (≥70%) and predictive potential (R^2_{pred}). Furthermore, models of these two assemblages tended to perform better in cross-validation and validation tests.

There are several reasons why it may be possible to build species-habitat models with more predictive capabilities for the fire suppressed and drain species assemblages. First, modeling species-habitat relationships based mainly on vegetative features may work especially well in habitats with greater vertical structural complexity and floristic diversity, such as the fire suppressed and drain habitats (see Chapter 2, *this manuscript*). Since there is more structural variation in vegetation in these habitats, there may be a higher probability of measuring vegetation variation that covaries with species occurrence or abundance. In fact, the vegetation sampling may have been biased toward more fully capturing the variation present in fire suppressed and drain habitats. The longleaf pine ecosystem is known for its diverse ground cover, characterized by a rich array of herbaceous species (Peet and Allard 1993). The sampling strategy protocol, designed for other systems (Martin 1994), captured the floristic variation of woody species but virtually ignored herbaceous floristic variation, except for ferns, vines, and cane. It is possible that the occurrence or abundance of some species of the longleaf pine assemblage may be correlated with floristic variation of herbaceous plants, especially if these plants fulfill an important component of nesting or foraging requirements. For example, the nests of Bachman's Sparrows and Prairie Warblers found on Fort Bragg included nesting materials derived from herbaceous plants.

Second, the species of the longleaf pine assemblage may respond strongly to factors influenced by fire management that were not measured during this study, such as variation in seed abundance, insect abundance, or the presence of predators. Futhermore, competition with other bird species also may have confounded the observed species-habitat relationships for the longleaf pine assemblage, as well as for the species of the other assemblages. In a long-term study of bird community dynamics by Diehl (1986), the competitive ability of individual species greatly influenced whether species relative abundance could be reliably predicted by habitat variation alone, with inferior competitors largely influenced by interspecific interactions rather than habitat variation. Third, although the models for the generalists do not indicate many strong habitat associations at the microhabitat scale, the generalists could be selecting ubiquitous habitat features throughout the study area and thus have low variation in their availability. Therefore, it may be difficult to detect associations with specific habitat features for a generalist.

Lastly, it is possible that the occurrence and abundance of species of the longleaf pine and generalist assemblages are influenced greatly by factors operating at a spatial scale other than the microhabitat. The spatial scale used in a study affects the perceived species-habitat patterns (Wiens et al. 1987; Wiens 1989; Steele 1992; Brandt et al. 1995; Pribil and Picman 1997; Sodhi et al. 1999). In a different study, I examined whether attributes measured at the microhabitat (50-m radius) or the landscape scale (300-m to

1500-m radius sites) had a larger influence on species occurrence (see Chapter 3, *this manuscript*). The proposition that a species may be more influenced by the landscape scale was not definitively supported by this study: the microhabitat scale was of greater importance to the majority of species in this forest-dominated landscape, regardless of species assemblage membership. Although landscape structure was of secondary importance for most species, there was evidence that certain landscape attributes may have a significant impact on the occurrence of species such as the Brown-headed Nuthatch and the Great Crested Flycatcher. Whether the patterns of occurrence and abundance for the breeding bird species in this longleaf pine ecosystem are influenced by factors operating at regional scales or scales smaller than the 50-m radius microhabitat scale, such as the availability of nesting sites within territories, is currently unknown.

Although most of these habitat models did account for at least half of the variation in species numbers, prediction errors still existed regardless of species assemblage membership. These could be caused by a multitude of factors, including incomplete sampling along the habitat gradient, problems in consistently detecting a species such as behavioral differences between individuals and unequal detectability across different habitats, and observer bias (Best and Stauffer 1986; Schamberger and O'Neil 1986; Edward et al. 1996). Furthermore, as mentioned earlier, species may respond to many factors that vary independently from breeding habitat conditions and populations may fluctuate stochastically across time and space. Additionally, although I excluded data points from the validation data sets if a variable varied beyond the range sampled during model development, if multiple variables at a count station within the validation data set covaried in a manner beyond the realm of the model development data set, it is still possible that a model was forced to extrapolate beyond the development data (Maurer 1986), thus causing model failure.

Modeling Approach for Species-Habitat Relationships

The premise behind most studies of species-habitat relationships is that individuals select habitats providing life requisites that best promote individual fitness, i.e., survival and reproduction. Habitat selection is an evolutionary-based process rooted in adaptive mechanisms benefiting those individuals that choose habitats associated with higher survival and reproductive rates (Pianka 1974; Rotenberry 1981; Morrison et al. 1992; Block and Brennan 1993). Habitat selection behavior of a bird is thought to consist of hierarchical choices where habitat features at one spatial scale may act as proximate cues for the bird to further select features at a finer scale (Johnson 1980; Wiens et al. 1986). A common method of assessing habitat relationships and making inferences about habitat selection by a species is to correlate population indices, such as species numbers and productivity, to habitat features. The approach I used in this study for the breeding birds of Fort Bragg, North Carolina, was a two-step modeling process directed first at ascertaining what habitat features are associated with species occurrence and then whether a species' abundance varies within occupied sites.

Although parameters of the LR and MLR models generally were not shared for a

particular species (see Table 1), I could not clearly evaluate whether a species' LR and MLR models indicated fine differences of habitat associations, possibly because variation across many vegetation variables may be correlated. That is, prior to any regression analyses, I conducted Pearson's correlation coefficient tests to exclude one variable from highly correlated ($r>0.8$) pairs. Yet, the results from these correlation tests indicated that statistically significant correlations (r ranged from 0.21 to 0.73) still existed between many variables across a species' LR and MLR models. For most species, it appears that its LR and MLR models represent similar habitat patterns mostly reflecting the effects of fire treatment (i.e., fire intense vs. fire suppression management practices) and location from drains (i.e., drain vs. upland habitat associations). For most species, the multiple number of correlated variables and the similar fire treatment and location patterns across its LR and MLR models suggest that the models for a particular species may indicate similar habitat associations. Conversely, uncorrelated variables still existed across a species' respective models and could indicate different habitat selection processes for determining species occurrence and then abundance within occupied sites.

Although it is unclear whether the LR and MLR models for a species represent distinctive habitat associations, both models for a species provide information useful in making management decisions since they indicate habitat parameters associated with particular bird species (Lancia et al. 1982; Starfield 1997). For instance, the occurrence of the Black-and-white Warbler is positively associated with steeper slopes, greater canopy height and various oak saplings and trees, which suggests that the warbler selects forests with well developed vertical structure in the proximity of drains. Therefore, altering forest structure within and adjacent to drains could negatively impact the Black-and-white Warbler population.

There are a few reasons why occurrence and abundance models might indicate similar habitat associations. First, occupied habitats clearly meet some minimum quality standard and the habitat gradient sampled within occupied sites lacks the breadth of the gradient sampled for species occurrence. Further habitat variation within suitable habitat that is important to species relative abundance may not always exist (Rotenberry 1986). Alternatively, my study design may not enable me to detect distinctive habitat associations caused by scale-dependent habitat selection choices because the sampling scale was the 50-m count station for detecting species occurrence and estimating species abundance. The study design is appropriate to detect occupancy patterns across the study area but further habitat selection choices within occupied sites may be associated with nest or foraging sites (e.g., Sodhi et al. 1999), neither of which was a focus of this study.

Third, occurrence and abundance, across many spatial scales, often are positively associated (Bart and Klosiewski 1989; Hanski et al. 1993; Gaston 1994). Vernier and Fahrig (1996) provided evidence that this relationship is caused by the amount of habitat available across a landscape, and that the success rate of dispersers is the mechanism responsible for correlation between abundance and occurrence. This positive relationship, if it occurs, implies that a two-step habitat selection process influencing species occurrence and then relative abundance within occupied sites may not exist.

Fourth, as mentioned earlier many variables still were correlated, especially the floristic variables commonly associated with drains, even after I removed one variable from each pair of highly correlated ($r>0.8$) habitat variables. This indicates that a multivariate covariance structure may have existed that could not be detected by the simple, pair-wise correlation analyses. More importantly, this suggests that different variables across a species' respective models may not represent different habitat relationships.

The species-habitat models presented here may reflect habitat quality, or the potential to support survival and successful reproduction, if occurrence and abundance covary with fitness. Demonstrating that effects of habitat on occurrence and abundance reflect effects on demography is critical (Van Horne 1983; Vickery et al. 1992). Krieger (1997) reported productivity data for several species of this bird community, and these data support the habitat relationships expressed in the models. For example, the Blue-gray Gnatcatcher nested more often and had a higher fledgling rate in fire suppressed habitats compared to fire intense habitats. This is consistent with the gnatcatcher models, which suggest that this species selects features associated with fire suppressed habitats, such as greater tree species richness. A similar pattern existed for the Prairie Warbler and Bachman's Sparrow in that both the reproductive data and species-habitat models suggested that the longleaf pine woodlands provided higher quality habitat for these species (Krieger 1997). Furthermore, features indicative of nest sites for the Prairie Warbler and Bachman's Sparrow were reflected in their respective habitat models. The warbler's nest sites and its occurrence and abundance both were associated with greater shrub cover and number of small and large saplings (<2.5 cm and >2.5-8 cm). The sparrow's nest sites and its occurrence and abundance both were associated with greater grass cover and less bare ground.

Floristic variables were more commonly associated with species occurrence or abundance than structural variables. Rotenberry (1985) contends that at a local population level, floristics may be more important than structure for habitat associations of shrubsteppe birds. A similar conclusion may apply to the bird species modeled on Fort Bragg, although the variation for floristic and structural variables may be correlated.

CONCLUSIONS

Although most of these predictive models may be sensitive to annual variation possibly caused by spatio-temporal stochasticity, most performed well at predicting species occurrence or relative abundance for an "average" breeding season, and most still exhibited satisfactory predictive capabilities to be useful in resource management planning. Lancia and Adams (1985) suggest that reliable predictive models can be developed for species that are abundant, have relatively small home ranges or territories, and have easily identified and specific habitat requirements. Developing reliable species-habitat models that predict occurrence was feasible for most of the breeding birds in this study, except for three generalist species, the Great Crested Flycatcher, Carolina Chickadee and Summer Tanager, possibly because these species lack specific habitat

requirements within the context of the Fort Bragg ecosystem. Species occurrence models for the drain and fire suppressed birds performed particularly well when tested, possibly because important habitat features could be easily identified and measured.

To develop models that can predict species relative abundance more precisely at a particular site, much more effort will be required, including increased sampling effort across several years to account for the full range of temporal variation. For many land management decisions, predicting species occurrence may provide sufficient information about how land use changes will affect a breeding bird population. If predictions about changes in relative abundance are required for sensitive species, such as threatened or endangered species, intensive studies that examine environmental parameters beyond the vegetation features at the microhabitat scale may be necessary. The approach used in this study (i.e., sampling multiple species simultaneously and using a broad array of vegetation characteristics) may not be adequate to produce a model with fine resolution capable of precisely predicting changes in abundance at individual sites. This approach can be used successfully for predicting the mean species relative abundance across an area or species occurrence at individual sites.

This study suggests that modeling species occurrence would have been sufficient to describe the general habitat associations of most species and to produce reliable models for predicting species occurrence in uncensused areas of the forests of Fort Bragg. Such models also are adequate to draw inferences about how habitat manipulations may affect a species.

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Table 1: Predictor variables from the logistic models predicting probability of occurrence and the multiple linear regression models predicting relative abundance for the breeding birds of Fort Bragg, NC. The "+" or "-" sign preceding a variable indicates its relationship with the response variable of occurrence or abundance. See Appendices V and VI for the entire model with coefficient values and significance values.

	Probability of Occurrence Models [a]		Relative Abundance Models [b]		
Species	C[c]	Variables	n	R^2_a / R^2_{pred}	Variables
Longleaf Pine Assemblage					
Eastern Wood Pewee	91.0	-% Fern cover, (-)Shrubs (>2.5-8 cm), +Longleaf pine (>8 cm), +Bracken fern, +Blueberry spp. (<2.5 cm), +Southern red oak saplings (<2.5 cm)	21	0.55/ 0.21	+% Bare ground, +Trees (>23-38 cm), +Bluejack oak saplings (<2.5 cm), +Post oak saplings (>2.5-8 cm)
Brown-headed Nuthatch	87.5	-Trees (8-23 cm), +Huckleberry (<2.5 cm), -Red chokeberry (<2.5 cm), +Hickory spp. (8-23 cm), -Hickory spp. (>23-38 cm), +Titi (<8 cm)	40	0.51/ 0.44	-Slope, -Litter depth, -% Fern cover, +Persimmon saplings (<2.5 cm), -Hickory spp. (8-23 cm), -Turkey oak (8-23 cm), +Turkey oak (>23-38 cm)
Prairie Warbler	88.7	+Slope, +Saplings (<2.5 cm), +Longleaf pine saplings (<8 cm), -Other species trees[d], +Longleaf pine (>38 cm)	40	0.51/ 0.14	+% Shrub cover, +Saplings (>2.5-8 cm), -Red chokeberry (<2.5 cm), -Blueberry spp. (<2.5 cm), +Pond pine saplings (<2.5 cm), +Pond pine (>38 cm), +Loblolly pine (>38 cm), -Tall gallberry holly (<8 cm)
Bachman's Sparrow	97.7	+% Grass cover, +% Shrub cover, -Tree species richness, -Cane	18	0.60/ 0.44	-% Bare ground, +Longleaf pine saplings (<8 cm), -Sapling species richness, -Black cherry saplings (<2.5 cm)
Fire Suppressed Assemblage					
Tufted Titmouse	78.5	+Trees (>38 cm), +Sassafras saplings (<2.5 cm), +Fetterbush (<8 cm), -American holly saplings (<8 cm), +Blackjack oak (>23-38 cm)	36	0.65/ 0.05	+% Downed logs, +Bracken fern, +Bluejack oak saplings (>2.5-8 cm), -Water oak (8-23 cm), -Titi (<8 cm), +Yellow poplar (>8 cm)
Blue-gray Gnatcatcher	94.3	+Slope, -Canopy cover, +Canopy height, -Trees (>23-38 cm), +Other pine species saplings (< 8 cm), +Tree species richness, -Huckleberry (<2.5 cm), -Black oak saplings (<8 cm)	50	0.51/ 0.44	-% Fern cover, +Saplings (>2.5-8 cm), +Cane , +Low gallberry holly (<2.5 cm), +Red maple (>23-38 cm), +Post oak (>23-38 cm), -Loblolly pine (>38 cm)

Table 1 continued.

Species	Probability of Occurrence Models [a]		Relative Abundance Models [b]		
	C^c	Variables	n	R^2_a / R^2_{pred}	Variables
Red-eyed Vireo	98.9	-% Bare ground, +Tree species richness, +Low gallberry holly (<2.5 cm), -Blackjack oak saplings (<2.5 cm), -Pond pine (8-23 cm), +Turkey oak (8-23 cm), +Black oak saplings (<8 cm), -Tulip poplar (>8 cm)	25	0.61/ 0.40	+Trees (>23-38 cm), -Cane, +Sweetgum saplings (<2.5 cm), -Flowering dogwood (>8-23 cm), +Alder spp. saplings (<8 cm)
Black-and-white Warbler	97.3	+Slope, +Canopy height, -% Leaf litter, +Turkey oak saplings (<2.5 cm), +Bluejack oak saplings (>2.5-8 cm), +Turkey oak (8-23 cm), +Sweetgum (>23-38 cm), +Blackjack oak (>23-38 cm), +Water oak saplings (<8 cm)	21	0.79/ 0.71	+Red maple saplings (<2.5 cm), +Pond pine saplings (<2.5 cm), +Sourwood saplings (>2.5-8 cm), +Hickory spp. (>23-38 cm)
Ovenbird	94.8	+Canopy height, +Other pine species trees (>8 cm), +Flowering dogwood saplings (>2.5 cm), +Hickory spp. (8-23 cm), +Turkey oak (>23-38 cm), -Post oak (>23-38 cm)	15	0.66/ 0.55	+Other pine species saplings (<8 cm), +Loblolly pine (>38 cm)
Drain Assemblage					
Carolina Wren	89.1	+Pond pine (>38 cm), +Sourwood saplings (>2.5-8 cm), +Red maple saplings (<2.5 cm), -Coast pepperbush (<2.5 cm), +Red maple (>23-38 cm), +Turkey oak (>23-38 cm), -Redbay saplings (>2.5-8 cm)	25	0.72/ 0.62	+Slope, +Blackjack oak saplings (<2.5 cm), -Flowering dogwood saplings (2.5-8 cm), +Blackjack oak (8-23 cm), +Post oak (8-23 cm)
White-eyed Vireo	98.9	+% Forb cover, +% Fern cover, +Sweetbay magnolia saplings (<2.5 cm), +Sourwood saplings (>2.5-8 cm), +Sourgum saplings (<8 cm)	12	0.80/ 0.72	+Shrubs (2.5-8 cm), +Post oak (>23-38 cm), +Sweetleaf saplings (<8 cm)

Table 1 continued.

	Probability of Occurrence Models [a]		Relative Abundance Models [b]		
Species	C[c]	Variables	n	R^2_a / R^2_{pred}	Variables
Common Yellowthroat	98.8	+% Shrub cover, -Saplings (>2.5-8 cm), -Other pine trees (>8 cm), -Sapling species richness, +Bracken fern, +Flowering dogwood saplings (<2.5 cm), -Sandpost oak saplings (<2.5 cm), +Blackjack oak saplings (<2.5 cm), -Turkey oak (8-23 cm), +Hickory spp. (>23-38 cm)	33	0.58/ 0.39	+Shrubs (2.5-8 cm), -Other species trees[d], +Sapling species richness, +Hickory spp. saplings (<2.5 cm), +Black cherry saplings (<2.5 cm), +Sourgum (8-23 cm)
Hooded Warbler	93.0	+Canopy height, +Sweetbay magnolia saplings (<2.5 cm), +Redbay saplings (>2.5-8 cm), +Bluejack oak saplings (>2.5-8 cm), +Sourgum saplings (<8 cm)	16	0.78/ 0.75	+Trees (>23-38 cm), +Sapling species richness, +Hickory spp. (>23-38 cm)
Northern Cardinal	93.7	-Common waxmyrtle (<2.5 cm), +Bluejack oak saplings (>2.5-8 cm), -Red maple (8-23 cm), +Pond pine (>38 cm), +Loblolly pine (>38 cm), +American holly saplings (<8 cm), +Sandpost oak (>8 cm)	20	0.70/ 0.21	+Canopy height, +Redbay saplings (<2.5 cm), +American holly saplings (<8 cm)
Eastern Towhee	91.3	+Slope, -Canopy height, +Trees (>38 cm), +Bracken fern, +Bluejack oak saplings (<2.5 cm), +Red maple (8-23 cm), +Pond pine (>38 cm)	43	0.48/ 0.40	+Canopy height, +% Fern cover, +Tree species richness, +Sweetbay magnolia saplings (2.5-8 cm), -Sweetgum (>23-38 cm), -Post oak (>23-38 cm)
Generalist					
Great Crested Flycatcher	78.7	+Trees (8-23 cm), -Longleaf pine (>8 cm), -Tree species richness, +Blackjack oak (>23-38 cm), +Poison sumac saplings (<8 cm)	45	0.54 0.06	+Longleaf pine (>8 cm), +Common waxmyrtle (<2.5 cm), -Flowering dogwood saplings (<2.5 cm), +Sweetgum saplings (<2.5 cm), +Loblolly pine saplings (2.5-8 cm), +Turkey oak saplings (2.5-8 cm), +Loblolly pine (>38 cm)
Blue Jay	88.8	+Litter depth, -% Shrub cover, +Staggerbush (<2.5 cm), +Loblolly pine saplings (2.5-8 cm), +Titi saplings (<8 cm)	14	0.64/ 0.54	+% Forb cover, +Longleaf pine (>8 cm)

Table 1 continued.

	Probability of Occurrence Models [a]		Relative Abundance Models [b]		
Species	C[c]	Variables	n	R^2_a / R^2_{pred}	Variables
Carolina Chickadee	82.3	-Shrubs (2.5-8 cm), +Cane, +Red chokeberry (<2.5 cm), -% Grass cover, +Persimmon saplings (<2.5 cm), -Loblolly pine (>38 cm), -Sweetleaf saplings (<8 cm)	37	0.55/ 0.24	-Litter depth, +% Downed logs, +Sweetgum saplings (<2.5 cm), +Sweetbay magnolia saplings (<2.5 cm), +Sourgum (8-23 cm)
Summer Tanager	88.8	+Slope, +Longleaf pine saplings (<8 cm), -Other pine species trees (>8 cm), +Huckleberry (<2.5 cm), -Sandpost oak saplings (<2.5 cm), +Turkey oak saplings (>2.5-8 cm), +Snags (8-23 cm), +Sweetgum (23-38 cm)	54	0.42/ 0.23	-Canopy cover, +Saplings (<2.5 cm), +Other pine species saplings (<8 cm), +Black cherry saplings (<2.5 cm), -Hickory spp. saplings (2.5-8 cm), -Persimmon saplings (2.5-8 cm), +Winged sumac (<8 cm)

[a] Logistic regression models based on presence and absence data at n=87 point count stations

[b] Multiple linear regression models based on relative abundance data at point count stations where a species was present; bird count data were square-root transformed; n is species-dependent; R^2_a is the adjusted R^2 value; R^2_{pred} is the prediction R^2 value

[c] Concordant (%): concordance between predictions and observations

[d] Excludes pine species

Table 2: Results of Spearman's Correlation Coefficient analyses for testing for a correlation between the observed and predicted values for the 1996-1997 MLR models of relative abundance.

	1YR			2YR		
Species	n	Correlation Coefficient	prob>$\|r_S\|$	n	Correlation Coefficient	prob>$\|r_S\|$
Longleaf Pine Assemblage						
Eastern Wood Pewee	19	-0.34	0.15	9	0.43	0.25
Brown-headed Nuthatch	32	0.09	0.62	17	-0.10	0.71
Prairie Warbler	18	-0.12	0.64	11	0.47	0.15
Bachman's Sparrow	12	0.30	0.35	10	0.01	0.97
Fire Suppressed Assemblage						
Tufted Titmouse	15	0.18	0.53	17	0.21	0.42
Black-and-white Warbler	20	0.42	0.07	11	-0.13	0.70
Blue-gray Gnatcatcher	53	0.04	0.80	23	0.31	0.15
Ovenbird	30	-0.11	0.57	8	-0.09	0.83
Red-eyed Vireo	23	0.48	0.02 *	14	0.38	0.18
Drain Assemblage						
Carolina Wren	24	0.14	0.51	10	-0.52	0.12
White-eyed Vireo [a,b]	9	-	-	3	-	-
Common Yellowthroat	21	0.21	0.36	15	0.73	0.002 *
Hooded Warbler	9	-0.41	0.27	8	-0.63	0.10
Northern Cardinal	17	-0.07	0.80	9	0.34	0.37
Eastern Towhee	38	0.33	0.04 *	17	0.04	0.88
Generalists						
Great Crested Flycatcher	35	-0.21	0.23	19	-0.43	0.07
Blue Jay[b]	14	0.31	0.28	4	-	-
Carolina Chickadee	22	0.22	0.32	18	-0.16	0.52
Summer Tanager	41	-0.001	0.99	24	0.13	0.56

[a] Not tested since standard error=0 for the observed data for 1YR
[b] Not tested since low sample size for 2YR

Table 3: Comparisons between predictions from testing MLR models (1996-1997) with the validation data set from 1996 and for correcting these predictions for annual variation. Mean differences between observed and predicted (or corrected predicted) values are shown.

Species	No Correction	Correction
Longleaf Pine Assemblage		
Eastern Wood Pewee	0.325	0.341
Brown-headed Nuthatch	0.272	0.422
Prairie Warbler	0.412	0.461
Bachman's Sparrow	0.503	0.455
Fire Suppressed Assemblage		
Tufted Titmouse	0.350	0.417
Black-and-white Warbler	0.199	0.139
Blue-gray Gnatcatcher	0.169	0.138
Ovenbird	0.299	0.348
Red-eyed Vireo	0.328	0.353
Drain Assemblage		
Carolina Wren	-0.065	-0.154
White-eyed Vireo	0.136	0.215
Common Yellowthroat	0.104	0.156
Hooded Warbler	0.510	0.573
Northern Cardinal	0.353	0.361
Eastern Towhee	0.373	0.308
Generalists		
Great Crested Flycatcher	0.329	0.349
Blue Jay	0.194	0.194
Carolina Chickadee	0.227	0.299
Summer Tanager	0.254	0.232

Table 4: Results of Spearman's Correlation Coefficient analyses for testing for a correlation between the observed and predicted values for the MLR models of species relative abundance for 1994-1996.

	1YR			2YR		
Species	n	Correlation Coefficient	prob>$\|r_S\|$	n	Correlation Coefficient	prob>$\|r_S\|$
Longleaf Pine Assemblage						
Eastern Wood Pewee	73	0.08	0.50	30	0.05	0.77
Prairie Warbler	64	0.16	0.20	26	0.27	0.18
Bachman's Sparrow	70	0.06	0.64	29	0.33	0.08
Fire Suppressed Assemblage						
Acadian Flycatcher	41	0.30	0.06	20	0.55	0.01 *
Tufted Titmouse	29	0.22	0.26	14	0.28	0.33
Black-and-white Warbler	68	0.13	0.29	25	0.31	0.13
Blue-gray Gnatcatcher	143	0.27	0.001 *	59	0.37	0.01 *
Ovenbird	64	-0.27	0.03 *	26	-0.03	0.89
Red-eyed Vireo	29	0.09	0.64	10	0.16	0.65
Drain Assemblage						
Carolina Wren	31	0.17	0.35	13	0.15	0.63
White-eyed Vireo	14	0.05	0.86	7	0.16	0.74
Common Yellowthroat	33	0.16	0.39	16	-0.02	0.93
Hooded Warbler	34	-0.08	0.64	17	-0.34	0.18
Northern Cardinal	32	0.22	0.22	13	-0.17	0.58
Eastern Towhee	11	0.55	0.08	6	0.97	0.001 *
Generalists						
Great Crested Flycatcher	149	0.04	0.62	62	-0.15	0.27
Summer Tanager	141	0.06	0.46	59	0.11	0.43

Table 5: Comparisons between predictions from testing MLR models (1994-1996) with the validation data set from 1996 and for correcting these predictions for annual variation. Mean differences between observed and predicted (or corrected predicted) values are shown.

Species	No Correction	Correction
Longleaf Pine Assemblage		
Eastern Wood Pewee	0.077	0.090
Prairie Warbler	-0.075	-0.091
Bachman's Sparrow	-0.067	-0.064
Fire Suppressed Assemblage		
Acadian Flycatcher	-0.101	-0.150
Tufted Titmouse	0.038	0.033
Black-and-white Warbler	0.101	0.108
Blue-gray Gnatcatcher	-0.052	0.054
Ovenbird	0.074	0.132
Red-eyed Vireo	-0.099	-0.119
Drain Assemblage		
Carolina Wren	0.078	-0.066
White-eyed Vireo	-0.177	-0.029
Common Yellowthroat	0.003	0.049
Hooded Warbler	0.082	0.120
Northern Cardinal	0.130	0.137
Eastern Towhee	0.315	0.234
Generalists		
Great Crested Flycatcher	0.117	0.129
Summer Tanager	0.003	0.045

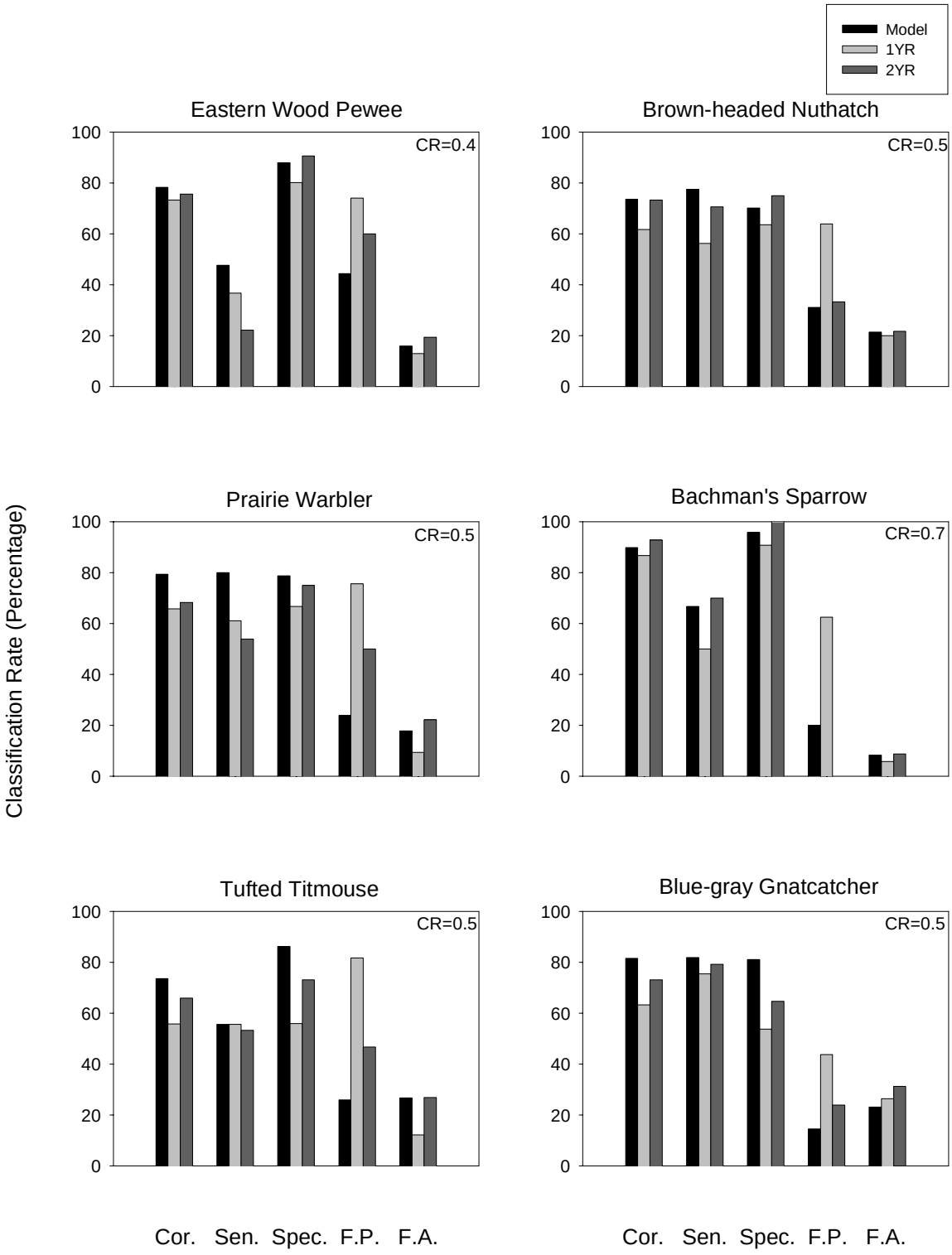


Figure 1: Classification rates (%) of model predictions for species occurence based on data used for model development and from two independent data sets, 1YR and 2YR. CR=cutoff rate for determining whether the predicted probability of occurrence indicates presence or absence. Classification summary rates: Cor.=correct predictions, Sen.=sensitivity (ability to predict presence), Spec.=specificity (ability to predict absence), F.P.=false presence predictions, and F.A. =false absence predictions.

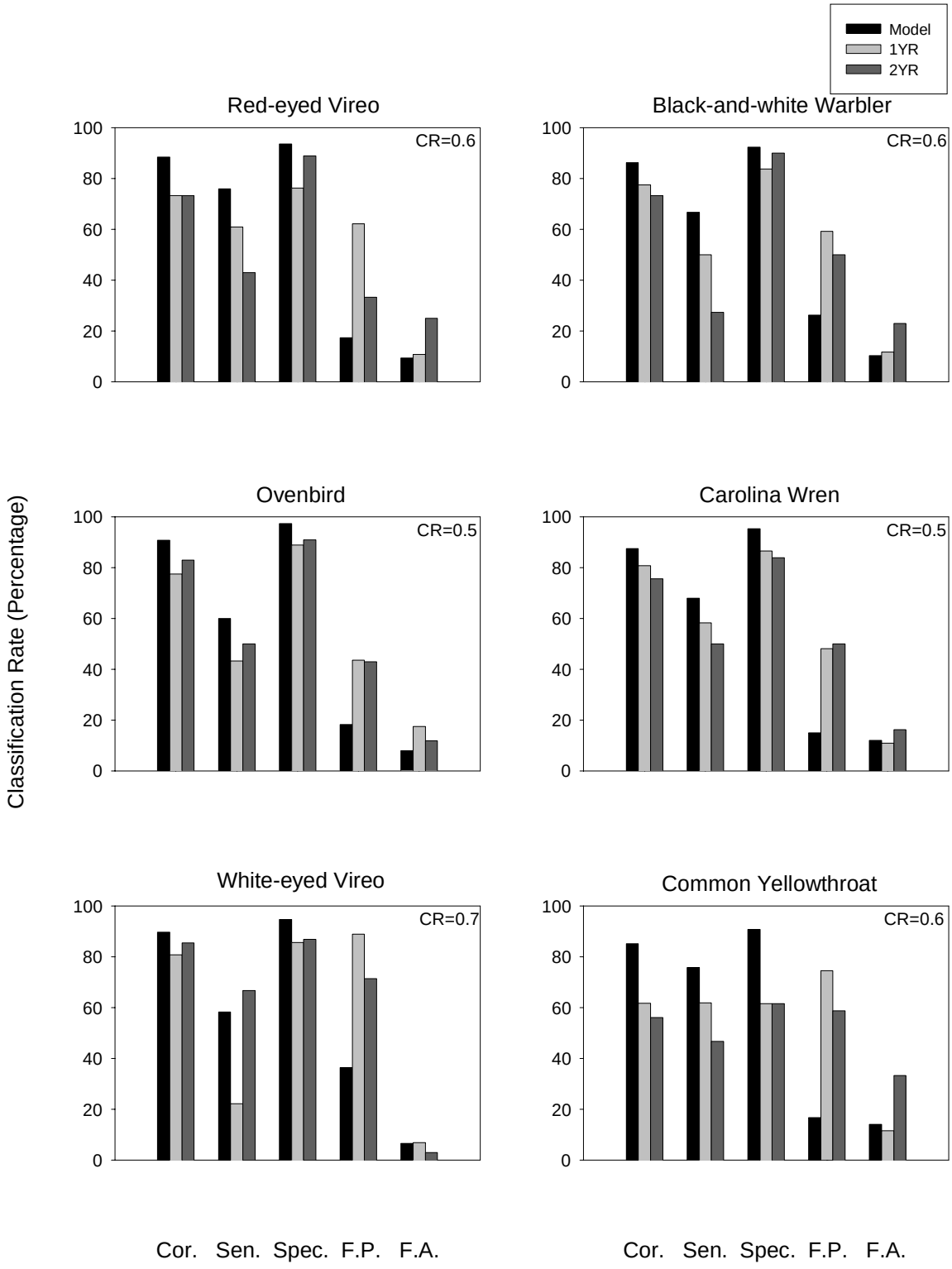
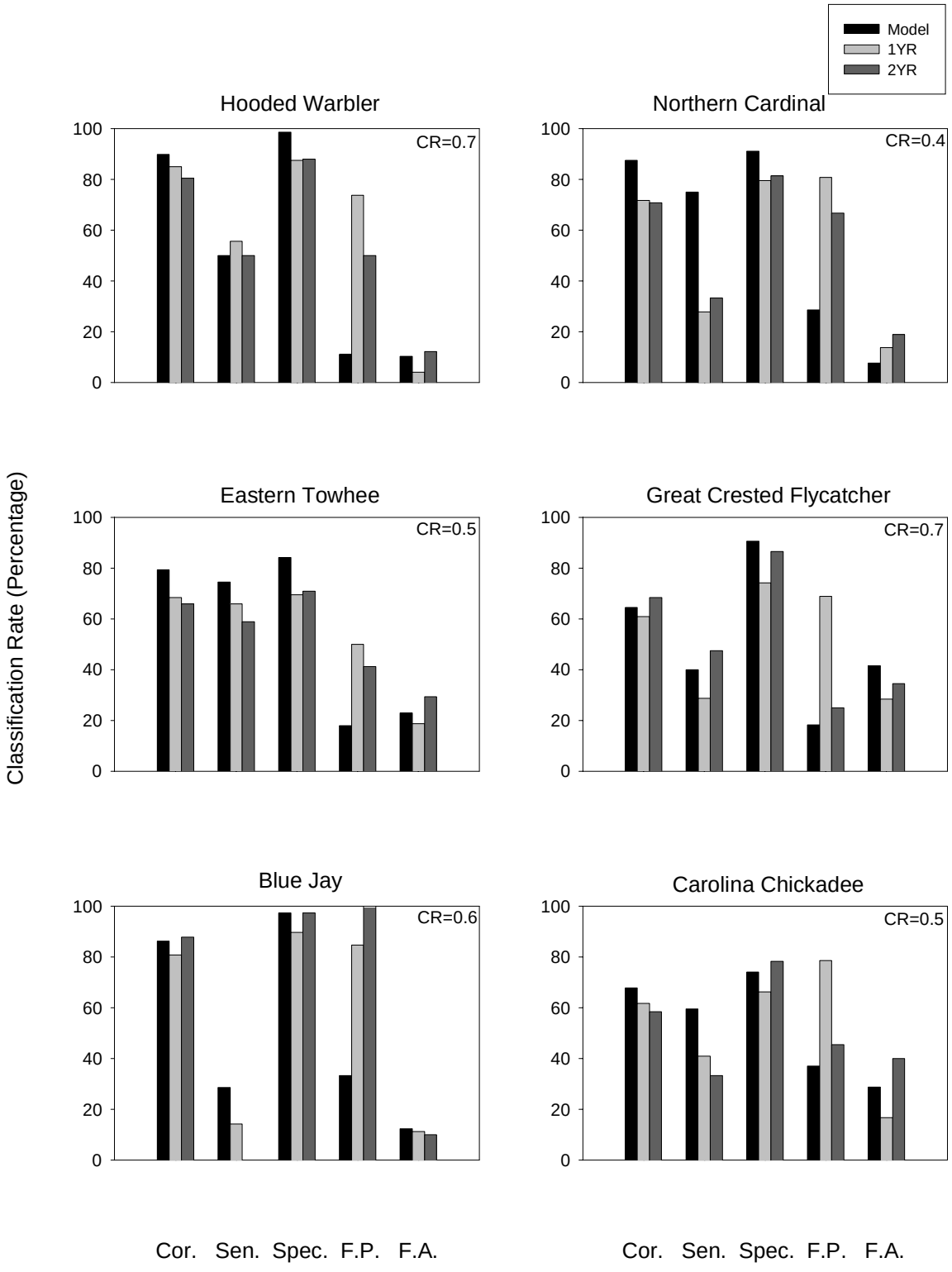


Figure 1 continued.



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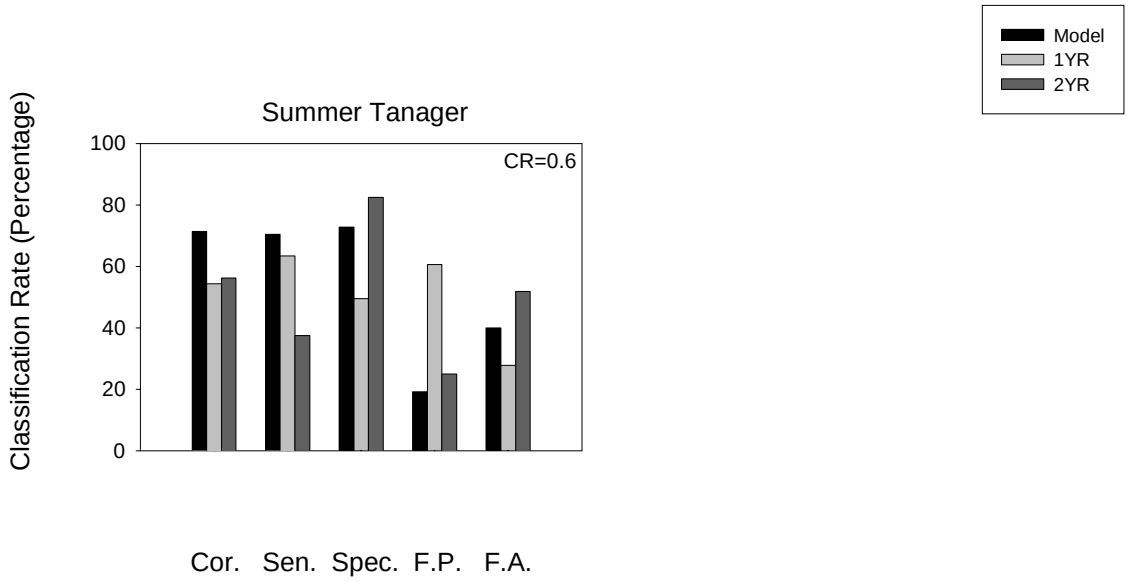

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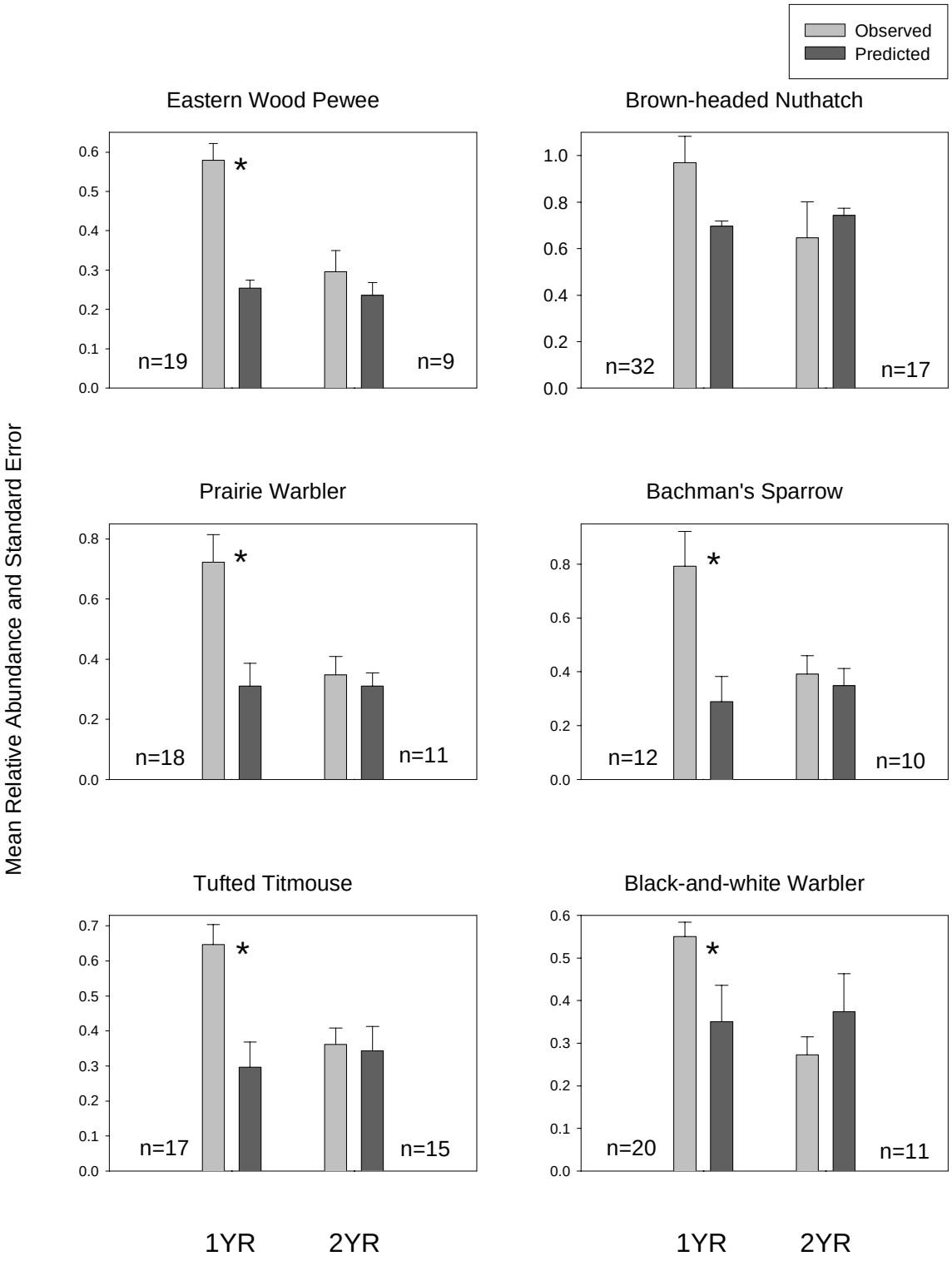

Figure 2: Observed and predicted values of mean relative abundance in occupied habitats used to test predictive models developed from data collected for breeding birds during 1996-1997 at Fort Bragg, NC. Two independent data sets, 1YR (1996) and 2YR (1996-1997) were used for model validation tests. Asterisks (*) denote statistical significance ($p<0.05$) when testing whether mean paired differences deviated from zero by Sign or t-tests.

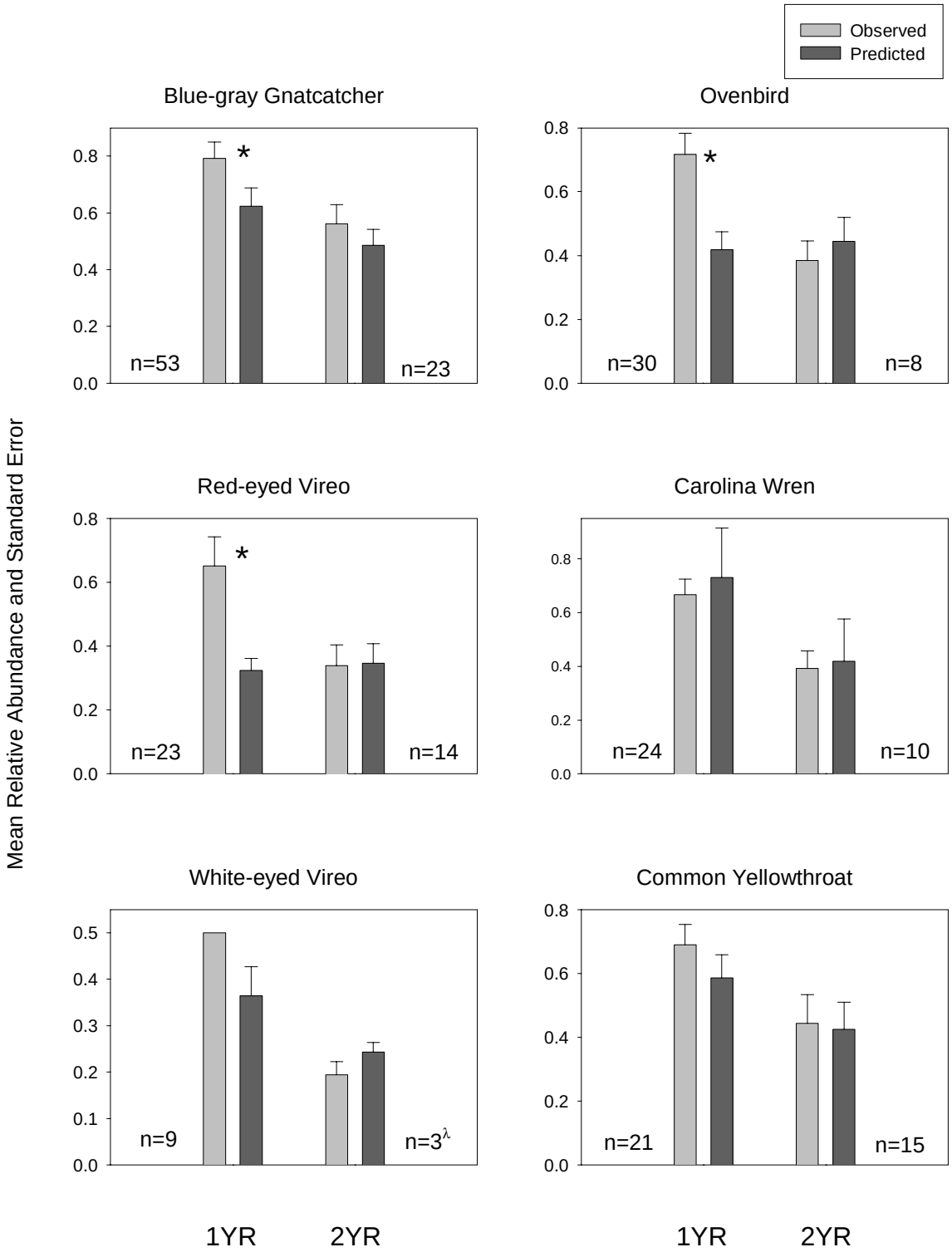

Figure 2 continued.

λ White-eyed Vireo was not tested for the 2YR data set because of low sample size (n<5).

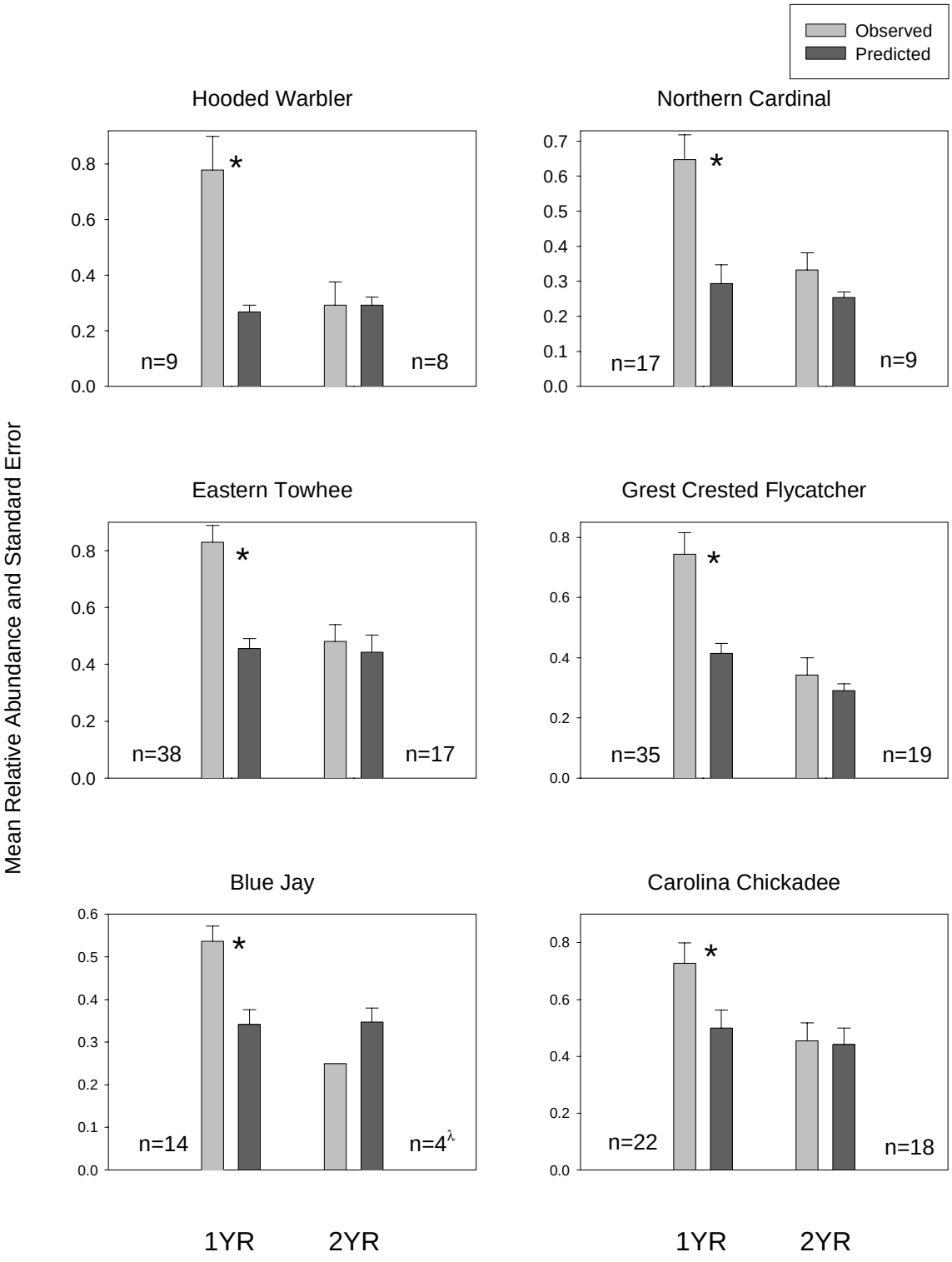

Figure 2 continued.

λ Blue jay not tested for 2YR data because of low sample size (n<5).

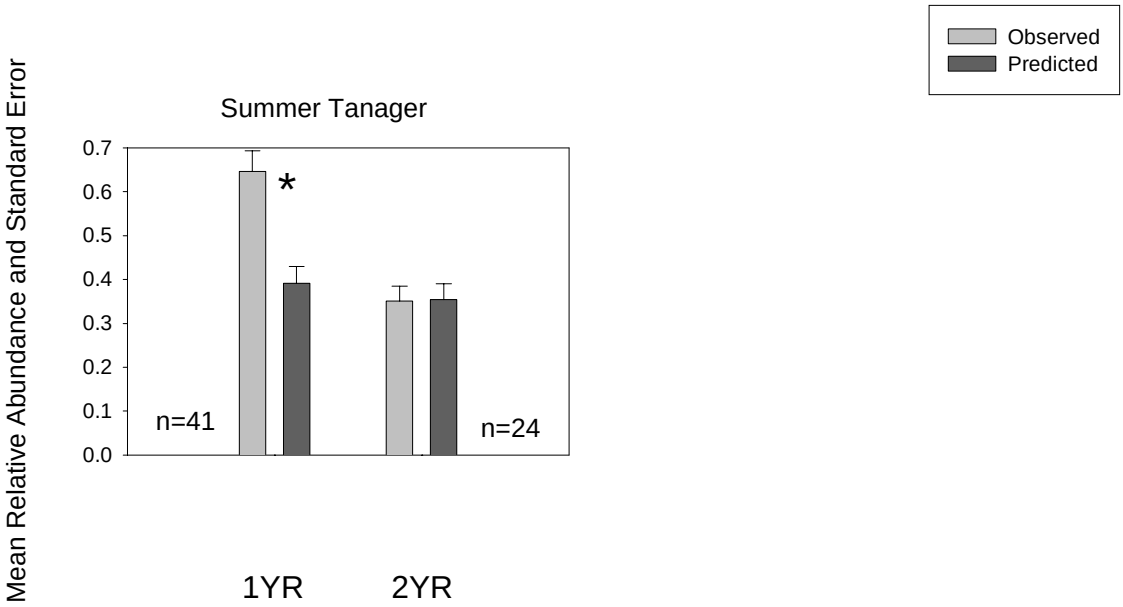

Figure 2 continued.

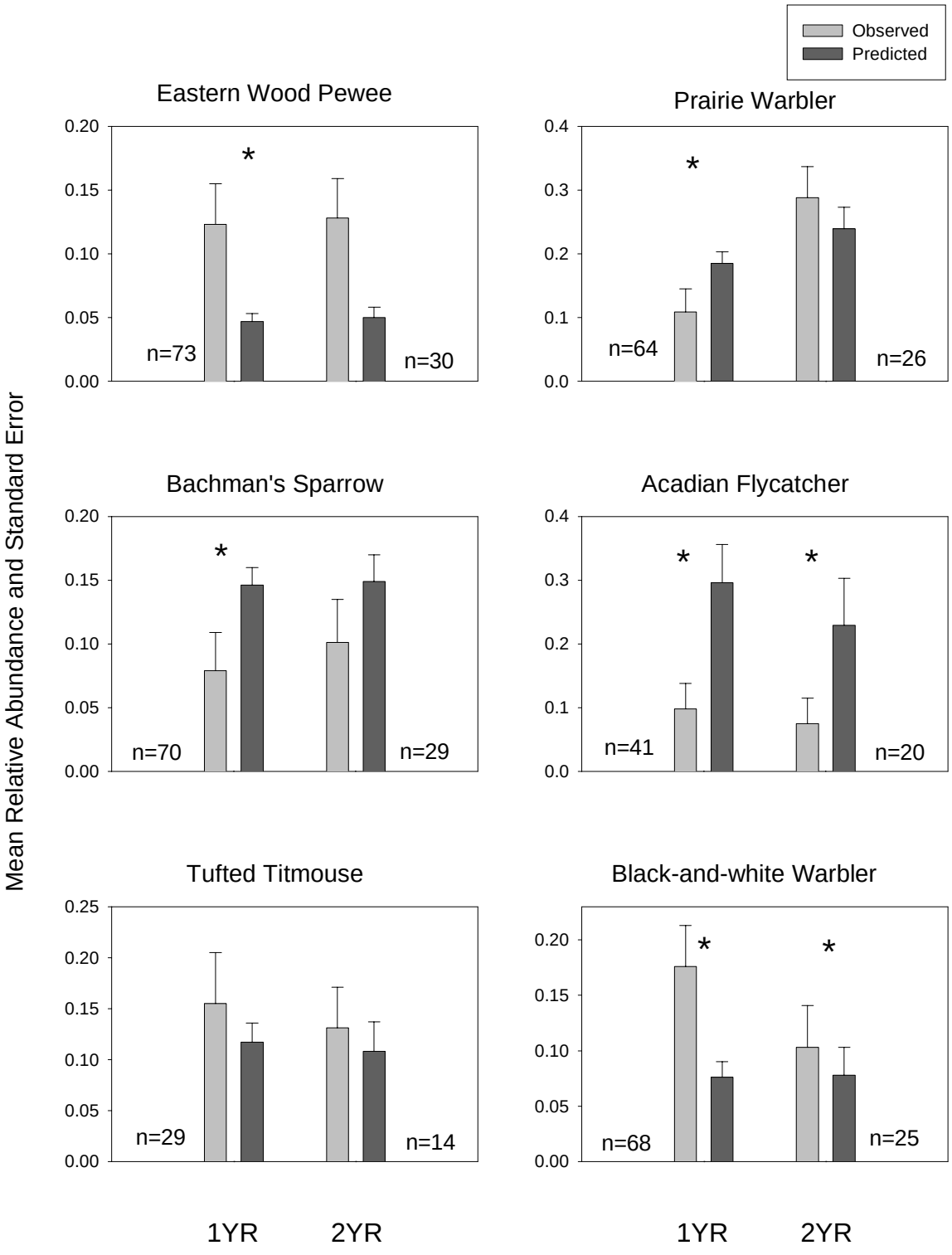

Figure 3: Observed and predicted values of mean relative abundances and standard errors used to test predictive models developed from data collected during 1994-1996 at Fort Bragg, NC. Two independent data sets, 1YR (1996) and 2YR (1996-1997) were used for the model validation tests. Asterisks (*) denote statistical significance ($p<0.05$) when testing whether mean paired differences deviated from zero by Sign or t-tests.

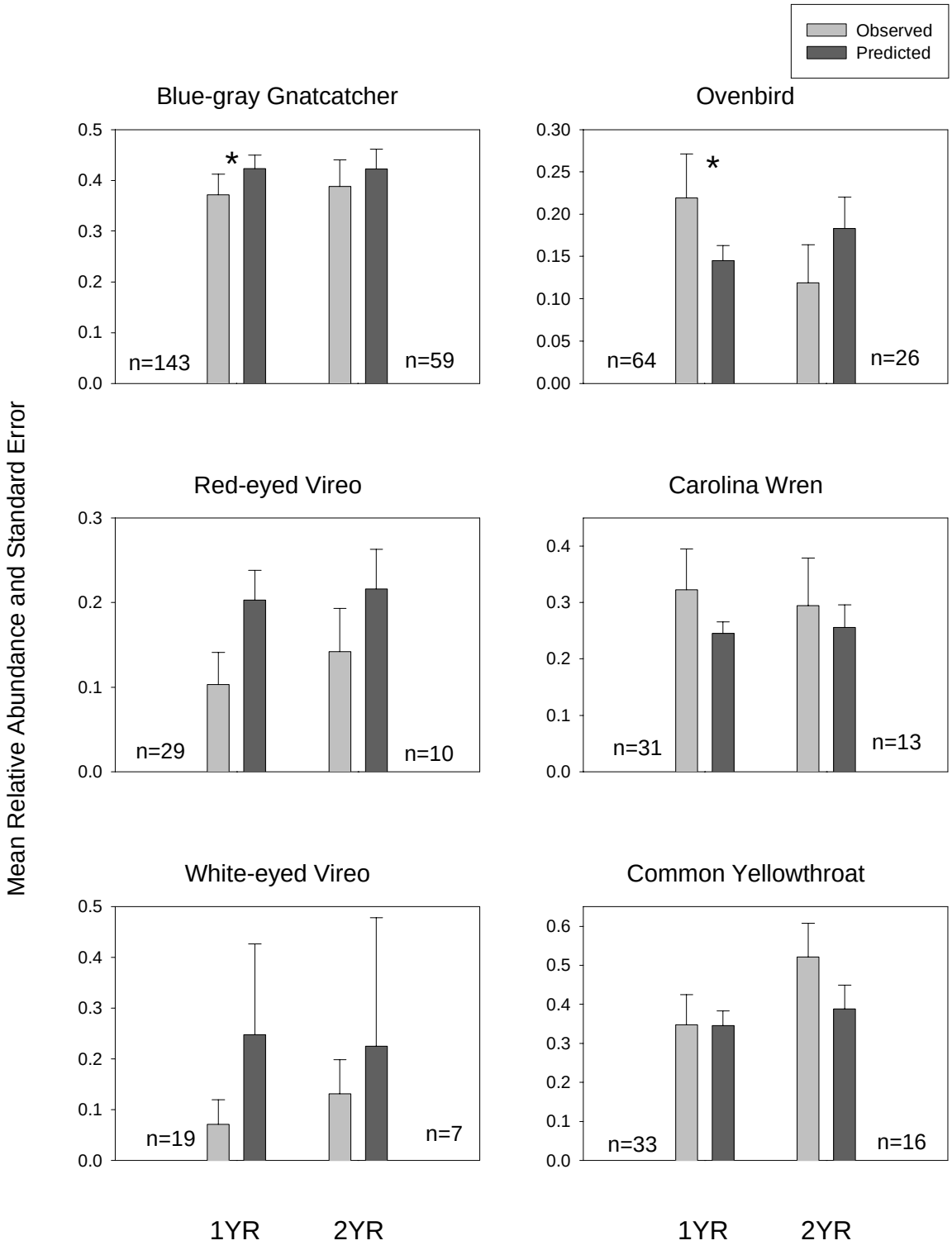

Figure 3 continued.

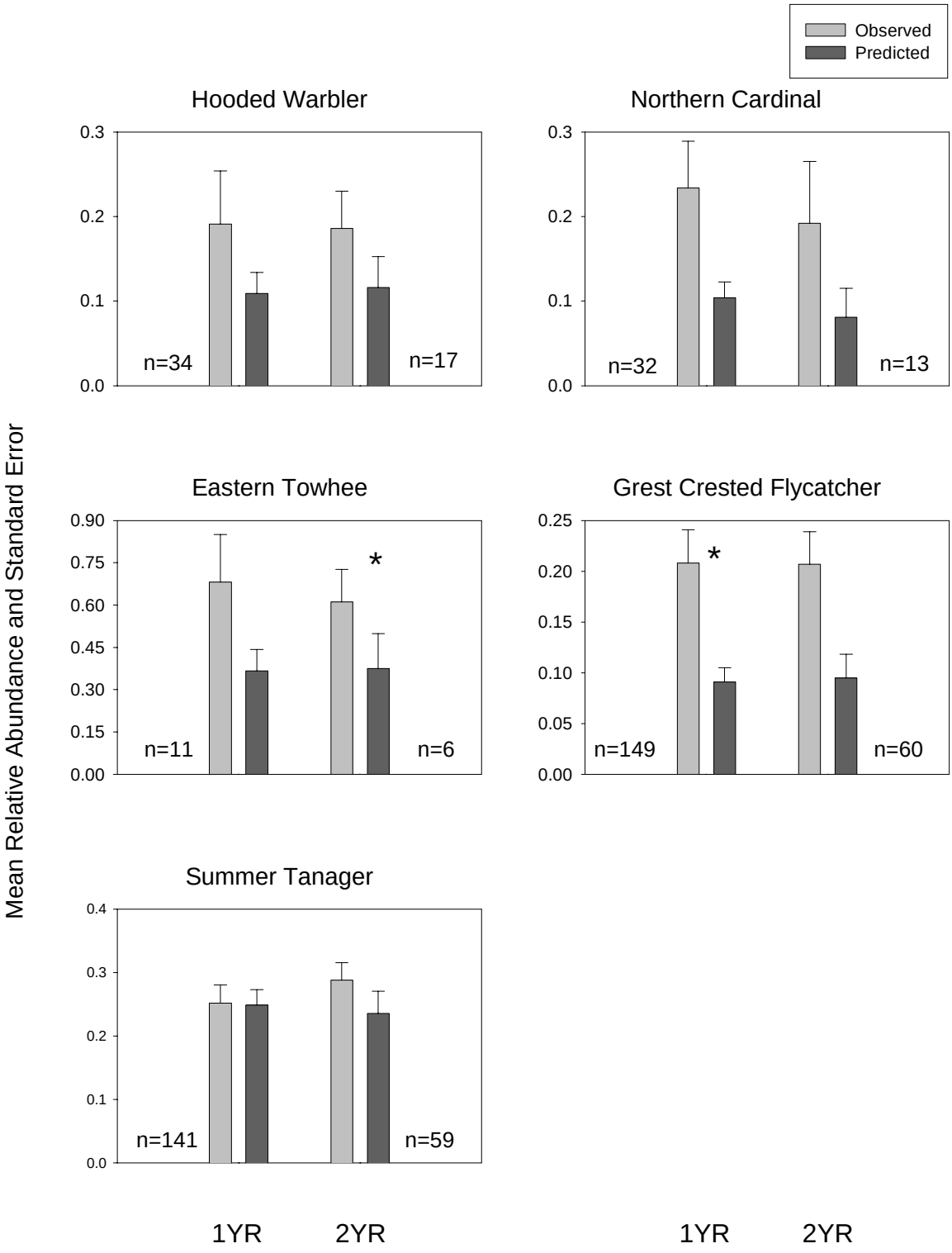

Figure 3 continued.

Appendix I: List of microhabitat variables used for model development and their mean and standard errors by fire treatment and location relative to drains (n=87; 1996-97). Results of two-way factorial tests based on GLM procedures for treatment, location, and interaction effects are shown.

	Fire Intense						Fire Suppressed						
	Drain n=17		Intermediate n=18		Upland n=17		Drain n=12		Intermediate n=12		Upland n=11		
Microhabitat Variable	x	se	x	se	x	se	x	se	x	se	x	se	Significant Effects[a]
Slope	6.72	0.57	6.85	0.52	3.97	0.63	6.56	1.56	5.21	0.54	5.16	1.11	L*
% Canopy Cover	71.20	2.47	67.37	2.51	60.22	2.40	86.50	3.04	74.28	5.12	77.75	5.64	T****, L**
Canopy Height (m)	21.51	1.22	18.57	0.70	18.13	0.80	20.27	0.83	16.78	1.12	16.47	0.92	L***
Litter Depth (cm)	3.70	0.41	2.68	0.26	1.95	0.24	3.59	0.34	2.93	0.32	3.72	0.49	T**, L**, I*
% Grass Cover	16.00	1.66	23.92	2.58	25.55	2.26	8.85	1.90	11.17	2.49	11.08	2.45	T****, L*
% Shrub Cover	42.95	3.59	18.36	1.87	13.44	1.61	35.59	4.16	16.64	2.79	18.00	1.63	L****
% Forb Cover	7.40	2.03	6.92	1.16	6.45	1.50	7.20	2.78	4.06	0.97	3.05	0.90	T*
% Fern Cover	9.48	2.25	0.72	0.34	0.48	0.29	5.16	1.76	1.16	0.59	0.80	0.64	L****
% Downed Logs	2.63	0.47	1.83	0.32	1.48	0.20	4.53	0.79	5.74	2.43	4.13	0.88	T****
% Leaf Litter	83.51	3.05	77.88	3.28	66.13	3.87	83.27	4.87	76.94	6.63	80.68	4.93	L*
% Bare Ground	5.28	1.57	8.68	1.27	17.84	2.67	5.73	2.25	17.36	6.49	9.46	3.48	L**
# Shrubs (>2.5-8 cm)	1.06	0.48	0.00	0.00	0.00	0.00	2.04	0.92	0.04	0.04	0.02	0.02	L****
# Saplings (<2.5 cm)	41.13	4.81	47.03	5.79	29.32	6.79	40.73	5.68	32.08	7.45	39.00	8.11	
# Saplings (>2.5-8 cm)	2.79	0.59	3.15	1.06	1.40	0.48	4.29	1.00	4.35	1.11	6.14	1.13	T***
# Trees (8-23 cm)	4.76	0.60	3.83	0.71	2.19	0.50	13.65	2.24	12.65	1.64	16.30	2.57	T****
# Trees (>23-38 cm)	3.09	0.30	3.69	0.49	3.96	0.37	4.44	0.61	3.83	0.59	3.64	0.64	
# Trees (>38 cm)	1.81	0.19	1.40	0.17	1.35	0.26	1.71	0.27	1.08	0.33	0.57	0.14	T*, L**
# Longleaf Pine Saplings	0.22	0.11	0.65	0.23	0.46	0.21	0.15	0.10	0.29	0.17	0.50	0.30	
# Other Pine Saplings	1.16	0.68	0.22	0.22	0.00	0.00	0.67	0.37	0.58	0.50	1.23	0.75	T***
# Longleaf Pine Trees	3.21	0.42	6.67	0.59	6.88	0.65	1.63	0.51	4.67	1.51	3.75	1.45	T****, L****
# Other Pine Trees	2.96	0.52	0.36	0.15	0.03	0.03	6.92	1.95	3.33	1.76	8.07	3.19	T****, L****
# Other Species Trees (non-pine)	3.28	0.64	1.86	0.66	0.53	0.20	10.71	1.57	9.40	1.31	8.52	1.81	T****, L***
Sapling Species Richness	10.06	0.85	5.67	0.48	3.76	0.38	10.67	1.18	5.50	1.06	6.64	0.77	T*, L****, I*

Appendix I continued.

	Fire Intense						Fire Suppressed						
	Drain n=17		Intermediate n=18		Upland n=17		Drain n=12		Intermediate n=12		Upland n=11		
Microhabitat Variable	x	se	x	se	x	se	x	se	x	se	x	se	Significant Effects[a]
Tree Species Richness	6.12	0.45	3.00	0.47	1.88	0.28	8.67	0.38	6.42	0.86	5.55	0.77	T****, L****
# Snag (≥12 cm)	0.25	0.13	0.04	0.03	0.10	0.05	0.46	0.13	0.19	0.09	0.23	0.06	T**, L*
# Cane	83.94	23.66	1.19	0.84	0.00	0.00	42.19	14.47	4.17	3.28	0.00	0.00	L****
# Coast Pepperbush (<2.5 cm)	55.74	12.97	4.49	3.85	0.50	0.42	40.69	11.56	6.73	4.89	0.09	0.09	L****
# Huckleberry (<2.5 cm)	62.96	12.03	0.49	0.46	0.21	0.21	57.10	25.24	1.02	0.73	1.27	1.18	L****
# Low Gallberry Holly (<2.5 cm)	74.54	20.81	8.39	7.69	0.44	0.44	44.63	17.17	1.75	1.58	0.00	0.00	L****
# Staggerbush (<2.5 cm)	1.04	0.52	2.88	2.44	0.00	0.00	1.67	1.01	0.08	0.08	0.77	0.52	
# Common Waxmyrtle (<2.5 cm)	0.18	0.16	0.24	0.24	0.00	0.00	1.90	1.52	1.35	1.16	0.27	0.27	
# Bracken Fern	6.71	1.60	1.08	0.89	0.63	0.43	1.75	0.80	0.02	0.02	1.25	1.25	L****
# Red Chokeberry (<2.5 cm)	0.68	0.20	0.00	0.00	0.00	0.00	1.00	0.43	0.00	0.00	0.00	0.00	L****
# Blueberry (<2.5 cm)	14.50	2.92	1.58	1.40	0.00	0.00	15.04	3.81	0.54	0.32	0.50	0.31	L****
# Muscadine Grape	0.87	0.43	0.00	0.00	0.00	0.00	1.88	0.91	1.25	0.90	2.39	1.79	T***, L****
# Blueberry (>2.5-8 cm)	0.51	0.32	0.00	0.00	0.00	0.00	1.27	0.68	0.00	0.00	0.02	0.02	T*, L****
# Titi (<8 cm)	0.12	0.10	0.00	0.00	0.00	0.00	0.48	0.37	0.00	0.00	0.00	0.00	L**
# Tall Gallberry Holly (<8 cm)	2.82	1.98	0.00	0.00	0.00	0.00	4.00	2.81	0.00	0.00	0.00	0.00	L****
# Fetterbush (<8 cm)	29.13	6.82	0.32	0.32	0.00	0.00	24.81	6.32	0.00	0.00	0.73	0.73	L****
# Black Bayberry (<8 cm)	2.82	0.49	0.13	0.13	0.00	0.00	1.40	0.51	0.00	0.00	0.70	0.59	L****, I**
# Winged Sumac (<8 cm)	0.60	0.19	0.11	0.05	0.00	0.00	0.81	0.28	1.46	0.67	0.43	0.28	T**, L***
# Red Maple Saplings (<2.5 cm)	3.96	1.68	0.32	0.32	0.01	0.01	6.46	1.64	0.00	0.00	0.00	0.00	L****
# Serviceberry Saplings (<2.5 cm)	0.15	0.07	0.00	0.00	0.00	0.00	0.21	0.10	0.00	0.00	0.00	0.00	L****
# Hickory Saplings (<2.5 cm)	0.13	0.06	0.42	0.25	0.00	0.00	0.40	0.30	0.98	0.67	0.32	0.18	
# Flowering Dogwood Saplings (<2.5 cm)	0.24	0.24	0.21	0.19	0.00	0.00	0.60	0.54	0.29	0.22	0.30	0.20	T*
# Persimmon Saplings (<2.5 cm)	2.44	0.56	5.31	1.65	2.44	0.78	1.50	0.53	2.96	1.33	2.02	0.61	
# Sweetgum Saplings (<2.5 cm)	1.26	1.02	2.04	2.04	0.00	0.00	3.06	1.54	1.25	1.25	4.98	4.61	
# Sweetbay Magnolia Saplings (<2.5 cm)	1.24	0.34	0.32	0.32	0.00	0.00	3.60	1.41	0.00	0.00	0.20	0.20	L****
# Sourwood Saplings (<2.5 cm)	5.91	1.64	0.00	0.00	0.00	0.00	1.46	1.08	3.58	2.78	0.02	0.02	L****

Appendix I continued.

	Fire Intense						Fire Suppressed						
	Drain n=17		Intermediate n=18		Upland n=17		Drain n=12		Intermediate n=12		Upland n=11		
Microhabitat Variable	x	se	x	se	x	se	x	se	x	se	x	se	Significant Effects[a]
# Redbay Saplings (<2.5 cm)	5.26	1.88	0.00	0.00	0.00	0.00	9.44	5.06	0.00	0.00	0.07	0.07	L****
# Pond Pine Saplings (<2.5 cm)	0.96	0.65	0.21	0.21	0.00	0.00	0.02	0.02	0.02	0.02	0.00	0.00	
# Loblolly Pine Saplings (<2.5 cm)	0.07	0.05	0.01	0.01	0.00	0.00	0.08	0.06	0.52	0.48	0.23	0.14	T*
# Black Cherry Saplings (<2.5 cm)	0.75	0.56	0.04	0.04	0.00	0.00	0.48	0.48	0.00	0.00	0.00	0.00	L*
# Southern Red Oak Saplings (<2.5 cm)	0.03	0.03	0.00	0.00	0.00	0.00	0.25	0.19	0.38	0.31	0.00	0.00	
# Bluejack Oak Saplings (<2.5 cm)	0.90	0.43	3.85	1.82	3.78	2.77	0.13	0.09	1.31	0.64	2.34	1.29	
# Turkey Oak Saplings (<2.5 cm)	3.47	1.79	23.42	4.90	19.38	6.33	1.92	1.55	8.92	3.38	21.93	9.44	T*, L***
# Sandpost Oak Saplings (<2.5 cm)	0.09	0.07	1.63	0.94	0.28	0.17	0.06	0.04	0.31	0.31	0.05	0.03	
# Blackjack Oak Saplings (<2.5 cm)	4.21	1.05	5.88	1.68	1.65	0.94	2.00	0.89	2.56	0.93	3.16	2.23	L*
# Post Oak Saplings (<2.5 cm)	1.01	0.61	3.00	1.39	1.25	1.16	0.71	0.38	2.54	1.78	0.82	0.72	
# Sassafras Saplings (<2.5 cm)	0.88	0.73	0.17	0.11	0.15	0.07	0.00	0.00	1.33	1.16	0.55	0.50	
# Hickory Saplings (>2.5-8 cm)	0.00	0.00	0.04	0.04	0.00	0.00	0.10	0.06	0.13	0.06	0.39	0.29	T***
# Flowering Dogwood Saplings (>2.5-8 cm)	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.06	0.04	0.03	0.05	0.05	T**
# Persimmon Saplings (>2.5-8 cm)	0.07	0.06	0.15	0.10	0.04	0.03	0.04	0.04	0.06	0.04	0.09	0.05	
# Sweetgum Saplings (>2.5-8 cm)	0.03	0.02	0.15	0.15	0.00	0.00	0.48	0.31	0.13	0.13	0.09	0.07	T*
# Sweetbay Magnolia Saplings (>2.5-8 cm)	0.40	0.22	0.00	0.00	0.00	0.00	0.10	0.07	0.00	0.00	0.00	0.00	L**
# Sourwood Saplings (>2.5-8 cm)	0.24	0.10	0.00	0.00	0.00	0.00	0.13	0.10	0.06	0.06	0.00	0.00	L***
# Redbay Saplings (>2.5-8 cm)	0.07	0.05	0.00	0.00	0.00	0.00	0.29	0.23	0.00	0.00	0.00	0.00	L***
# Loblolly Pine Saplings (>2.5-8 cm)	0.04	0.03	0.00	0.00	0.00	0.00	0.52	0.31	0.04	0.03	0.91	0.60	T****
# Bluejack Oak Saplings (>2.5-8 cm)	0.00	0.00	0.29	0.25	0.12	0.12	0.00	0.00	0.17	0.09	0.32	0.24	L*
# Turkey Oak Saplings (>2.5-8 cm)	0.32	0.17	1.33	0.59	0.59	0.23	0.10	0.10	2.04	0.92	2.18	0.84	L**

Appendix I continued.

	Fire Intense						Fire Suppressed						
	Drain n=17		Intermediate n=18		Upland n=17		Drain n=12		Intermediate n=12		Upland n=11		
Microhabitat Variable	x	se	x	se	x	se	x	se	x	se	x	se	Significant Effects[a]
# Sandpost Oak Saplings (>2.5-8 cm)	0.00	0.00	0.18	0.14	0.01	0.01	0.00	0.00	0.19	0.19	0.14	0.09	
# Blackjack Oak Saplings (>2.5-8 cm)	0.24	0.08	0.31	0.14	0.15	0.12	0.50	0.20	0.60	0.20	0.82	0.35	T*
# Post Oak Saplings (>2.5-8 cm)	0.04	0.03	0.04	0.04	0.03	0.02	0.35	0.29	0.38	0.33	0.32	0.20	T*
# Alder Saplings (<8 cm)	2.46	1.39	0.00	0.00	0.00	0.00	2.73	1.68	0.00	0.00	0.00	0.00	L****
# American Holly Saplings (<8 cm)	0.32	0.21	0.00	0.00	0.00	0.00	0.19	0.09	0.00	0.00	0.00	0.00	L****
# Sourgum Saplings (<8 cm)	0.21	0.16	0.00	0.00	0.00	0.00	0.40	0.14	0.00	0.00	0.02	0.02	T**, L****, I*
# Black Oak Saplings (<8 cm)	0.01	0.01	0.19	0.19	0.00	0.00	0.19	0.13	0.06	0.06	0.70	0.47	T*
# Water Oak Saplings (<8 cm)	0.15	0.15	0.00	0.00	0.00	0.00	1.75	1.24	1.00	0.70	0.07	0.07	T*
# Sweetleaf Saplings (<8 cm)	2.54	0.91	0.01	0.01	0.12	0.12	2.63	2.08	4.21	3.92	1.43	1.43	L**
# Poison Sumac Saplings (<8 cm)	1.63	0.36	0.01	0.01	0.00	0.00	0.44	0.15	0.00	0.00	0.00	0.00	T*, L****, I*
# Red Maple Trees (8-23 cm)	0.66	0.31	0.00	0.00	0.00	0.00	1.73	0.51	0.00	0.00	0.00	0.00	T**, L****, I**
# Hickory Trees (8-23 cm)	0.12	0.09	0.08	0.08	0.01	0.01	0.19	0.11	0.63	0.29	0.23	0.11	T****
# Flowering Dogwood Trees (8-23 cm)	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.14	0.35	0.20	0.95	0.68	T****
# Sourgum Trees (8-23 cm)	0.37	0.20	0.00	0.00	0.00	0.00	1.71	0.59	0.08	0.04	0.02	0.02	T****, L****, I*
# Redbay Trees (8-23 cm)	0.09	0.04	0.00	0.00	0.00	0.00	0.25	0.14	0.00	0.00	0.00	0.00	L****
# Pond Pine Trees (8-23 cm)	0.91	0.33	0.06	0.04	0.00	0.00	1.19	0.66	0.02	0.02	0.00	0.00	L****
# Bluejack Oak Trees (8-23 cm)	0.00	0.00	0.08	0.05	0.03	0.02	0.02	0.02	0.42	0.18	0.30	0.15	T*, L*
# Turkey Oak Trees (8-23 cm)	0.18	0.08	0.94	0.44	0.37	0.17	0.40	0.27	3.06	1.43	1.91	0.74	L*
# Blackjack Oak Trees (8-23 cm)	0.38	0.11	0.51	0.27	0.01	0.01	0.88	0.30	1.73	0.60	2.95	1.41	T**
# Water Oak Trees (8-23 cm)	0.09	0.07	0.01	0.01	0.00	0.00	0.17	0.12	0.15	0.15	0.02	0.02	
# Post Oak Trees (8-23 cm)	0.15	0.08	0.11	0.10	0.04	0.03	0.08	0.05	0.60	0.24	0.66	0.50	T*
# Black Oak Trees (8-23 cm)	0.07	0.04	0.01	0.01	0.00	0.00	0.21	0.15	0.27	0.19	0.48	0.43	T**

Appendix I continued.

	Fire Intense						Fire Suppressed						
	Drain n=17		Intermediate n=18		Upland n=17		Drain n=12		Intermediate n=12		Upland n=11		
Microhabitat Variable	x	se	x	se	x	se	x	se	x	se	x	se	Significant Effects[a]
# Snags (12-23 cm)	0.10	0.05	0.04	0.03	0.03	0.03	0.23	0.10	0.15	0.08	0.16	0.07	T*
# Red Maple Trees (>23-38 cm)	0.04	0.02	0.00	0.00	0.00	0.00	0.13	0.07	0.00	0.00	0.00	0.00	L***
# Hickory Trees (>23-38 cm)	0.03	0.02	0.03	0.02	0.00	0.00	0.02	0.02	0.02	0.02	0.00	0.00	
# Sweetgum Trees (>23-38 cm)	0.01	0.01	0.00	0.00	0.00	0.00	0.27	0.13	0.04	0.04	0.07	0.07	T**
# Turkey Oak Trees (>23-38 cm)	0.00	0.00	0.04	0.02	0.04	0.03	0.00	0.00	0.21	0.17	0.09	0.07	
# Blackjack Oak Trees (>23-38 cm)	0.04	0.03	0.03	0.02	0.00	0.00	0.08	0.06	0.21	0.14	0.05	0.05	
# Post Oak Trees (>23-38 cm)	0.03	0.03	0.00	0.00	0.00	0.00	0.06	0.04	0.17	0.08	0.09	0.05	T***
# Longleaf Pine Trees (>38 cm)	1.01	0.17	1.33	0.18	1.31	0.25	0.44	0.22	0.31	0.13	0.30	0.09	T****
# Pond Pine Trees (>38 cm)	0.31	0.09	0.03	0.02	0.00	0.00	0.25	0.14	0.02	0.02	0.00	0.00	L****
# Loblolly Pine Trees (>38 cm)	0.22	0.09	0.03	0.03	0.00	0.00	0.54	0.18	0.54	0.32	0.16	0.09	T**, L**
# Yellow Poplar Trees (>8 cm)	0.04	0.03	0.00	0.00	0.00	0.00	0.04	0.03	0.02	0.02	0.00	0.00	
# Sandpost Oak Trees (>8 cm)	0.09	0.05	0.00	0.00	0.00	0.00	0.23	0.16	0.06	0.06	0.02	0.02	L*

[a] Codes and asterisks indicate significance: T=fire treatment effect; L=location effect; I=interaction effect; *=p<0.05; **=p<0.01; ***=p<0.001; ****=p<0.0001

Appendix II. Formulas for the classification summary rates for testing the logistic regression models.

% Correct = (# correct predictions / n)*100, where n = sample size

% Sensitivity = (# correct presence predictions / # observed presence)*100

% Specificity = (# correct absence predictions / # observed absence)*100

% False Presence = (# false presence predictions / # presence predictions) *100

% False Absence = (# false absence predictions / # absence predictions) *100

Appendix III. Species-habitat MLR models developed by Krieger (1997) from data collected in 1994-1996. Information is summarized from Krieger (1997).

Species	Treatment/ Location[a]	n	Intercept	Parameter	Coefficient
Blue-gray Gnatcatcher[b]	All	65	0.41	Fire Intense	-0.16
				Fire Suppressed	0.16
				Drain	0.30
				Intermediate	-0.07
				Upland	-0.23
				%Bare Ground	0.01
				Bluejack oak (>8-23 cm)	0.35
				Hickory spp. (>23-38 cm)	0.68
Summer Tanager	All	65	0.19	Fire Intense	0.05
				Fire Suppressed	-0.05
				Drain	0.12
				Intermediate	0.01
				Upland	-0.02
				Tupelo spp. saplings (2.5-8 cm)	-0.64
				Bluejack oak saplings (2.5-8 cm)	0.10
				Turkey oak saplings (2.5-8 cm)	0.06
				Sandpost oak saplings (2.5-8 cm)	-0.33
				Loblolly pine (>8-23 cm)	-0.03
				Blackjack oak (>8-23 cm)	0.15
				Longleaf pine (>23-38 cm)	-0.03
Eastern Wood Pewee	Fire Intense/All	48	0.20	Drain	0.01
				Intermediate	0.0004
				Upland	-0.01
				%Canopy cover	-0.003
				Longleaf pine (>38 cm)	0.05

Appendix III continued.

Species	Treatment/ Location[a]	n	Intercept	Parameter	Coefficient
Red-eyed Vireo	Fire Suppressed/ All	17	-0.13	Drain	-0.09
				Intermediate	0.09
				Upland	0.01
				%Forb Cover	0.06
				Persimmon saplings (2.5-8 cm)	-0.44
				Red maple (>8-23 cm)	0.14
White-eyed Vireo	Fire Suppressed/ Drain	16	0.43	Winged sumac (2.5-8 cm)	-0.04
				Pond pine (>8-23 cm)	0.63
				Turkey oak (>8-23 cm)	-4.68
				Longleaf pine (>38 cm)	-0.21
Black-and-white Warbler[b]	Fire Suppressed/ All	17	-0.02	Drain	0.08
				Intermediate	-0.05
				Upland	-0.03
				%Bare ground	0.01
				Sweetgum saplings (2.5-8 cm)	0.33
				Sweetbay (2.5-8 cm)	0.96
Ovenbird	Fire Suppressed/ All	17	0.07	Drain	0.02
				Intermediate	-0.02
				Upland	-0.001
				%Fern Cover	0.06
				Horsesugar (<2.5 cm)	0.12
Prairie Warbler	Fire Intense/ All	48	0.10	Drain	0.04
				Intermediate	0.03
				Upland	-0.07
				%Downed logs	0.04
				Tulip poplar (>23-38 cm)	-0.69
				Pond pine (>38 cm)	0.93

Appendix III continued.

Species	Treatment/ Location[a]	n	Intercept	Parameter	Coefficient
Bachman's Sparrow	Fire Intense/ All	48	-0.14	Drain	0.06
				Intermediate	-0.06
				Upland	0.003
				%Grass Cover	0.01
				Longleaf pine (>23-38 cm)	0.04
Eastern Towhee	Fire Intense/ Drain	16	-0.21	Litter depth	0.09
				Red maple saplings (<2.5 cm)	0.04
				Longleaf pine (>38 cm)	0.23
Acadian Flycatcher[b]	All/Drain	22	0.49	Fire Intense	-0.31
				Fire Suppressed	0.31
				Sourwood saplings (2.5-8 cm)	-0.21
				Blackjack oak (>8-23 cm)	-0.41
				Tupelo spp. (>38 cm)	0.59
				White oak (>38 cm)	0.94
Great Crested Flycatcher	All	65	0.14	Fire Intense	0.03
				Fire Suppressed	-0.03
				Drain	0.10
				Intermediate	-0.01
				Upland	-0.09
				Red maple saplings (2.5-8 cm)	-0.06
				Sweetgum saplings (2.5-8 cm)	-0.46
				Tupelo spp (>8-23 cm)	-0.09
				White oak (>23-38 cm)	0.57
				Water oak (>23-38 cm)	2.84
				Tupelo spp. (>38 cm)	0.57

Appendix III continued.

Species	Treatment/ Location[a]	n	Intercept	Parameter	Coefficient
Tufted Titmouse	All/Drain	22	0.18	Fire Intense	-0.02
				Fire Suppressed	0.02
				%Downed logs	-0.05
				Fetterbush (<2.5 cm)	0.002
				Longleaf pine (>8-23 cm)	-0.06
				Loblolly pine (>8-23 cm)	0.05
				Red maple (>23-38 cm)	-0.17
Carolina Wren	All/Drain	22	0.16	Fire Intense	0.02
				Fire Suppressed	-0.02
				Blueberry (2.5-8 cm)	0.10
				Tupelo spp. saplings (<2.5 cm)	0.44
				Loblolly pine (>23-38 cm)	-0.11
Common Yellowthroat	All/Drain	22	0.47	Fire Intense	0.002
				Fire Suppressed	-0.002
				Greenbriar (<2.5 cm)	0.02
				Tupelo spp. saplings (<2.5 cm)	-0.81
				Sweetgum saplings (2.5-8 cm)	0.25
				Blackjack oak (>23-38 cm)	-0.45
				Loblolly pine (>38 cm)	-0.31
Hooded Warbler	All/Drain	22	0.10	Fire Intense	-0.01
				Fire Suppressed	0.01
				Sweet pepperbush (<2.5 cm)	-0.002
				Gallberry (<2.5 cm)	0.003
				Loblolly pine saplings (<2.5 cm)	0.32
				Red maple saplings (2.5-8 cm)	0.04
				Blackjack oak (>38 cm)	0.60

Appendix III continued.

Species	Treatment/ Location[a]	n	Intercept	Parameter	Coefficient
Northern Cardinal	All/Drain	22	0.11	Fire Intense	-0.02
				Fire Suppressed	0.02
				Sweet pepperbush (<2.5 cm)	-0.003
				Winged sumac (<2.5 cm)	0.04
				Blueberry spp. (2.5-8 cm)	0.07
				Blackjack oak saplings (<2.5 cm)	0.02
				Bluejack oak saplings (2.5-8 cm)	0.49

[a] Refers to the fire treatments and/or locations that model predictions are limited
[b] Census data power transformed

Appendix IV: Species-habitat models predicting the probability of occurrence by logistic regression for 19 breeding bird species of Fort Bragg, NC. Models based on n=87 count stations from 1996-1997.

	Whole Model[a]			Model Parameters			
Species	C(%)	Pr>X^2	Intercept	Variable	Parameter Estimate	Standardized Estimate[b]	Prob>X^2
Longleaf Pine Assemblage							
Eastern Wood Pewee	91.0	0.0001	-3.76	% Fern cover	-1.91	-6.22	0.0212
				Shrubs (>2.5-8 cm)	-7.22	-6.41	0.0092
				Longleaf pine (>8 cm)	0.36	0.72	0.0032
				Bracken fern	1.30	3.21	0.0076
				Blueberry spp. (<2.5 cm)	0.49	2.71	0.0129
				Southern red oak saplings (<2.5 cm)	9.63	2.54	0.0074
Brown-headed Nuthatch	87.5	0.0001	1.97	Trees (8-23 cm)	-0.38	-1.50	0.0003
				Huckleberry (<2.5 cm)	0.04	0.94	0.0082
				Red chokeberry (<2.5 cm)	-4.65	-1.93	0.0091
				Hickory spp. (8-23 cm)	2.06	0.57	0.0108
				Hickory spp. (>23-38 cm)	-10.21	-0.36	0.0445
				Titi (<8 cm)	2.05	0.59	0.0590
Prairie Warbler	88.7	0.0001	-2.93	Slope	0.19	0.33	0.0433
				Saplings (<2.5 cm)	0.04	0.55	0.0100
				Longleaf pine saplings (<8 cm)	1.32	0.55	0.0219
				Other species trees[c]	-0.40	-1.18	0.0007
				Longleaf pine (>38 cm)	1.24	0.58	0.0064
Bachman's Sparrow	97.7	0.0001	-10.58	% Grass cover	0.31	1.82	0.0025
				% Shrub cover	0.35	2.93	0.0034
				Tree species richness	-1.94	-3.20	0.0080
				Cane	-0.04	-1.18	0.0986

Appendix IV continued.

	Whole Model[a]			Model Parameters			
Species	C(%)	Pr>X^2	Intercept	Variable	Parameter Estimate	Standardized Estimate[b]	Prob>X^2
Fire Suppressed Assemblage							
Tufted Titmouse	78.5	0.0003	-1.93	Trees (>38 cm)	0.65	0.34	0.0206
				Sassafras saplings (<2.5 cm)	0.49	0.57	0.1411
				Fetterbush (<8 cm)	0.06	0.64	0.0071
				American holly saplings (<8 cm)	-3.95	-0.90	0.0907
				Blackjack oak (>23-38 cm)	3.71	0.45	0.1089
Blue-gray Gnatcatcher	94.3	0.0001	-4.60	Slope	0.40	0.71	0.0111
				Canopy cover	-0.12	-0.95	0.0083
				Canopy height	0.53	1.15	0.0007
				Trees (>23-38 cm)	-0.78	-0.78	0.0020
				Other pine species saplings (< 8 cm)	1.32	1.30	0.1432
				Tree species richness	1.03	1.70	0.0001
				Huckleberry (<2.5 cm)	-0.03	-0.85	0.0046
				Black oak saplings (<8 cm)	-4.37	-1.71	0.1009
Red-eyed Vireo	98.9	0.0001	-13.85	% Bare ground	-0.53	-3.62	0.0069
				Tree species richness	2.73	4.51	0.0030
				Low gallberry holly (<2.5 cm)	0.07	1.97	0.0157
				Blackjack oak saplings (<2.5 cm)	-1.16	-3.36	0.0035
				Pond pine (8-23 cm)	-6.72	-4.17	0.0247
				Turkey oak (8-23 cm)	1.20	1.57	0.0072
				Black oak saplings (<8 cm)	3.56	1.40	0.0139
				Tulip poplar (>8 cm)	-32.08	-1.31	0.0216

Appendix IV continued.

	Whole Model[a]			Model Parameters			
Species	C(%)	Pr>X^2	Intercept	Variable	Parameter Estimate	Standardized Estimate[b]	Prob>X^2
Black-and-white Warbler	97.3	0.0001	-31.80	Slope	0.56	1.00	0.0115
				Canopy height	1.54	3.36	0.0048
				% Leaf litter	-0.13	-1.25	0.0213
				Turkey oak saplings (<2.5 cm)	0.09	1.08	0.0845
				Bluejack oak saplings (>2.5-8 cm)	5.41	1.80	0.0058
				Turkey oak (8-23 cm)	1.84	2.42	0.0034
				Sweetgum (>23-38 cm)	5.70	0.65	0.0109
				Blackjack oak (>23-38 cm)	26.45	3.24	0.0018
				Water oak saplings (<8 cm)	2.28	2.38	0.0028
Ovenbird	94.8	0.0001	-14.05	Canopy height	0.50	1.10	0.0188
				Other pine species trees (>8 cm)	0.23	0.72	0.0011
				Flowering dogwood saplings (>2.5 cm)	11.92	0.66	0.1261
				Hickory spp. (8-23 cm)	4.27	1.18	0.0009
				Turkey oak (>23-38 cm)	5.41	0.72	0.0147
				Post oak (>23-38 cm)	-22.36	-1.81	0.0239
Drain Assemblage							
Carolina Wren	89.1	0.0001	-2.77	Pond pine (>38 cm)	9.17	1.40	0.0261
				Sourwood saplings (>2.5-8 cm)	11.02	1.50	0.0251
				Red maple saplings (<2.5 cm)	0.59	1.43	0.0057
				Coast pepperbush (<2.5 cm)	-0.08	-1.55	0.0444
				Red maple (>23-38 cm)	59.52	3.32	0.1310
				Turkey oak (>23-38 cm)	2.42	0.32	0.0873
				Redbay saplings (>2.5-8 cm)	-18.37	-3.12	0.1250
White-eyed Vireo	98.9	0.0001	-20.12	% Forb cover	0.46	1.62	0.1217
				% Fern cover	0.78	2.55	0.0982
				Sweetbay magnolia saplings (<2.5 cm)	1.73	2.19	0.0896
				Sourwood saplings (>2.5-8 cm)	10.90	1.48	0.0895
				Sourgum saplings (<8 cm)	11.32	2.29	0.1104

Appendix IV continued.

	Whole Model[a]			Model Parameters			
Species	C(%)	Pr>X^2	Intercept	Variable	Parameter Estimate	Standardized Estimate[b]	Prob>X^2
Common Yellowthroat	98.8	0.0001	-8.83	% Shrub cover	0.72	6.08	0.0038
				Saplings (>2.5-8 cm)	-1.51	-2.99	0.0074
				Other pine trees (>8 cm)	-1.20	-3.83	0.0074
				Sapling species richness	-0.86	-1.82	0.0360
				Bracken fern	2.07	5.12	0.0034
				Flowering dogwood saplings (<2.5 cm)	3.22	1.69	0.0060
				Sandpost oak saplings (<2.5 cm)	-3.07	-3.28	0.0037
				Blackjack oak saplings (<2.5 cm)	0.66	1.90	0.0054
				Turkey oak (8-23 cm)	-3.74	-4.93	0.0064
				Hickory spp. (>23-38 cm)	65.51	2.30	0.0051
Hooded Warbler	93.0	0.0001	-14.00	Canopy height	0.54	1.18	0.0140
				Sweetbay magnolia saplings (<2.5 cm)	0.32	0.41	0.0907
				Redbay saplings (>2.5-8 cm)	13.30	2.26	0.0431
				Bluejack oak saplings (>2.5-8 cm)	1.98	0.66	0.0047
				Sourgum saplings (<8 cm)	2.07	0.42	0.0193
Northern Cardinal	93.7	0.0001	-3.71	Common waxmyrtle (<2.5 cm)	-0.60	-0.85	0.0723
				Bluejack oak saplings (>2.5-8 cm)	1.23	0.41	0.0182
				Red maple (8-23 cm)	-3.09	-1.77	0.1866
				Pond pine (>38 cm)	8.46	1.29	0.0005
				Loblolly pine (>38 cm)	4.43	1.31	0.0008
				American holly saplings (<8 cm)	2.58	0.59	0.0276
				Sandpost oak (>8 cm)	5.19	0.70	0.0070

Appendix IV continued.

	Whole Model[a]			Model Parameters			
Species	C(%)	Pr>X^2	Intercept	Variable	Parameter Estimate	Standardized Estimate[b]	Prob>X^2
Eastern Towhee	91.3	0.0001	0.86	Slope	0.24	0.43	0.0345
				Canopy height	-0.33	-0.72	0.0276
				Trees (>38 cm)	1.48	0.77	0.0067
				Bracken fern	0.20	0.50	0.0585
				Bluejack oak saplings (<2.5 cm)	0.15	0.53	0.0809
				Red maple (8-23 cm)	6.12	3.51	0.0068
				Pond pine (>38 cm)	12.37	1.89	0.0108
Generalists							
Great Crested Flycatcher	78.7	0.0010	2.00	Trees (8-23 cm)	0.18	0.71	0.0025
				Longleaf pine (>8 cm)	-0.20	-0.41	0.0220
				Tree species richness	-0.60	-0.99	0.0005
				Blackjack oak (>23-38 cm)	5.56	0.68	0.0658
				Poison sumac saplings (<8 cm)	1.09	0.55	0.0104
Blue Jay	88.8	0.0001	-2.32	Litter depth	0.69	0.54	0.0056
				% Shrub cover	-0.13	-1.11	0.0259
				Staggerbush (<2.5 cm)	0.26	0.71	0.1537
				Loblolly pine saplings (2.5-8 cm)	2.64	1.23	0.0557
				Titi saplings (<8 cm)	2.12	0.61	0.0685
Carolina Chickadee	82.3	0.0008	0.70	Shrubs (2.5-8 cm)	-0.93	-0.83	0.0222
				Cane	0.03	1.01	0.0270
				Red chokeberry (<2.5 cm)	1.71	0.71	0.0573
				% Grass cover	-0.07	-0.42	0.0205
				Persimmon saplings (<2.5 cm)	0.11	0.26	0.0664
				Loblolly pine (>38 cm)	-1.81	-0.53	0.0303
				Sweetleaf saplings (<8 cm)	-0.27	-0.90	0.1402

Appendix IV continued.

	Whole Model[a]			Model Parameters			
Species	C(%)	Pr>X^2	Intercept	Variable	Parameter Estimate	Standardized Estimate[b]	Prob>X^2
Summer Tanager	88.8	0.0002	-1.42	Slope	0.17	0.30	0.1387
				Longleaf pine saplings (<8 cm)	1.13	0.47	0.0637
				Other pine species trees (>8 cm)	-0.22	-0.69	0.0326
				Huckleberry (<2.5 cm)	0.02	0.60	0.0534
				Sandpost oak saplings (<2.5 cm)	-1.10	-1.18	0.0824
				Turkey oak saplings (>2.5-8 cm)	0.55	0.63	0.0320
				Snags (8-23 cm)	9.23	1.16	0.0529
				Sweetgum (23-38 cm)	6.87	0.78	0.0578

[a] C=% concordant (concordance between predictions and observations); Pr> $\mathscr{X}^2$=Wald $\mathscr{X}^2$ value

[b] Standardized estimate of the parameter coefficient can be used to compare relative importance of model parameters

[c] excludes all pine species

Appendix V: Species-habitat models predicting relative abundance by multiple linear regression for 19 breeding bird species of Fort Bragg, NC (1996-1997). For each species, zero count data were excluded from regression analysis.

	Whole Model				Model Parameters		
Species[a]	n	Adj. R^2/ CV[b] (%)	Prob>F	Intercept	Variable	Coefficient	Prob>F
Longleaf Pine Assemblage							
Eastern Wood Pewee	21	0.55 / 4.3	0.0017	0.76	% Bare ground	0.004	0.0066
					Trees (>23-38 cm)	0.01	0.0362
					Bluejack oak saplings (<2.5 cm)	0.002	0.0179
					Post oak saplings (>2.5-8 cm)	0.17	0.0081
Brown-headed Nuthatch	40	0.51 / 13.2	0.0001	1.30	Slope	-0.02	0.0217
					Litter depth	-0.04	0.0227
					% Fern cover	-0.01	0.0149
					Persimmon saplings (<2.5 cm)	0.01	0.0474
					Hickory spp. (8-23 cm)	-0.08	0.0348
					Turkey oak (8-23 cm)	-0.07	0.0001
					Turkey oak (>23-38 cm)	0.48	0.0387
Prairie Warbler	40	0.51 / 9.1	0.0001	0.79	% Shrub cover	0.01	0.0011
					Saplings (>2.5-8 cm)	0.01	0.0229
					Red chokeberry (<2.5 cm)	-0.11	0.0123
					Blueberry spp. (<2.5 cm)	-0.02	0.0001
					Pond pine saplings (<2.5 cm)	0.02	0.0180
					Pond pine (>38 cm)	0.50	0.0001
					Loblolly pine (>38 cm)	0.41	0.0019
					Tall gallberry holly (<8 cm)	-0.26	0.0002
Bachman's Sparrow	18	0.60 / 8.2	0.0025	1.04	% Bare ground	-0.01	0.0016
					Longleaf pine saplings (<8 cm)	0.07	0.0015
					Sapling species richness	-0.02	0.0377
					Black cherry saplings (<2.5 cm)	-0.16	0.1413

Appendix V continued.

		Whole Model			Model Parameters		
Species[a]	n	Adj. R^2/ CV[b] (%)	Prob>F	Intercept	Variable	Coefficient	Prob>F
Fire Suppressed Assemblage							
Tufted Titmouse	36	0.65 / 6.7	0.0001	0.84	% Downed logs	0.01	0.0001
					Bracken fern	0.004	0.0827
					Bluejack oak saplings (>2.5-8 cm)	0.10	0.0002
					Water oak (8-23 cm)	-0.10	0.0175
					Titi (<8 cm)	-0.63	0.0208
					Yellow poplar (>8 cm)	0.46	0.0009
Black-and-white Warbler	21	0.79 / 11.1	0.0001	0.83	Red maple saplings (<2.5 cm)	0.01	0.0003
					Pond pine saplings (<2.5 cm)	0.46	0.0135
					Sourwood saplings (>2.5-8 cm)	0.17	0.0005
					Hickory spp. (>23-38 cm)	0.81	0.0005
Blue-gray Gnatcatcher	50	0.51 / 11.1	0.0001	0.90	% Fern cover	-0.005	0.0843
					Saplings (>2.5-8 cm)	0.01	0.0097
					Cane	0.001	0.0023
					Low gallberry holly (<2.5 cm)	0.001	0.0002
					Red maple (>23-38 cm)	0.53	0.0004
					Post oak (>23-38 cm)	0.51	0.0001
					Loblolly pine (>38 cm)	-0.14	0.0004
Ovenbird	15	0.66 / 7.8	0.0006	0.85	Other pine species saplings (<8 cm)	0.04	0.0222
					Loblolly pine (>38 cm)	0.08	0.0013
Red-eyed Vireo	25	0.61 / 8.8	0.0003	0.85	Trees (>23-38 cm)	0.01	0.0725
					Cane	-0.001	0.0390
					Sweetgum saplings (<2.5 cm)	0.004	0.0402
					Flowering dogwood (>8-23 cm)	-0.05	0.0641
					Alder spp. saplings (<8 cm)	0.02	0.0004

Appendix V continued.

	Whole Model				Model Parameters		
Species[a]	n	Adj. R^2/ CV[b] (%)	Prob>F	Intercept	Variable	Coefficient	Prob>F
Drain Assemblage							
Carolina Wren	25	0.72 / 6.4	0.0001	0.78	Slope	0.02	0.0017
					Blackjack oak saplings (<2.5 cm)	0.01	0.0272
					Flowering dogwood saplings (2.5-8 cm)	-0.40	0.0090
					Blackjack oak (8-23 cm)	0.05	0.0162
					Post oak (8-23 cm)	0.41	0.0003
White-eyed Vireo	12	0.80 / 4.5	0.0010	0.82	Shrubs (2.5-8 cm)	0.02	0.0056
					Post oak (>23-38 cm)	0.19	0.0284
					Sweetleaf saplings (<8 cm)	0.01	0.0039
Common Yellowthroat	33	0.58 / 7.9	0.0001	0.88	Shrubs (2.5-8 cm)	0.02	0.0096
					Other species trees[c]	-0.02	0.0027
					Sapling species richness	0.01	0.0115
					Hickory spp. saplings (<2.5 cm)	0.08	0.0001
					Black cherry saplings (<2.5 cm)	0.02	0.0187
					Sourgum (8-23 cm)	0.06	0.0026
Hooded Warbler	16	0.78 / 4.5	0.0001	0.67	Trees (>23-38 cm)	0.02	0.0041
					Sapling species richness	0.01	0.0008
					Hickory spp. (>23-38 cm)	1.02	0.0001
Northern Cardinal	20	0.70 / 6.0	0.0001	0.68	Canopy height	0.01	0.0006
					Redbay saplings (<2.5 cm)	0.01	0.0019
					American holly saplings (<8 cm)	0.06	0.0014

Appendix V continued.

		Whole Model			Model Parameters		
Species[a]	n	Adj. R^2/ CV[b] (%)	Prob>F	Intercept	Variable	Coefficient	Prob>F
Eastern Towhee	43	0.48 / 9.0	0.0001	0.67	Canopy height	0.01	0.0039
					% Fern cover	0.004	0.0492
					Tree species richness	0.01	0.0139
					Sweetbay magnolia saplings (2.5-8 cm)	0.08	0.0010
					Sweetgum (>23-38 cm)	-0.11	0.0840
					Post oak (>23-38 cm)	-0.23	0.0513
Generalist Assemblage							
Great Crested Flycatcher	45	0.54 / 8.5	0.0001	0.80	Longleaf pine (>8 cm)	0.01	0.0002
					Common waxmyrtle (<2.5 cm)	0.03	0.0727
					Flowering dogwood saplings (<2.5 cm)	-0.04	0.0138
					Sweetgum saplings (<2.5 cm)	0.004	0.0081
					Loblolly pine saplings (2.5-8 cm)	0.03	0.0108
					Turkey oak saplings (2.5-8 cm)	0.02	0.0015
					Loblolly pine (>38 cm)	0.13	0.0023
Blue Jay	14	0.64 / 6.1	0.0014	0.83	% Forb cover	0.01	0.0188
					Longleaf pine (>8 cm)	0.01	0.0028
Carolina Chickadee	37	0.55 / 8.3	0.0001	0.96	Litter depth	-0.03	0.0154
					% Downed logs	0.01	0.0037
					Sweetgum saplings (<2.5 cm)	0.01	0.0041
					Sweetbay magnolia saplings (<2.5 cm)	0.02	0.0008
					Sourgum (8-23 cm)	0.02	0.0854

Appendix V continued.

	Whole Model				Model Parameters		
Species[a]	n	Adj. R^2/ CV[b] (%)	Prob>F	Intercept	Variable	Coefficient	Prob>F
Summer Tanager	54	0.42 / 7.6	0.0001	1.02	Canopy cover	-0.002	0.0040
					Saplings (<2.5 cm)	0.001	0.0211
					Other pine species saplings (<8 cm)	0.01	0.0291
					Black cherry saplings (<2.5 cm)	0.02	0.0067
					Hickory spp. saplings (2.5-8 cm)	-0.12	0.0611
					Persimmon saplings (2.5-8 cm)	-0.06	0.0831
					Winged sumac (<8 cm)	0.04	0.0025

[a] Relative abundance data were square-root transformed

[b] Coefficient of variation (CV) represents the quality of fit and measures spread of noise around the regression line (Myers 1990).

[c] Excludes pine species

VITA

J E N N I F E R C. A L L E N

EDUCATION

Master of Science, March 2001, Ecology, Department of Biology, Virginia Polytechnic Institute & State University, Blacksburg, Virginia

Bachelor of Science, May 1993, Wildlife Science, Department of Fisheries & Wildlife Sciences, Cum Laude, Virginia Polytechnic Institute & State University, Blacksburg, Virginia

EXPERIENCE

Stewardship Ecologist. January 2001 to present, The Nature Conservancy, Charlottesville, Virginia

- Responsible for developing and implementing biological monitoring projects to track the status of conservation targets and to measure the success of ecological restoration strategies on The Nature Conservancy preserves in Virginia; Develop monitoring methods for projects at the species, community, and landscape levels
- Responsible for developing and maintaining a database storing monitoring information, and for analyzing biological monitoring information; Write small grants to support ongoing monitoring projects for threatened, endangered, and rare species; Assist with administration of grants to support monitoring and research projects; Assist with the development of management goals for rare species and natural communities; Participate in prescribed burns and invasive species control

Chesapeake Bay Region Steward. February 1999 to January 2001, Division of Natural Heritage, Department of Conservation & Recreation, Gloucester Point, Virginia

- Responsible for the ecological management of eight state-owned natural area preserves and provided technical assistance to five natural area preserves owned by other entities
- Developed and implemented a management and monitoring plan for the invasive plant *Phragmites australis*; Prepared an assessment report on shoreline erosion for a preserve and impacts of various shoreline management strategies on a federally threatened species; Initiated database development for and analysis of public use observations at preserves
- Conducted biological monitoring of rare species and updated element occurrence records; Coordinated habitat restoration, preserve management, and research activities with federal, state, and non-government agencies and academic institutions; Participated in invasive species control and prescribed burns; Provided technical expertise to public/private organizations and private landowners; Collected scientific and historic literature, maps, and other information pertinent to resource management plans

Graduate Research Assistant. September 1995 - December 1998, Department of Biology, Virginia Polytechnic Institute & State University, Blacksburg, Virginia

- Studied habitat associations of the breeding bird community in a fire-maintained longleaf pine ecosystem at Fort Bragg, North Carolina to determine effects of longleaf pine restoration activities
- Taught Biology Laboratory course

Field Technician. May - August 1995, North Carolina Cooperative Fish & Wildlife Research Unit, Raleigh, North Carolina

- Searched for songbird nests at Fort Bragg, North Carolina; Monitored nests; Sampled vegetation and nest characteristics at each nest location

Research Assistant. January 1993 - May 1995, Virginia Cooperative Fish & Wildlife Research Unit, Blacksburg, Virginia
- DNA fingerprinting of 31 black bear populations to determine population genetic structure and subspecies status for the Louisiana and Florida populations; Assisted in training two technicians in molecular techniques; Database and laboratory management
- Assisted in trapping black bears in South Carolina and collecting biological data
- Co-authored grant proposal to The Peregrine Fund to develop population genetic markers of North American tundra breeding populations of peregrine falcons to elucidate migratory pathways for identification and conservation of migratory and wintering habitats

Field Assistant. June-July 1993, Department of Fisheries & Wildlife Sciences, Virginia Polytechnic Institute & State University, Blacksburg, Virginia
- Measured food consumption rates in a foraging and nutritional study for ruffed grouse

Undergraduate Researcher. September 1992 - May 1993, Department of Fisheries & Wildlife Sciences, Virginia Polytechnic Institute & State University, Blacksburg, Virginia
- Conducted bioelectrical impedance analysis of body fat of female black bears to study the effects of nutrition on reproductive physiology; Analyzed relationship between diet and fat deposition; Blood collection and morphological measurements of adult and juvenile bears; Preparation of technical reports; Assisted in checking female black bear dens in Shenandoah National Park, Virginia; Morphological measurements of female and juvenile bears

Volunteer Assistant. September 1992, Department of Biology, Virginia Polytechnic Institute & State University, Blacksburg, Virginia
- Checked pitfall traps and measured vegetation parameters in a study of gypsy moth defoliation effects on small mammals in Shenandoah National Park, Virginia

Volunteer Assistant. June-August 1991, U.S. Fish & Wildlife Service, Harford Glen Bird Banding Station, Harford County, Maryland
- Captured songbirds with mistnets; Identified birds and determined sex, hatch year, and breeding status; Morphological measurements

Volunteer Assistant. June 1991, Department of Fisheries & Wildlife Sciences, Virginia Polytechnic Institute & State University, Blacksburg, Virginia
- Monitored bald eagles in Blackmarsh, Maryland on the Chesapeake Bay

PROFESSIONAL PRESENTATIONS

- **J.C. Allen**, J.R. Walters, S.M. Krieger, and J.A. Collazo. 1998. Validating Species-Habitat Models for Breeding Birds in a Longleaf Pine System. North American Ornithological Conference, St. Louis, Missouri.
- **J.C. Allen**. 1997. Species-habitat relationships for the breeding birds of Fort Bragg, North Carolina. Annual Wildlife Research Meeting, Fort Bragg Military Installation, North Carolina.
- **J.C. Allen**. 1996. Bird-habitat associations and evaluating species-habitat models at Fort Bragg, North Carolina. Annual Wildlife Research Meeting, Fort Bragg Military Installation, North Carolina.