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Bats forage over calm, open water presumably because of high insect abundance, low echolocation interference, and few flight obstacles. Changes to the physical structure of water sources could be important to bats. Many wetlands in coastal North Carolina have been drained and commercial forestry is now a primary land use. Water sources within managed forests are mostly man-made ponds and ditches. I examined bats in a managed pine landscape and an adjacent natural wetland to determine how water source type and insect abundance affected commuting and foraging activity, species activity, and species diversity of bats. I collected data using remote acoustic sampling, mist nets, and passive insect traps. In 2006, total bat activity and the number of eastern red, eastern pipistrelle, and big brown bats recorded per night were higher at helipонds. In 2007, the number of eastern pipistrelle, big brown, and hoary bats recorded per night was highest at helipонds and there was a water source * insect abundance interaction. In both years, foraging activity levels and bat species diversity were similar among water sources. Helipонds appear to be an important resource for insect prey and bats in managed pine forests. Management for bats and other wildlife should include helipond maintenance.

THE INFLUENCE OF WATER SOURCE TYPE AND INSECT ABUNDANCE ON

BAT FORAGING BEHAVIOR IN A MANAGED PINE LANDSCAPE

by

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APPROVAL PAGE

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CHAPTER I

INTRODUCTION

Landscape modifications have the potential to change wildlife distributions and community structure. For example, if water source modification alters insect distribution, there is the potential for organisms at higher trophic levels to be affected. In general, after a modification, generalist plant and animal species dominate forests, while specialist plant and animal species are rare and slow to return (Woltmann 2003, Medellin et al. 2000). Forest managers are increasingly interested in the implications of landscape changes in order to determine the affect of silvicultural practices on biodiversity (Guldin et al. 2007).

Bats are potentially good indicators of environmental change (Golet et al. 2001, Clarke et al. 2005). Many bats drink from, and forage directly over, water sources (Kunz & Fenton 2003, Hayes 2004, Korine & Pinshow 2004, Menzel et al. 2005a) Bats prefer large, open, calm bodies of water (Mackey & Barclay 1989, Warren et al. 2000, Siemers et al. 2001). Riparian zones generally have higher insect abundance due to the addition of emerging aquatic insects to terrestrial systems (Jackson & Fisher 1986, Jackson & Resh 1989). Calm water produces less ultrasound interference and this facilitates hearing returning echoes used to detect prey (Mackey & Barclay 1989, Warren et al. 2000, Siemers et al. 2001). Water with low habitat complexity creates an environment that enables bats to navigate and detect prey (Mackey & Barclay 1989). Altering water sources (e.g., by draining large calm water bodies into narrow ditches) can change the characteristics of water sources and could potentially alter the foraging behavior and community structure of bats that utilize those sources.

Water sources, such as rivers and streams, can also be used as corridors for flight. Upon emerging from roosts, bats navigate to foraging grounds by flying along streams (Kalcounis & Brigham 1995, Sleep & Brigham 2003). Flyways are especially important for larger bats, which fly above, more often than within, the canopy of pine forests (Kalcounis et al. 1999, Menzel et al. 2005b). From the perspective of increased flyways, modifying large, calm bodies of water into ditches may be beneficial as increased numbers of interior ditches provides entry to less accessible interior forest habitat.

Abundant, widespread bats with no specific habitat associations, such as big brown bats (*Eptesicus fuscus*), are considered habitat generalists (Geggie & Fenton 1985, Furlonger et al. 1987, Agosta 2002) capable of using a multitude of habitat and water source types for foraging. Gleaners, such as Rafinesque's big-eared (*Corynorhinus rafinesquii*) (Menzel et al. 2005b) and northern myotis (*Myotis septentrionalis*) (Audet 1990, Caceres & Barclay 2000) bats, capture terrestrial insects from vegetation surfaces and are restricted to foraging in the interior of forests.

A large amount of information exists on the basic ecology of temperate bats (Kunz & Fenton 2003, Hayes 2004). For example, many studies have assessed bat roosting ecology in southeastern managed pine forests and found forests provide roosting habitat (e.g. Campbell et al 1996, Elmore et al. 2004, Elmore et al. 2005) and are sufficient for reproduction (e.g. Miller 2003). However, few studies have examined bat foraging behavior in managed pine forests. Although it is clear that these forests support populations with reproductive individuals (Miller 2003), we know very little about the ability of managed forests to sustain diverse bat populations (Campbell et al. 1996).

When first settled, North Carolina's Northern Coastal Plain was modified for settlement and agricultural purposes. Historically, the coastal plain consisted of wetlands, marsh forests, and pocosin habitat with large, calm bodies of water (Chescheir et al. 2003). Trees in pocosin habitat include large bald cypress (*Taxodium distichum*), and white cedars (*Chamaecyparis thyoides*) (N.C. Department of Parks and Recreation 2008). Trees in wetlands include swamp tupelo (*Nyssa sylvatica*), bald cypress (*Taxodium distichum*), tulip poplar (*Liriodendron tulipifera*), and red maple (*Acer rubrum*) (Chescheir et al. 2003). Additionally, the dominant pine species in coastal North Carolina was longleaf pine (*Pinus palustris*) (Crawford 2007).

Currently, managed pine forests make up 18% of the costal plain in the southeastern United States (Wear & Greis 2002). Similar to the rest of the southeastern United States, pine (*Pinus* species) is the primary plantation type in coastal North Carolina (Wear & Greis 2002) and, as of 2002, Southeastern pine production accounted for 60% of the total timber products made in the United States (Harvey & Lien 2005). Though managed forest acreage is not expected to increase in the future, an increase in forestry intensity (decreased rotation time) is expected within 10 to 15 years (Miller 2003, Harvey & Lien 2005).

One of the most obvious changes from natural forested wetlands to managed pine forests is the shift in available water sources. Open water sources found in natural wetlands are channeled into numerous linear ditches within managed pine forests of coastal North Carolina (Chescheir et al. 2003) . Ditches run through pine stands (henceforth referred to as "interior ditches") and along road and forest stand edges (henceforth referred to as "edge ditches"). Additionally, water from edge ditches runs into helipends. Helicopters use these sources to access water for fighting forest fires. Heliponds are large, deep, open, man-made ponds with little surrounding tall vegetation found at the corners of road intersections. Heliponds are relatively infrequent in the pine plantations landscape.

It is necessary to examine how bats are responding to modified water sources given the extent of intensively managed pine forests in the southeastern United States and the lack of data on bat foraging ecology within these landscapes. Understanding impacts of intensive pine management on bat foraging ecology will guide forest management decisions. Therefore, the purpose of my study was to determine how water source type and insect abundance in the Northern Coastal Plain of North Carolina influence bat ecology and foraging behavior within a landscape of intensively managed pine stands. I compared bat activity levels (total activity and foraging activity), species activity (number of individuals per species recorded), and species diversity among four water source types (heliponds, interior ditches, edge ditches, and natural forested wetlands). Water sources differ in insect community structure (Fukui et al. 2006) and available habitat (Hayes 2004). Therefore, my first hypothesis was that there are differences in bat activity (both total and foraging) among water source types. Some bat species are common over a wide range of habitats (Agosta 2002, Elmore et al. 2004), while others have very specific habitat requirements (Fujita & Kunz 1984, Caceres & Barclay 2000). Therefore, my second hypothesis was that there would be differences in bat species activity and bat species diversity among water source types.

CHAPTER II

METHODS

Study Area

I conducted my research southeast of Plymouth, North Carolina from June to July of 2006 and 2007 on Weyerhaeuser's Parker Tract and at the Washington County Wetland Site (Figure 1). The Parker Tract was approximately 4,000 ha of intensively managed loblolly pine (*Pinus taeda*) stands. Typical silviculture of intensively managed stands included clearcut harvest at 27-35 years old followed by site preparation, planting of loblolly pine (*Pinus taeda*) seedlings on a wide (6.1m) row spacing, vegetation control, fertilization, thinning (1 to 3 times) (Watts & Wilson 2005), and final harvest. Stands of pine monoculture were classified by structural appearance into 3 classes (Figure 2). An open canopy and substantial understory growth was characteristic of young open canopy stands (2-10 years old). Completely closed canopies and little to no understory vegetation was characteristic of closed canopy stands (9-21 years old). An open canopy and variable amounts of understory growth were characteristic of thinned stands (11-22 years old) (Miller et al. 2004). A fourth class of stands exists in the form of small, unmanaged, natural deciduous stands (Chescheir et al. 2003). Within the Parker Tract 956 ha have been set aside as part of a conservation easement between Weyerhaeuser Company and the Environmental Defense Fund (1997). In the Parker Tract, water drained into ditches was located within stands and along most roads (Figure 3). Ditches are 80 to 100m apart and 0.6 to 1.2m deep (Chescheir et al. 2003). There are also 5 heliponds, approximately 12m by 24m in size, within the Parker Tract (Figure 3).

A 350 ha remnant natural forested wetland is located adjacent to the Parker Tract (Washington County Wetland Site in Chescheir et al. 2003). I used this site as a natural water source to compare with modified water sources within the managed pine forest. Trees in the wetland site consisted manly of bald cypress (*Taxodium distichum*), red maple (*Acer rubrum*), and some loblolly pines (*Pinus taeda*) (Chescheir et al. 2003). Natural forested wetlands are inundated by water for all or most of the year (Chescheir et al. 2003).

Sampling Design

I sampled every night that there was no significant rainfall during June and July of 2006 and 2007. On each sampling night, I collected data on all dependent and independent variables. Dependent variables included bat activity (total activity and foraging activity), bat species activity (number of individuals per species recorded) and bat species diversity. I also collected data on insect abundance (number of individuals per order) which served as an independent variable along with water source type.

Throughout the study, sampling occurred within one managed pine forest (the Parker Tract) and one natural forested wetland (the Washington County Wetland Site). Each night, I simultaneously sampled 2 of the 4 water source types. I classified sampling sites as 1 of 4 sampling units (water source types): heliponds, interior ditches, edge ditches, or natural forested wetlands. Sampling of interior and edge ditches occurred in both thinned and unmanaged stands, which I considered mature because they contain the oldest trees found on the Parker Tract. Sampling in these two stands types allowed for direct comparisons with mature natural forested wetland sites (Figure 2). I selected natural forested wetland sites based on the presence of water at the beginning of the summer. Over the course of the summer, some sites dried out. Sampling continued as sites dried out to maintain the overall design of the study and because drying out is characteristic of water sources throughout the managed pine forest and natural forested wetland.

For year 1 of this study, sampling took place at 5 helipondss, 10 interior ditches, and 15 edge ditches in the managed forest. Sampling also occurred at 2 sites in the natural forested wetland. During the first year, I repeatedly sampled the same helipondss and natural forested wetland sites, while I randomly sampled interior ditch and edge ditch sites. During the second year, I repeatedly sampled all water source types. I sampled 5 helipondss, 5 interior ditches, and 5 edge ditches in the managed pine forest. I sampled 3 natural forested wetland sites in the natural forested wetland. All helipondss from the first year were re-sampled the second year. I randomly selected interior and edge ditch sampling sites for the second year of study from among the first year sampling sites. Natural forested wetland sites for the second year included two sites from the first year and 1 additional site.

Data Collection

At each site, bat echolocation calls were recorded with 2 Pettersson D240x (Pettersson Elektronik AB, Uppsala, Sweden) ultrasonic detectors. I used 2 detectors because echolocation calls can provide data on the activity of bats as calls are produced and the particular species producing calls (e.g. Kalcounis-Rueppell et al. 2007). I attached a digital sound recorder to each sound activated detector using a stereo-to-stereo cable and placed both into a watertight Ruppermaid container. A hole was predrilled into the container to expose the detector microphone (Kalcounis-Rueppell et al. 2007). The microphone was flush with the hole and held in place with lab tape. I placed sealed containers inside a wooden rain guard constructed to hold microphones at a 45° angle from the ground. I affixed rain guards to trees or poles approximately 1.5m off the ground. Microphones were pointed directly at or along water sources to minimize interference of vegetation on the detection of bats (Johnson et al. 2002, Patriquin et al. 2003). All detectors were set to record from dusk until dawn.

I used 1 of the 2 bat detectors to record all echolocation calls, in real time, of bats as they flew past the microphone (henceforth referred to as bat activity recordings). Detectors were set in heterodyne mode at 40 kHz and were most sensitive to echolocation calls between 35 and 45 kHz (Pettersson Elektronik). After recording continuously through the night, I downloaded files from recorders to computers using Sony Digital Voice Editor Software® (Sony Corporation of America, New York, USA). I categorized echolocation sequences as commuting sequences (search phase calls) or foraging sequences (containing feeding buzzes) (Griffin et al. 1960, Fukui et al. 2006). I assumed that each sequence represented 1 individual. Only sequences with ≥ 3 clear, audible echolocation calls were analyzed and sequences were considered separate if there was a ≥ 1 second gap between 2 elements (Johnson et al. 2002, Kalcounis-Rueppell et al. 2007). Total bat activity equaled the total number of passes recorded (both commuting and foraging) per night. Foraging activity (proportion of time bats spent foraging) was determined by dividing number of foraging passes recorded per night by total number of passes recorded (total bat activity) per night.

The second detector was set in time-expanded mode (henceforth referred to as species activity recordings) which recorded high quality full spectrum calls that retained nearly all characteristics of the original call to facilitate species identification (Pettersson Elektronik). These detectors recorded periodically throughout the night (because of the time expansion) and, in the morning, I downloaded files from recorders to computers using iRiver® Music Manager Software. I analyzed full spectrum echolocation calls using SONOBAT® software (DNDesign, Arcata, CA) to determine which bat species produced the call. I assumed that each sequence of calls represented 1 individual. I qualitatively compared variables of recorded calls, such as duration, maximum and minimum frequency and frequency at maximum amplitude, to reference echolocation calls to determine species identity (see Kalcounis-Rueppell et al. 2007). I obtained reference echolocation calls from a library of calls collected from other studies and including calls collected from bats captured in this study (see below). For most calls, species identification was possible. I grouped *Myotis* species (*M. austroriparius* and *M. septentrionalis*) together because overlapping characteristics of *Myotis* species echolocation calls made species identification difficult. Bat species activity was determined as the number of species activity recordings identified per species or species group per night. I calculated a diversity index for each site per night using species activity data. The Shannon-Weiner Function of Diversity was calculated from the formula: $H' = -\Sigma\, p_i \ln p_i$, where H' = diversity and p_i = the proportion of a specific species found at a sampling site (number individuals in a species divided by total number of bats recorded at that site) (Krebs 1989).

I used mist netting to confirm bat species presence and obtain reference echolocation calls from bats in the study area. Mist netting occurred on the same nights as acoustic and insect sampling. Netting occurred at one site per night and took place at a site different from acoustic and insect sampling to avoid interfering with passive sampling equipment. Mist netting efforts were concentrated at heliponds and within the natural forested wetland to increase the likelihood of capturing bats. Nets (from 2 to 6 per night of sizes varying from 2.6m, 6m, 12m 4 shelf nets; 38.0 mm mesh, Avinet, Inc. Dryden, New York; USA) were set out at dusk and monitored in 10 to 20-minute intervals. Bats were removed from nets and identified to species using standard characteristics including fur color, forearm length (mm), mass (g), and ear/tragus shape and length (mm). Upon release, record reference calls to a reference call library (see above). All bat capture and handling protocols followed animal care guidelines of the American Society of Mammalogists, the UNCG Institutional Animal Care and Use Committee Protocol #06-11, and the Wildlife Resources Commission of the State of North Carolina.

I used a single malaise trap at each site every night to sample available insect prey. I set traps over the vegetation within 2m of the edge of the water. In the morning, I removed captured insects from traps and stored them in 80% ethanol. Insects were identified to Order using an Olympus SZ30 dissecting microscope (magnification ranging from 9x – 40x) (Olympus America, Inc. Center Valley, PA) and a dichotomous key of American insects (Arnett 2000). Total insect abundance was the sum of individual insects from each order per night. To use insect abundance as a categorical variable, I categorized sites as having low, medium, or high total insect abundance as follows: low = 0 to 99 insects, medium = 100 to 199 insects, and high = 200+ insects.

Statistical Analyses

Normality and homogeneity of variance of data were examined using box plots, skewness, frequency histograms, and Kolmogorov-Smirnov Tests (SPSS version 15.0, SPSS, Inc., Chicago, IL). Four of the 10 variables (total bat activity, bat foraging activity, counts of *Lasiurus borealis*, and bat species diversity) departed from univariate normal distribution and were natural log transformed to normalize distributions before analyses were conducted.

I analyzed data from 2006 and 2007 separately because of sampling design differences between years (see Sampling Design). To test my hypotheses about bat activity (both total and foraging), bats species activity, and bat species diversity, I analyzed data from 2006 using a multivariate analysis of variance (MANOVA). Dependent variables included total bat activity (total number of sequences analyzed), foraging activity (proportion of time bats spent foraging), bat species activity of 6 bat species and 1 species group (number of calls identified per species), and bat species diversity. Categorical independent variables included water source type (helipons, interior ditches, edge ditches, and natural forested wetlands) and total insect abundance (low, medium, and high). The MANOVA produced an overall model that examined the effects of water source type, total insect abundance, and the water source type * total insect abundance interaction on a composite of my dependent variable. If the overall model showed significant effects (main effects or interaction), I further examine dependent variables individually using univariate ANOVA's and Tukey Post-Hoc tests on the same data from the MANOVA model. Post-Hoc tests were only run for significant main effects.

To test my hypotheses on bat activity (both total and foraging), bats species activity, and bat species diversity, I analyzed data from 2007 using a multivariate repeated measures analysis. As in 2006, dependent variables included total bat activity (total number of sequences analyzed), foraging activity (proportion of time bats spent foraging), bat species activity of 6 bat species and 1 species group (number of calls identified per species) and species diversity. Categorical independent variables were water source type (heliponds, interior ditches, edge ditches, and natural forested wetlands) and insect abundance (low, medium, and high). The multivariate repeated measures analysis produced an overall Between-Subjects Effects table of the main effects of water source type, total insect abundance, and water source type * total insect abundance interaction on a composite of my dependent variables. If the Between-

Subjects Effects (main effects or interactions) were significant, I further examined individual dependent variables using univariate ANOVA's and Tukey Post-Hoc tests on the same data from the multivariate repeated measures analysis. Post-Hoc tests were only run for significant main effects.

CHAPTER III

RESULTS

Sampling Results

Full and complete acoustic and insect sampling from 2006 resulted in 11 nights of sampling from 5 heliponds, 18 nights of sampling from 10 interior ditch sites, 20 nights of sampling from 15 edge ditch sites, and 10 nights of sampling from 2 natural forested wetland sites (Figure 4). Full and complete acoustic and insect sampling from 2007 resulted in 17 nights of sampling from 5 heliponds, 20 nights of sampling from 5 interior ditch sites, 14 nights of sampling from 5 edge ditch sites, and 18 nights of sampling from 3 natural forested wetland sites (Figure 4).

Activity recordings yielded 45,810 (14,722 from 2006 and 31,088 from 2007) analyzable echolocation sequences used to determine total bat activity and foraging activity. Species activity recordings yielded 10,504 (3,701 from 2006 and 6,803 from 2007) analyzable echolocation sequences used to identify the presence of 6 species and 1 species group (Table 1). I recorded all bat species at all water source types (Table 1). Not all species identified through recordings were captured in mist nets and not all species that were captured in mist nets were recorded. I captured 143 bats in mist nets representing 6 species (Table 2). *Myotis septentrionalis* were only caught over natural forested wetlands, while eastern pipistrelle bats (*Perimyotis subflavus*) were only caught over helipods (Table 2).

I collected 17,482 insects (8,524 from 2006 and 8,958 from 2007) in malaise traps. Both terrestrial and emerging aquatic insects were represented in the sample. The majority of insects captured belonged to the order Diptera. Other abundant orders included Coleoptera, Lepidoptera, Hemiptera, Homoptera, and Hymenoptera (Table 3). Less abundant (rare) orders included, but were not limited to, Orthoptera, Odonata, and Neuroptera. I captured all major insect orders, but not all rare orders, at all water source types.

Activity Levels and Bat Species Activity

In 2006 there was a significant effect of water source type (Wilks' Lambda = 0.353, $F_{30, 112}$ = 1.592, p = 0.043) on the composite dependent variable. There was no effect of total insect abundance (Wilks' Lambda = 0.698, $F_{20, 76}$ = 0.748, p = 0.764) on the composite dependent variable. There was no water source type * total insect abundance interaction (Wilks' Lambda = 0.226, $F_{60, 204}$ = 0.283, p = 0.132) effect on the composite dependent variable.

In 2006, there was a water source type effect on 4 of 10 dependent variables: total bat activity and the number of eastern red (*Lasiurus borealis*), eastern pipistrelle (*Perimyotis subflavus*), and big brown (*Eptesicus fuscus*) bats recorded per night. Total bat activity was higher at helipods than interior ditches and natural forested wetlands (ANOVA $F_{3, 55}$ = 4.416, p = 0.008; Figure 5, Table 4). The number of eastern red bats recorded per night was higher at heliponds than interior ditches and natural forested wetlands (ANOVA $F_{3, 55} = 6.437$, $p < 0.001$; Figure 6, Table 4). The number of eastern pipistrelle bats recorded per night was higher at heliponds compared to the other water sources (ANOVA $F_{3, 55} = 4.125$, $p = 0.011$; Figure 7, Table 4). The number of big brown bats recorded per night was higher at heliponds than interior ditches and natural forested wetlands (ANOVA $F_{3, 55} = 3.165$, $p = 0.033$; Figure 8, Table 4). Bat foraging activity (ANOVA $F_{3, 55} = 0.101$, $p = 0.959$), bat species diversity (ANOVA $F_{3, 55} = 0.955$, $p = 0.422$) and the number of evening (*Nycticeius humeralis*) (ANOVA $F_{3,55} = 0.729$, $p = 0.540$), Brazilian free-tailed (*Tadarida brasiliensis*) (ANOVA $F_{3, 55} = 0.320$, $p = 0.811$), hoary (*Lasiurus cinereus*) (ANOVA $F_{3, 55} = 0.279$, $p = 0.841$), and *Myotis* species (ANOVA $F_{3, 55} = 0.767$, $p = 0.422$) bats recorded per night did not differ among water sources.

In 2007, there was a significant effect of water source type (Between-Subjects Effects $F_{3, 53} = 16.642$, $p < 0.001$) and total insect abundance (Between-Subjects Effects $F_{2, 54} = 3.768$, $p = 0.029$) on the composite dependent variable. There was a significant water source type * total insect abundance interaction effect on the composite dependent variable (Between-Subjects Effects $F_{6, 50} = 3.919$, $p = 0.002$). The significant interaction suggests that at different water source types, bats do not respond to insect abundance in the same way.

In 2007, there was a water source type*total insect abundance interaction effect on 3 of 10 dependent variables: the number of eastern pipistrelle (ANOVA $F_{6, 50} = 3.557$, $p = 0.005$; Figure 9, Table 4), big brown (ANOVA $F_{6,50} = 4.017$, $p = 0.002$; Figure 10,

Table 4), and hoary (ANOVA $F_{6, 50} = 6.055$, $p = 0.001$; Figure 11, Table 4) bats recorded per night. At helipond, as insect abundance increased so did the number of eastern pipistrelle bats recorded per night (Figure 9). On the other hand, a relationship between insect abundance and eastern pipistrelle activity at the other water sources was not apparent (Figure 9). When considering only edge ditches, eastern pipistrelle bats were only recorded when insect abundance was low (Figure 9). Relative to helipond, the number of eastern pipistrelle bats recorded per night at other water source types was low (Figure 9, Table 4). The number of big brown bats recorded per night at helipond was high when insect abundance was medium and high (Figure 10). When considering only edge ditches, the number of big brown bats recorded per night was high when insect abundance was low (Figure 10). Relative to helipond, the number of big brown bats recorded per night at other water source types was low (Figure 10, Table 4). The number of hoary bats recorded per night at helipond was high when insect abundance was medium and high (Figure 11). When considering edge ditches, hoary bats were only recorded when insect abundance was low (Figure 11). Relative to helipond, the number of hoary bats recorded per night at other water source types was low (Figure 11, Table 4).

There was no significant water source type*total insect abundance interaction on bat foraging activity (ANOVA $F_{6, 50} = 0.973$, $p = 0.452$), total bat activity (ANOVA $F_{3, 65} = 2.455$, $p = 0.072$), bat species diversity (ANOVA $F_{6, 50} = 1.233$, $p = 0.303$) or the number of eastern red (ANOVA $F_{6, 50} = 1.169$, $p = 0.336$), evening (ANOVA $F_{6, 50} = 1.462$, $p = 0.208$), Brazilian free-tailed (ANOVA $F_{6, 50} = 1.921$, $p = 0.136$) and *Myotis* species (ANOVA $F_{6, 50} = 2.314$, $p = 0.086$) bats recorded per night.

In summary, there was a significant water source type effect in 2006. Total bat activity and the number of eastern red, eastern pipistrelle, and big brown bats recorded per night was highest at heliponds. In 2007, there was a significant water source type*total insect abundance interaction effect. The overall number of eastern pipistrelle, big brown, and hoary bats recorded per night was higher at heliponds than other water source types.

CHAPTER IV

DISCUSSION

Heliponds appear to be an important water resource for bats in this community. In 2006, total bat activity and the number of eastern red (*Lasiurus borealis*) bats recorded per night were significantly higher at heliponds. In 2007, the number of hoary (*Lasiurus cinereus*) bats were recorded per night was significantly higher at heliponds versus other water sources. In both years, the number of eastern pipistrelle (*Perimyotis subflavus*) and big brown (*Eptesicus fuscus*) bats recorded per night were higher at heliponds. Larger bat species, such as big brown and hoary bats, are more likely to be found over open, less structurally complex water sources, like heliponds, due to their increased body size and low frequency echolocation calls (Barclay et al. 1999, Jacobs 1999, Sleep & Brigham 2003, Ober & Hayes 2008). Based on small body size, bats such as eastern pipistrelles, are not expected to be highly active over open water sources due to their high frequency echolocation calls which are suited for flying through areas with high stem density, such as forest interiors (Barclay 1999, Jacobs 1999, Menzel et al. 2005b). However, eastern pipistrelle bats are known to forage over water sources and are considered riparian specialists (Fujita and Kunz 1984, Ford et al. 2005). Heliponds represent a reliable source of water with high insect abundance and little overhanging vegetation throughout the summer. Continuously available water and insect prey may explain the concentration of bat activity at these features.

Other bat species also showed trends toward being recorded more often at helipонds. There was a non-significant trend in both years toward the number of Brazilian free-tailed (*Tadarida brasiliensis*) bats recorded per night being highest at heliponds. There was also a non-significant trend in 2006 toward the number of evening (*Nycticeius humeralis*) bats recorded per night being higher at heliponds than the other water source types. Brazilian free-tailed bats are large bodied with low frequency echolocation calls (Sleep & Brigham 2003, Ober & Hayes 2008), so their presence at heliponds is expected. Evening bats, although not as small bodied as eastern pipistrelle bats, are generally thought to prefer forest interiors with high vegetation complexity (Menzel et al. 2005b). Interior foraging bats, such as evening bats, can alter the structure of their echolocation calls when flying in the open (Saunders & Barclay 1992, Barclay et al. 1999, Jacobs 1999, Sleep & Brigham 2003). Overall, my results suggest that bats favor less structurally complex heliponds with high insect abundance. Concentrated activity at heliponds, along with their rarity in this landscape, suggests that heliponds are key resources for wildlife.

Patterns at edge ditches differed from heliponds as well as interior ditches and natural forested wetlands. In 2007, the number of eastern pipistrelle, big brown, and hoary bats recorded per night was high when insect abundance was low. Edges are known to be important landscape features for bats (Walsh and Harris 1996, Grindal &Brigham 1999, Furlonger et al. 1987, Morris 2008). Bats may have been cuing in on some feature at edges that was not measured during my study and this unknown feature may explain why there was high species activity at low insect abundance.

Interior ditches, although abundant in this landscape, had few bats recorded per night. High vegetation density, low insect abundance, and the potential to dry out, as was seen in my study, make these features less important for bats. It has been shown that the number of bats found in an area decreases as stem density increases, in part, because few species of bats are suited for navigating high complexity environments (Law & Chidel 2002, Miles et al. 2006, Ober & Hayes 2008). Despite the low number of recordings per night, the *Myotis* species group was recorded more often per night at interior ditches in both years. Northern myotis (*Myotis septentrionalis*) bats, which were identified from mist netting, are known to glean prey from vegetation surfaces (Audet 1990, Caceres & Barclay 2000) and are expected over interior ditches where vegetation cover is higher (Ober & Hayes 2008). The concentration of bats at this water source type, which is not often used by other species, suggests that *Myotis* bats may be taking advantage of insect prey that is unavailable to other bat species in this community.

The number of bats recorded per night at natural forested wetland sites was low in both years. Natural forested wetlands, although large in surface area with abundant insect prey, are relatively shallow and can dry out as the season progresses as I found in my study. Bats are readily found at water sources (Walsh & Harris 1996, Pierson & Rainey 1998, Hayes 2004) and the temporal availability of water may explain why the number of bat recorded at natural forested wetland sites was low.

Despite few bats recorded per night at natural forested wetlands, in 2007, northern myotis bats were captured at 2 natural forested wetland sites. Northern myotis bats were not expected in the area as the southern extent of their range is the Great Dismal Swamp in Virginia (Caceres & Barclay 2000). Captures of northern myotis bats represent a species range extension southward and suggests that natural forested wetlands may be important for this species.

Despite differences in total bat activity and species activity levels, bat diversity did not differ among water sources types in either year. All 6 bat species and the 1 species group were acoustically sampled at all 4 water source types. These results suggest that instead of having distinct bat communities at each water source type, there is one large community encompassing all water source types.

I found foraging activity rates were similar among water source types in both years. In 2006, rates of foraging ranged from 12% at heliponds to 7% at interior ditches and natural forested wetlands. In 2007, foraging activity ranged from 15% at natural forested wetlands to 7% at edge ditches. Foraging rates between 7% and 15% are within the range of published rates (Thomas 1988, Kalcounis-Rueppell et al. 2007). Rates similar in both years, similar among sites, and similar to published foraging rates suggest that bats are at a constant rate while flying. Similar rates among water source types suggest that bats are capable of foraging throughout the landscape regardless of water source type, water availability, or insect abundance.

Although my study clearly demonstrates that heliponds are an important resource for bats, there are limitations to my study that need to be considered. In my study, both mist netting and acoustic sampling detected common bat species, such as eastern red and big brown bats. However, both methods did not detect rare species. For example, Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) were only captured in mist nets and may not have been acoustically detected due to low, slow, and quiet echolocation calls that make them virtually undetectable by bat detectors (Barclay 1999, Menzel et al. 2005b). Brazilian free-tailed bats were only recorded with bat detectors and were probably not mist net captured because they are known to fly higher than average mist net height (Wilkins 1989). Moreover, Brazilian free-tailed bats were recorded most often along edges where mist netting was difficult. Neither method verified the presence of southeastern myotis (*Myotis austroriparius*) bats. Southeastern myotis were the only *Myotis* species expected to be in this area. Although they may have been acoustically recorded, due to the lack of reference echolocation calls for this species, I was unable to positively identify southeastern myotis bats from echolocation calls.

My study was conducted over only two years, 2006 and 2007. I was unable to statistically test for a year effect for two reasons. Differences seen may or may not be due to normal year fluctuations and I used different sampling methods for both years. In the second year, a severe drought occurred throughout most of the southeast. Many ditches and most natural forested wetland sites dried out and helipond water levels were lower than in 2006. This change in water source availability likely altered distribution and abundance of bats. During summer, heliponds were one of a few reliable sources of water. The drought emphasizes the importance of heliponds in this landscape. However, long-term studies over multiple years will help clarify the importance of heliponds in wet years and aid in making reliable management recommendations (Miller et al. 2003).

The lack of replication across multiple plantations and natural forested wetlands in my study, restricts both scope and scale of result interpretation. Future research should sample multiple managed pine forests and natural forested wetlands. Replicate sampling of multiple managed forests and wetlands will allow for broad-scale comparisons on the impacts of forest management practices on bat activity levels and species presence in this landscape. However, it will be difficult to replicate natural forested wetlands, as few remnant patches exist.

Future studies should intensify mist net efforts and focus on sampling all available water source types. In my study, mist net efforts were concentrated at heliponds and natural forested wetlands. Efforts should be made regularly to net edge ditches and interior ditches. One advantage of increased mist netting is the increased number of captures and reference echolocation calls for the area. More reference calls will allow for easier, more accurate species identification of unknown field recordings. For example, more reference calls may aid in the identification of the *Myotis* species group clarifying specifically which species are present in this community. I captured 143 bats from mist net efforts and captured one new species (*Myotis septentrionalis*) for the area. The hoary and Brazilian free-tailed bats were acoustically recorded but not captured in mist nets. Capturing bats also allows for a more detailed picture of the population including sex, age, and reproductive condition of individuals.

Heliponds were found to be key a landscape feature. Heliponds, though few in number, are open, reliable sources of water with high insect abundance making them excellent foraging habitat for multiple species of bats. A future study should examine interspecific and intraspecific interactions at heliponds. Research should focus on how use of heliponds changes over time (time of night and time of year) and competitive interactions between bats for both prey and water. Heliponds provide an opportunity to examine many research questions and our knowledge of bat ecology will benefit from future study at these important water resources.

CHAPTER V

CONCLUSION

My study found that helipонds were important water sources for bats. Total bat activity and the number of eastern red, eastern pipistrelle, big brown, and hoary bats recorded per night showed significant trends toward being highest at heliponds. Although not significant, Brazilian free-tailed and evening bats were also often recorded at heliponds where water availability and insect abundance was high and vegetation complexity was low. Unlike other species, I recorded *Myotis* bats more often at interior ditches in both years suggesting that these bats may be taking advantage of resources unavailable to other species. Bat diversity did not differ among water source types in either year suggesting that the same bat community can be found at all water source types. Foraging rates were also similar among water source types in both years suggesting that bats are foraging at a constant rate regardless of water availability or insect abundance.

My results suggest that heliponds, though few in number, may be a key landscape feature as they are reliable sources of open water with relatively high insect abundance and little overhanging vegetation. My results also suggest that bats do not use ditches and heliponds in the same way. Heliponds should be maintained as deep open bodies of water and forest managers should manage heliponds as a water source for wildlife.

Forest managers should consider clearing vegetation cover from edge ditches to allow easier access to water surfaces, which will benefit wildlife. In addition, forest managers should consider keeping interior ditches slightly covered by vegetation, as in my study, as *Myotis* bats are known to glean prey from vegetation surfaces making these ditches potential foraging grounds. Overall, bats appear capable of using water sources within managed pine forests despite alterations to the landscape and the general lack of natural forested wetlands.

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APPENDIX A: TABLES

Table 1. Number of bats identified at four water source types from the summers of 2006 and 2007 at the Parker Tract and Washington County Wetland Site, Washington County, North Carolina, USA. The "Total" row represents the total number of bats identified per species from all water source types. All column totals were calculated from species activity recordings.

	Lasiurus borealis		*Eptesicus fuscus*		*Perimyotis subflavus*		*Nycticeius humeralis*		*Tadarida brasiliensis*		*Lasiurus cinereus*		*Myotis* species	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
Helipond	1,073	1,913	399	1,086	236	411	93	91	11	165	35	82	8	14
Interior Ditch	286	1,034	120	164	24	34	99	89	10	32	57	25	33	107
Edge Ditch	654	688	361	215	37	17	5	79	27	28	32	13	6	19
Natural Water	41	228	11	139	8	8	0	8	12	24	12	48	11	42
Total	2,054	3,863	891	1,604	305	470	197	267	60	249	136	168	58	182

Table 2. Total number of mist net captured bats from two different water source types from the summers of 2006 and 2007, Washington County, North Carolina, USA. Helipond sites were located within the Parker Tract and natural forested wetlands sites were located within the Washington County Wetland Site.

	Lasiurus borealis	*Nycticeius humeralis*	*Eptesicus fuscus*	*Myotis septentrionalis*	*Perimyotis subflavus*	*Corynorhinus rafinesquii*
Helipond	71	38	17	0	2	1
Natural Water	3	1	3	6	0	1
Total	74	39	20	6	2	2

Table 3. Total number of insects identified per major insect orders used to determine total insect abundance at four different water source types. The group "Others" is a summation of all minor insect orders. The "Total" row represents the total number of insects per order from all water source types. Insect abundance data was collected during the summers of 2006 and 2007 at the Parker Tract and Washington County Wetland Site, Washington County, North Carolina, USA.

	Diptera	**Homoptera**	**Hemiptera**	**Hymenoptera**	**Lepidoptera**	**Coleoptera**	**Other**
Helipond	3,595	306	28	65	187	40	83
Interior Ditch	3,406	153	9	71	189	71	244
Edge Ditch	3,204	396	18	59	162	42	135
Natural Water	4,257	176	34	125	320	79	128
Total	14,462	1,031	89	320	858	232	590

Table 4. Tukey Post-Hoc test results showing differences among water source types in 2006 and 2007. 2006 data was collected from bat activity data and species activity data, while 2007 data was collected from species activity data at the Parker Tract and Washington County Wetland Site, Washington County, North Carolina, USA. In table H = Heliponds, NFW = Natural Forested Wetlands, ID = Interior Ditches, and ED = Edge Ditches.

Tukey Post-Hoc Tests				**Tukey Post-Hoc Tests**			
2006	**Water Sources**	**Mean ± Std Error**	**p-value**	**2007**	**Water sources**	**Mean ± Std Error**	**p-value**
Total Activity	H vs NFW	2.247 ± 0.689	0.011	*Perimyotis subflavus*	H vs NFW	23.732 ± 4.945	< 0.001
	H vs ID	2.518 ± 0.604	0.001		H vs ED	22.962 ± 5.277	< 0.001
					H vs ID	22.527 ± 4.824	< 0.001
Lasiurus borealis	H vs NFW	2.831 ± 0.679	0.001				
	H vs ID	2.62 ± 0.594	< 0.001	*Eptesicus fuscus*	H vs NFW	56.160 ± 9.752	< 0.001
					H vs ED	48.525 ± 10.407	< 0.001
Perimyotis subflavus	H vs NFW	20.655 ± 6.636	0.016		H vs ID	56.032 ± 9.512	< 0.001
	H vs ED	19.605 ± 5.701	0.007				
	H vs ID	20.121 ± 5.813	0.006	*Lasiurus cinereus*	H vs NFW	8.373 ± 2.741	0.017
					H vs ED	7.706 ± 2.925	0.051
Eptesicus fuscus	H vs NFW	35.173 ± 11.256	0.016		H vs ID	8.206 ± 2.673	0.017
	H vs ID	29.606 ± 9.859	0.021				

APPENDIX B: FIGURES

Figure 1. Study area showing the locations of the modified pine forest and the natural forested wetland where I sampled for bat activity levels, species activity and diversity, and total insect abundance in Washington County, North Carolina, USA, summers 2006 and 2007. The top panel shows the study site location, near Plymouth, within the state of North Carolina in relation to Greensboro, NC. The bottom panel is an enlargement of the general study area to show the natural forested wetland Washington County Wetland Site adjacent to the Parker Tract managed pine forest.

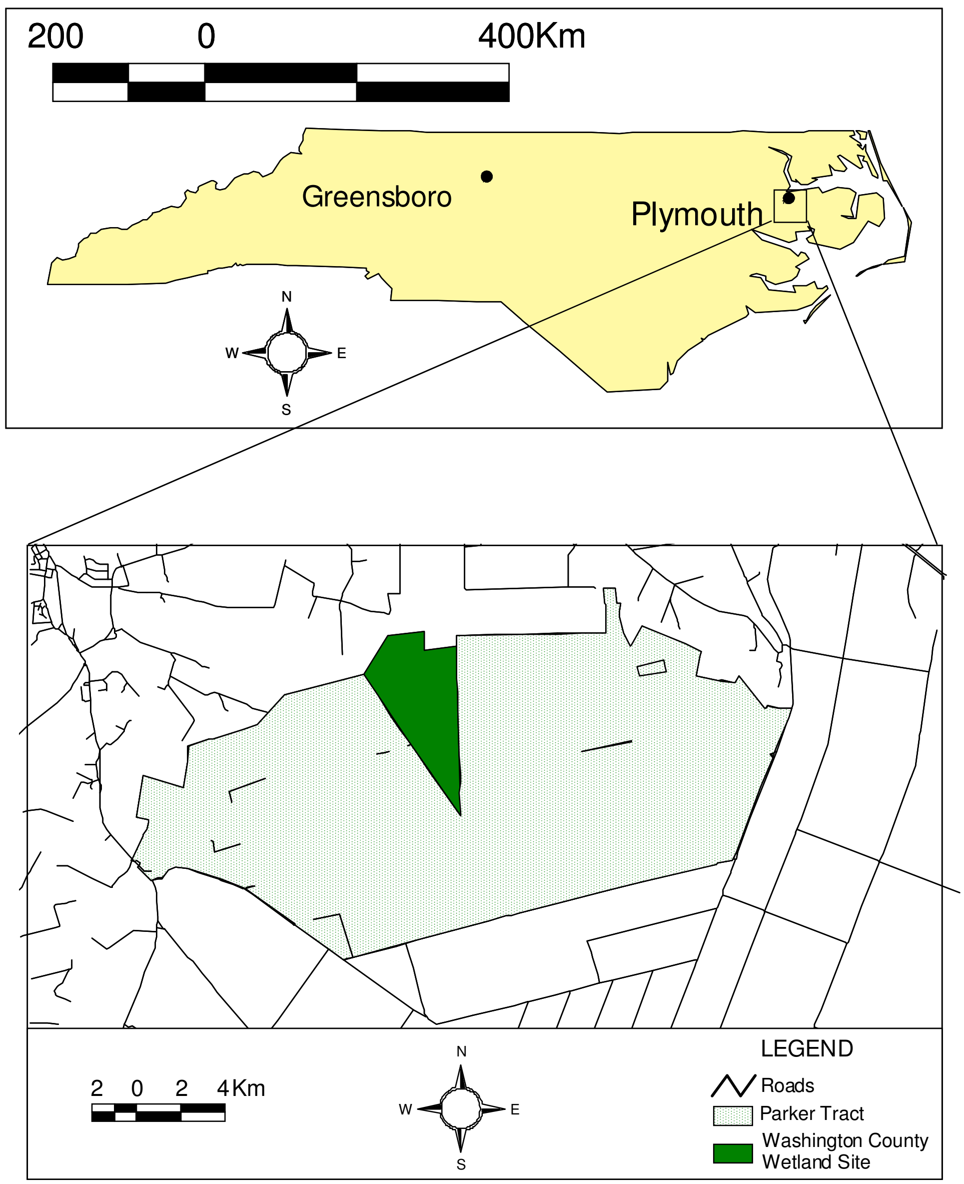

Figure 2. Study area showing the different age class of pine stands within the Parker Tract managed pine forest Washington County, North Carolina, USA. Ditch sampling took place in unmanaged and managed, mature stands only.

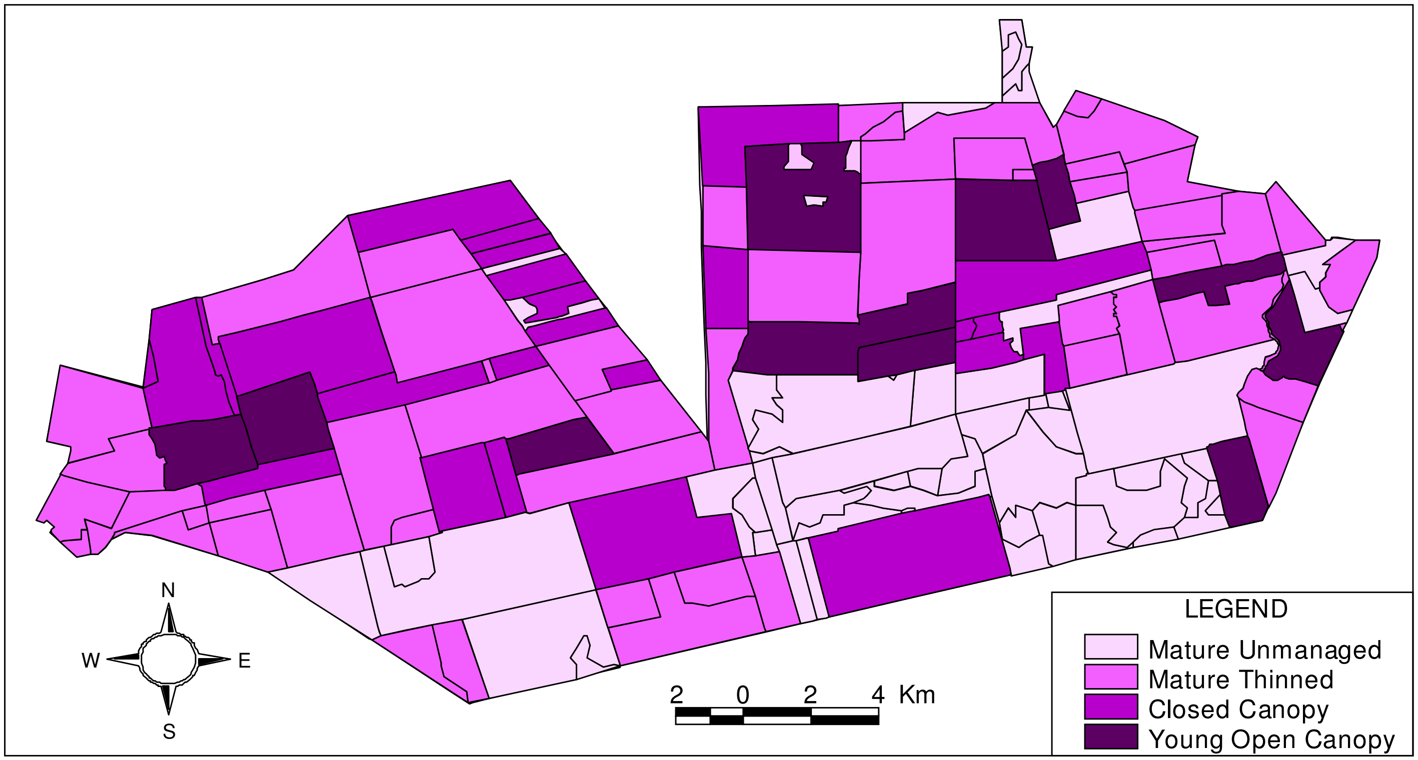

Figure 3. Study area showing water source types (interior ditches, edge ditches and helíponds) that I sampled for bat activity levels, species activity and diversity, and insect abundance within Parker Tract managed pine forest Washington County, North Carolina, USA, summers 2006 and 2007. Edge ditches are found along roads (black) and between stands while interior ditches (light blue) are found within stands. There are 5 Heliponds within the Parker Tract (yellow circles).

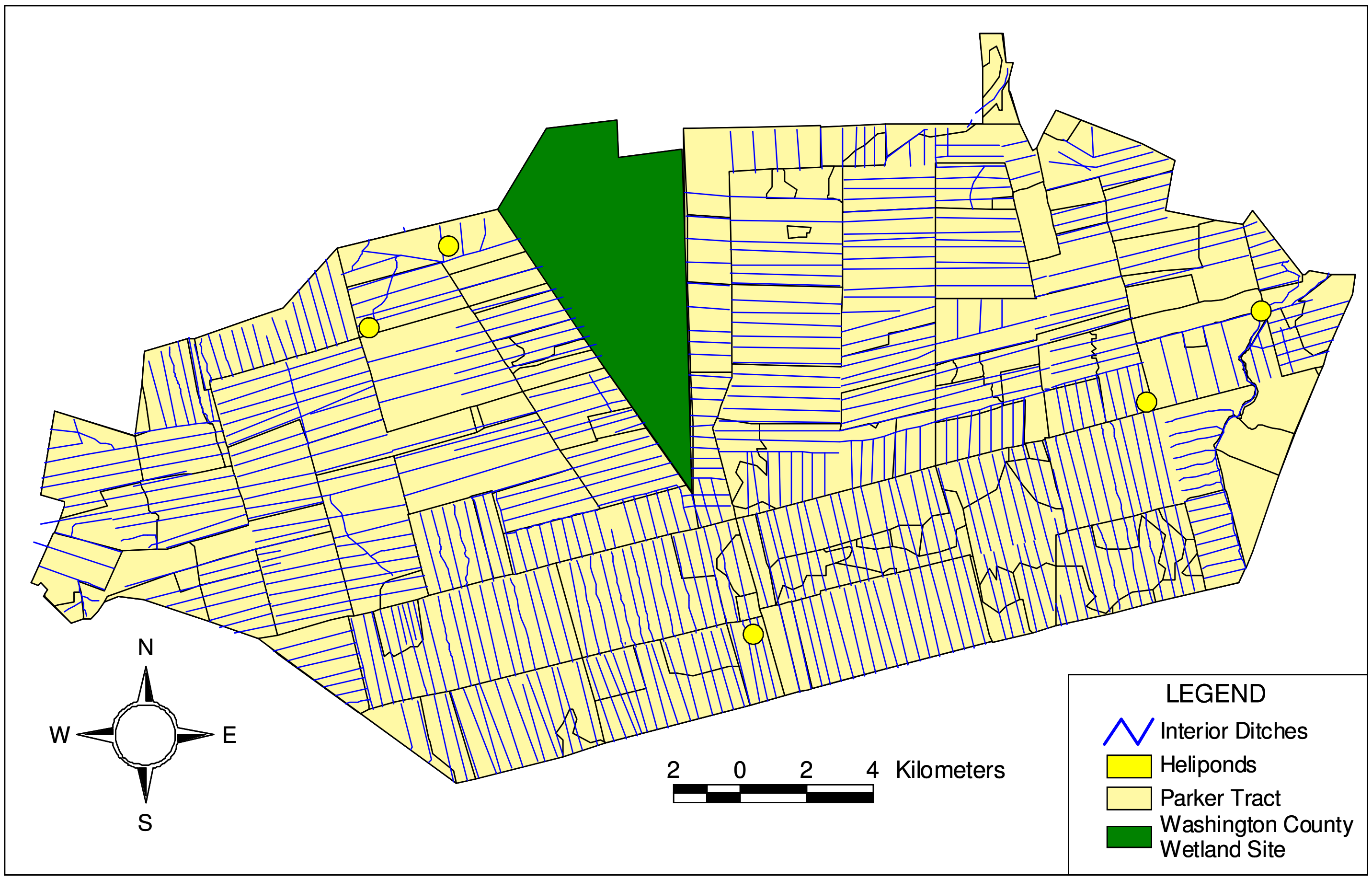

Figure 4. Locations of 128 sampling sites where I collected data on bat activity levels, species activity and diversity, and insect abundance in the Parker Tract managed pine forest and the Washington County Wetland Sites natural forested wetlands, Washington County, North Carolina, USA, summers 2006 and 2007. Yellow circles = Heliponds, Red circles = Edge Ditches, Green circles = Interior Ditches, and Gold circles = Natural Forested Wetlands.

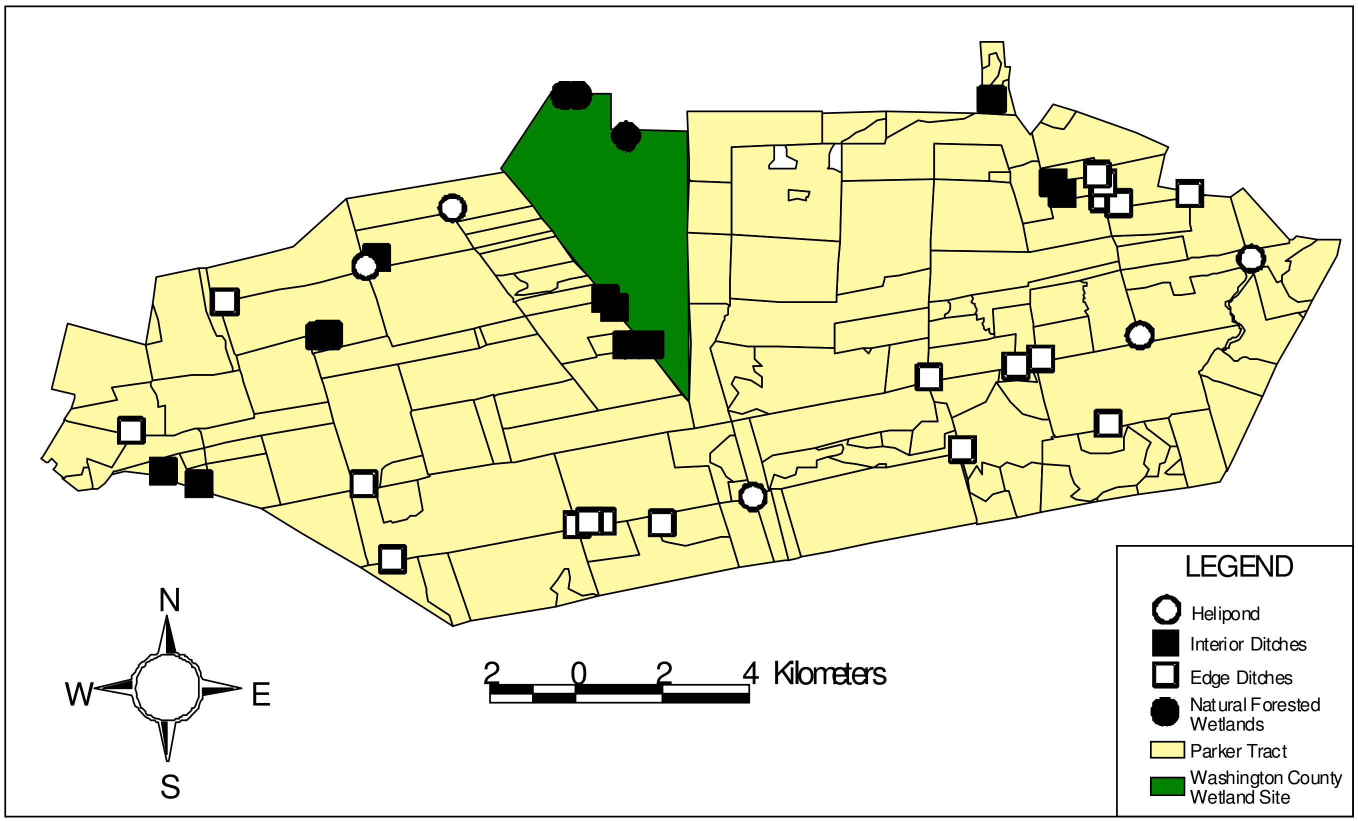

Figure 5. Average (± 1 SE) total bat activity (both commuting and foraging) per night at four water source types during the summer of 2006. Data from bat activity recordings collected from the Parker Tract managed pine forest and Washington County Wetland site natural forested wetland, Washington County, North Carolina, USA. Letters above denote significant differences.

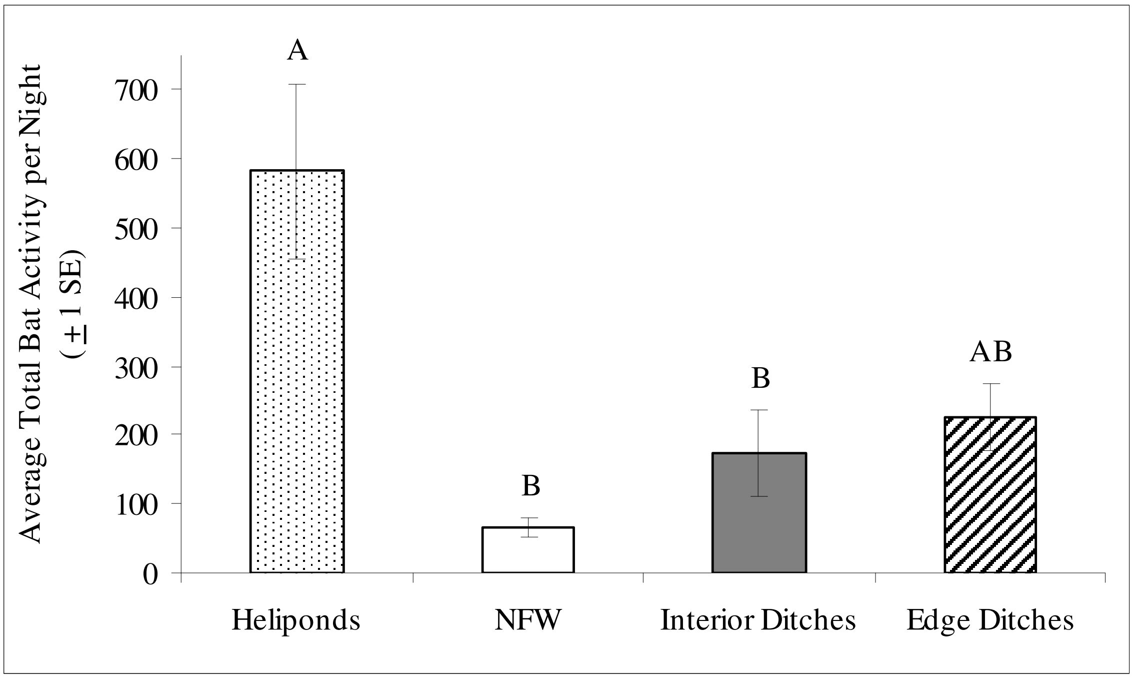

Figure 6. Average (± 1 SE) number of eastern red (*Lasiurus borealis*) bats recorded per night at four water source types during the summer of 2006. Data from bat species activity recordings collected from the Parker Tract managed pine forest and Washington County Wetland site natural forested wetland, Washington County, North Carolina, USA. Letters above denote significant differences.

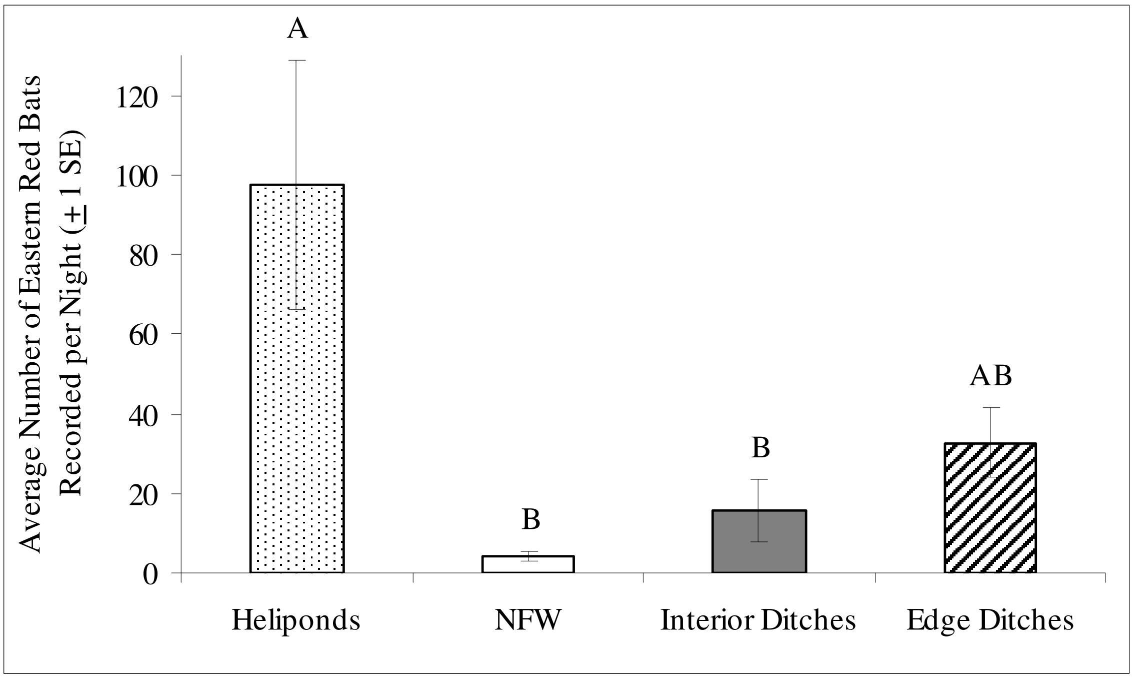

Figure 7. Average (± 1 SE) number of eastern pipistrelle (*Perimyotis subflavus*) bats recorded per night at four water source types during the summer of 2006. Data from bat species activity recordings collected from the Parker Tract managed pine forest and Washington County Wetland site natural forested wetland, Washington County, North Carolina, USA. Letters above denote significant differences.

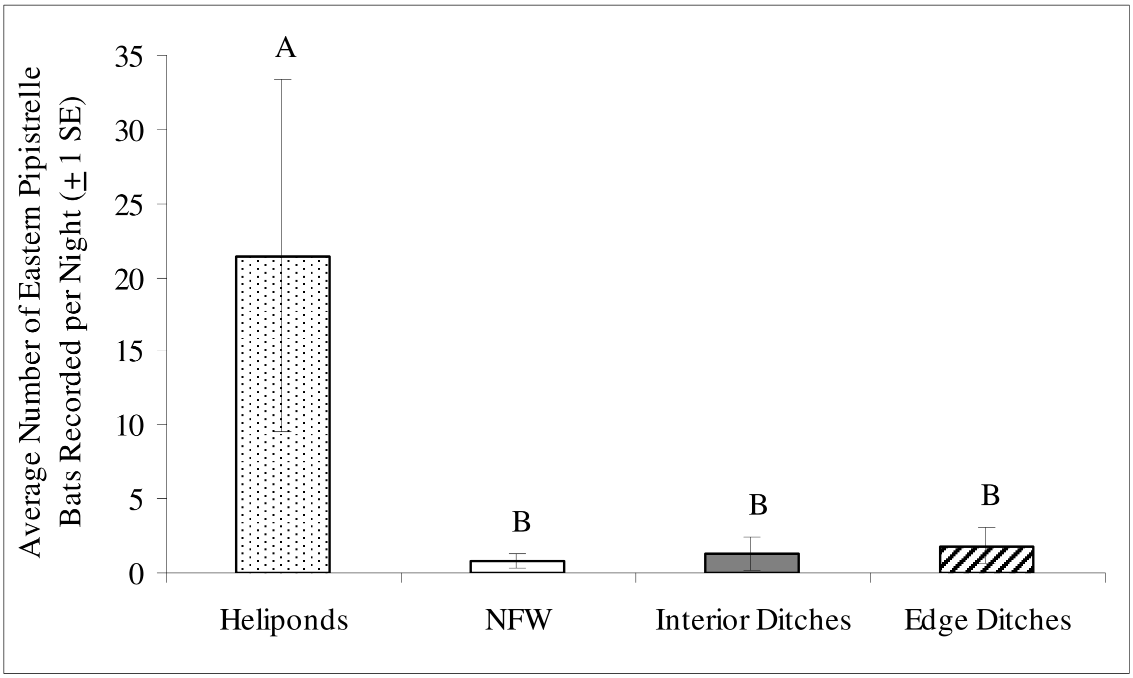

Figure 8. Average (± 1 SE) number of big brown (*Eptesicus fuscus*) bats recorded per night at four water sources during the summer of 2006. Data from bat species activity recordings collected from the Parker Tract managed pine forest and Washington County Wetland site natural forested wetland, Washington County, North Carolina, USA. Letters above denote significant differences.

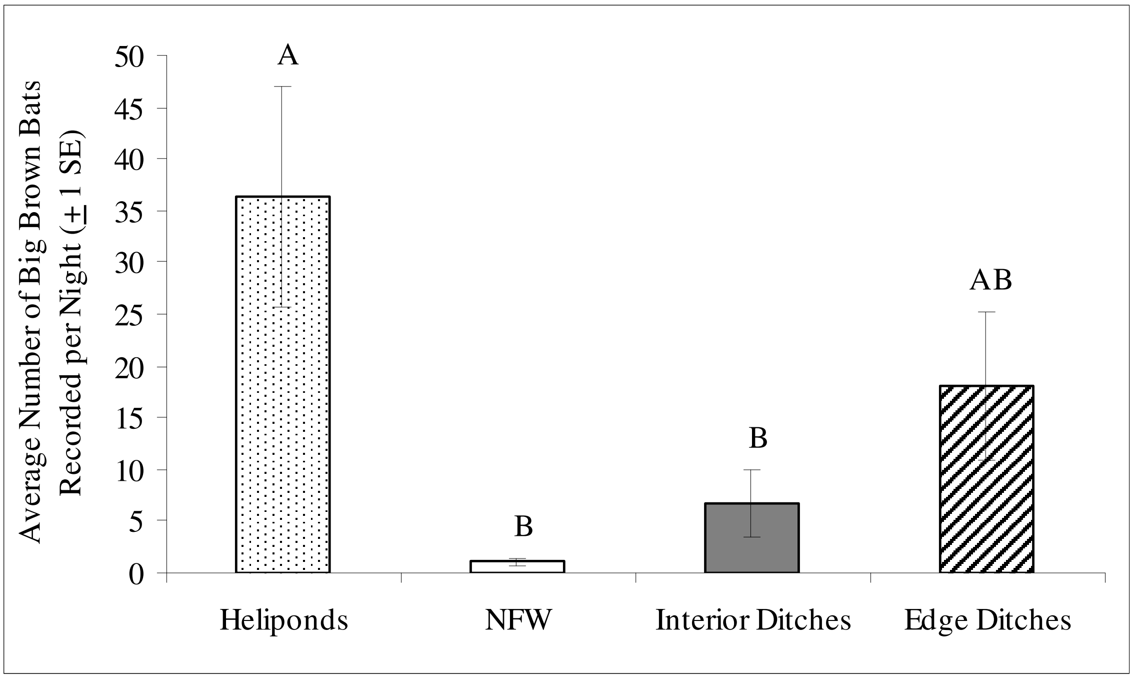

Figure 9. Relationship between the average number of eastern pipistrelle (*Perimyotis subflavus*) bats recorded per night and average insect abundance per night during summer 2007. Data from bat species activity recordings and insects collected from the Parker Tract managed pine forest and Washington County Wetland site natural forested wetland, Washington County, North Carolina, USA. NFW = Natural Forested Wetlands.

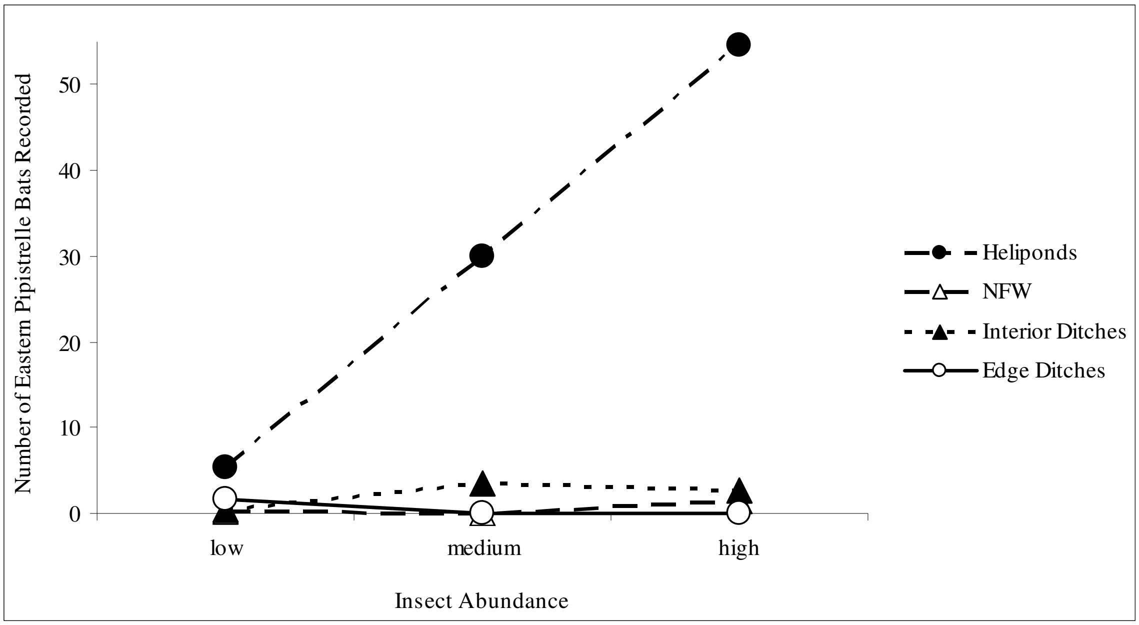

Figure 10. Relationship between the average number of big brown bats (*Eptesicus fuscus*) recorded per night and average insects abundance per night during summer 2007. Data from bat species activity recordings and insects collected from the Parker Tract managed pine forest and Washington County Wetland site natural forested wetland, Washington County, North Carolina, USA. NFW = Natural Forested Wetlands.

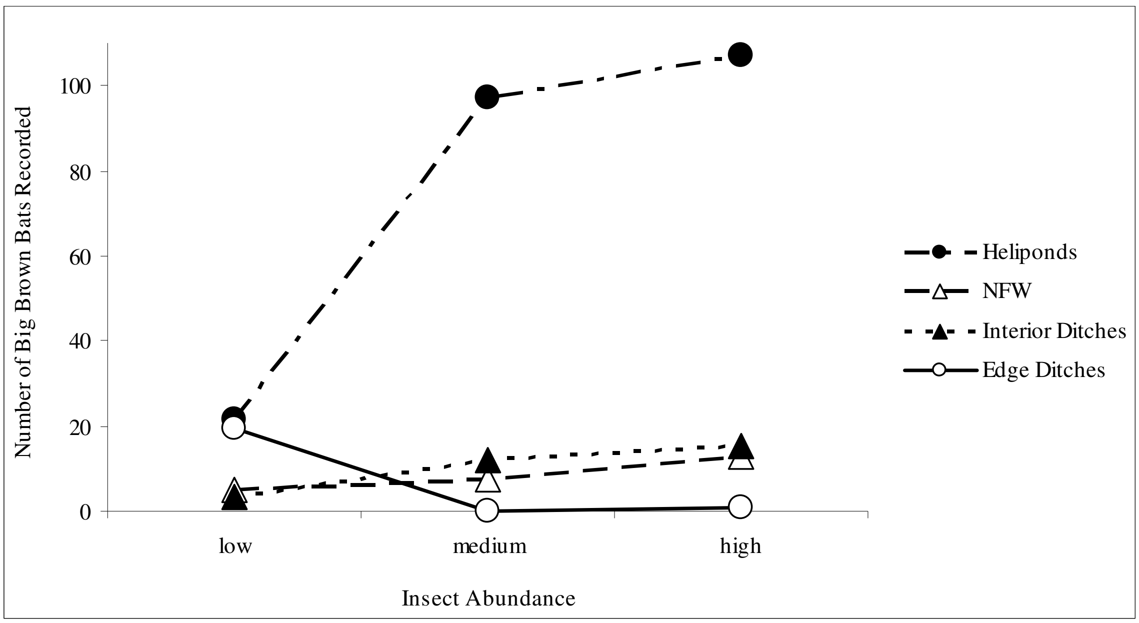

Figure 11. Relationship between the average number of hoary (*Lasiurus cinereus*) bats recorded per night and average insect abundance per night during summer 2007. Data from bat species activity recordings and insects collected from the Parker Tract managed pine forest and Washington County Wetland site natural forested wetland, Washington County, North Carolina, USA. NFW = Natural Forested Wetlands.